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APPLICATION NO.	ISSUE DATE	PATENT NO.	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	10/19/2021	11152882	35099.008C1	7971

34395 7590 09/29/2021

OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
Gig Harbor, WA 98332

ISSUE NOTIFICATION

The projected patent number and issue date are specified above.

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(application filed on or after May 29, 2000)

The Patent Term Adjustment is 0 day(s). Any patent to issue from the above-identified application will include an indication of the adjustment on the front page.

If a Continued Prosecution Application (CPA) was filed in the above-identified application, the filing date that determines Patent Term Adjustment is the filing date of the most recent CPA.

Applicant will be able to obtain more detailed information by accessing the Patent Application Information Retrieval (PAIR) WEB site (http://pair.uspto.gov).

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Application Assistance Unit (AAU) of the Office of Data Management (ODM) at (571)-272-4200.

APPLICANT(s) (Please see PAIR WEB site http://pair.uspto.gov for additional applicants):

Resonant Systems, Inc., Seattle, WA;

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Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
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34395 7590 06/14/2021
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Joanne Bourguignon	(Typed or printed name)
/Joanne Bourguignon/	(Signature)
September 14, 2021	(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008C1	7971

TITLE OF INVENTION: OSCILLATING-RESONANT-MODULE CONTROLLER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$600	$0.00	$0.00	$600	09/14/2021

EXAMINER	ART UNIT	CLASS-SUBCLASS
IMTIAZ, ZOHEB S	2846	318-119000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

☐ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

☐ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list Olympic Patent Works PLLC
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3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE: RESONANT SYSTEMS, INC.

(B) RESIDENCE: (CITY and STATE OR COUNTRY): Seattle, WA

Please check the appropriate assignee category or categories (will not be printed on the patent): ☐ Individual ☒ Corporation or other private group entity ☐ Government

4a. Fees submitted: ☒ Issue Fee ☐ Publication Fee (if required) ☐ Advance Order - # of Copies .....

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5. **Change in Entity Status** (from status indicated above)

☐ Applicant certifying micro entity status. See 37 CFR 1.29

☐ Applicant asserting small entity status. See 37 CFR 1.27

☐ Applicant changing to regular undiscounted fee status.

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Authorized Signature /Robert W. Bergstrom/ Date September 14, 2021

Typed or printed name Robert W. Bergstrom Registration No. 39,906

Electronic Patent Application Fee Transmittal

Application Number:	16806925
Filing Date:	02-Mar-2020
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER
First Named Inventor/Applicant Name:	Robin Elenga
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
Attorney Docket Number:	35099.008C1

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
UTILITY APPL ISSUE FEE	2501	1	600	600

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension-of-Time:				
Miscellaneous:				
			Total in USD ($)	**600**

Electronic Acknowledgement Receipt	
EFS ID:	43758815
Application Number:	16806925
International Application Number:	
Confirmation Number:	7971
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER
First Named Inventor/Applicant Name:	Robin Elenga
Customer Number:	34395
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
Filer Authorized By:	Robert Walter Bergstrom
Attorney Docket Number:	35099.008C1
Receipt Date:	14-SEP-2021
Filing Date:	02-MAR-2020
Time Stamp:	12:50:23
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$600
RAM confirmation Number	E20219DC51123859
Deposit Account	502976
Authorized User	Joanne Bourguignon
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: 37 CFR 1.21 (Miscellaneous fees and charges) 37 CFR 1.20 (Post Issuance fees)	

37 CFR 1.19 (Document supply fees)

37 CFR 1.17 (Patent application and reexamination processing fees)

37 CFR 1.16 (National application filing, search, and examination fees)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1	Issue Fee Payment (PTO-85B)	35099-008C1-E-ISSUEFEE-1.pdf	81491 b65491fb2ca912a7485ab7a410af9c9faca16a34	no	1
Warnings:					
Information:					
2	Fee Worksheet (SB06)	fee-info.pdf	38059 ba9e687b67cc07e1aa43c9426674cbb760ed484b	no	2
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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

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New International Application Filed with the USPTO as a Receiving Office

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008C1	7971

34395 7590 06/29/2021
OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
Gig Harbor, WA 98332

EXAMINER	
IMTIAZ, ZOHEB S	

ART UNIT	PAPER NUMBER
2846	

NOTIFICATION DATE	DELIVERY MODE
06/29/2021	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

joanne@olympicpatentworks.com

Response to Rule 312 Communication	Application No. 16/806,925	Applicant(s)
	Examiner	Art Unit

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address –

1. ☒ The amendment filed on *24 June 2021* under 37 CFR 1.312 has been considered, and has been:

a) ☒ entered.

b) ☐ entered as directed to matters of form not affecting the scope of the invention.

c) ☐ disapproved because the amendment was filed after the payment of the issue fee.
Any amendment filed after the date the issue fee is paid must be accompanied by a petition under 37 CFR 1.313(c)(1) and the required fee to withdraw the application from issue.

d) ☐ disapproved. See explanation below.

e) ☐ entered in part. See explanation below.

/C Bowen/

Charles Bowen

PTO/SB/92 (07-16)
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3. ☑ EFS-Web transmitted to the USPTO.

/Robert W. Bergstrom/	June 24, 2021
Signature	Date
Robert W. Bergstrom	206.621.1933
Typed or printed name	Telephone number

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Response to Notice to File Corrected Application Papers

Marked Up Specification

Substitute Specification

This collection of information is required by 37 CFR 1.8. The information is required to obtain or retain a benefit by the public, which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1.8 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Robin Elenga et l.
Application No.:	16/806.925
Filed:	March 2, 2020
Title:	OSCILLATING-RESONANT-MODULE CONTROLLER
	Conf. No.: 7971
	Examiner: Zoheb S. Imtiaz
	Art Unit: 2846
	Docket No.: 35099.008C1

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

RESPONSE TO NOTICE TO FILE CORRECTED APPLICATION PAPERS
Notice of Allowance Mailed

In response to the "Notice to File Corrected Application Papers—Notice of Allowance Mailed" dated June 23, 2021, which sets forth a two-month period for reply ending on March 12, 2021, is:

Substitute Specification

☒ A Substitute Specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125. The substitute specification contains no new matter.

☒ A marked up copy of a Substitute Specification as set forth in 37 CFR 1.125(c).

☒ No additional fee is due.

☒ The Commissioner is hereby requested to grant an extension of time for the appropriate length of time, should one be necessary, in connection with this filing or any future filing submitted to the U.S. Patent and Trademark Office in the above-

identified application during the pendency of this application. The Commissioner is further authorized to charge any fees related to any such extension of time to Deposit Account 50-2976.

☒ The Commissioner is hereby authorized to charge any deficiency or credit any overpayment of the fees associated with this communication to Deposit Account No. 50-2976.

Respectfully submitted,
Robin Elenga et l.
OLYMPIC PATENT WORKS PLLC

/Robert W. Bergstrom/
Robert W. Bergstrom
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UNITED STATES PATENT AND TRADEMARK OFFICE

Commissioner for Patents
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P.O. Box 1450
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Application No. : 16806925
Applicant : Elenga
Filing Date : 03/02/2020
Date Mailed : 06/23/2021

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Notice of Allowance Mailed

This application has been accorded an Allowance Date and is being prepared for issuance. The application, however, is incomplete for the reasons below.

Applicant is given two (2) months from the mail date of this Notice within which to respond. This time period for reply is extendable under 37 CFR 1.136(a) for only TWO additional MONTHS.

The informalities requiring correction are indicated in the attachment(s). If the informality pertains to the abstract, specification (including claims) or drawings, the informality must be corrected with an amendment in compliance with 37 CFR 1.121 (or, if the application is a reissue application, 37 CFR 1.173). Such an amendment may be filed after payment of the issue fee if limited to correction of informalities noted herein. See Waiver of 37 CFR 1.312 for Documents Required by the Office of Patent Publication, 1280 Off. Gaz. Patent Office 918 (March 23, 2004). In addition, if the informality is not corrected until after payment of the issue fee, for purposes of 35 U.S.C. 154(b)(1)(iv), "all outstanding requirements" will be considered to have been satisfied when the informality has been corrected. A failure to respond within the above-identified time period will result in the application being ABANDONED.

See attachment(s).

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/Kevin Danemark/
Publication Branch
Office of Data Management
(571) 272-4200

Application No. 16806925

IDENTIFICATION OF APPLICATION DEFICIENCIES IN APPLICATION FILED ON OR AFTER SEPTEMBER 16, 2012

[X] Applicant must provide legible text for the following item(s).

- [X] Specification filed 05/18/2020, page(s) 26, 27, 28.
- [ ] Claims filed , claim(s) .
- [ ] Other: .

[ ] Applicant must provide missing information on the following page(s) of the specification by amending the specification to add the missing text. No new matter may be added.
Page/line no(s).

[ ] The specification refers to one or more applications by attorney docket number and does not show the U.S. application number(s). Applicant must supply the U.S. application number in place of each attorney docket number.
Page/line no(s).

[ ] Applicant must provide an Abstract of the Disclosure.

[ ] The Application Data Sheet (ADS dated) does not supply the inventor's city and/or does not supply the inventor's U.S. state and/or does not supply the inventor's country. Applicant must submit a signed, in accordance with 37 CFR 1.76(e) and 1.33(b), application data sheet that corrects this deficiency. To be in compliance with 37 CFR 1.76, the corrected application data sheet must identify the information being changed by using underlining for additions and strikethroughs or brackets for deletions.

[ ] Other:

MARKED UP SPEC

OSCILLATING-RESONANT-MODULE CONTROLLER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of Application No. 15/043,584, filed February 14, 2016, which claims the benefit of Provisional Patent Application No. 62/116,144, filed February 13, 2015.

TECHNICAL FIELD

The current document is related to vibration-generating devices and, in particular, to vibration modules that can be incorporated into a wide variety of different types of electromechanical devices and systems to produce predetermined vibration responses.

BACKGROUND

Vibration-inducing motors and mechanisms have been used for many years in a wide variety of different consumer appliances, toys, and other devices and systems. Examples include vibration signals generated by pagers, smart phones, vibration-driven appliances, such as hair-trimming appliances, electric toothbrushes, electric toy football games, and many other appliances, devices, and systems. The most common electromechanical system used for generating vibrations is an intentionally unbalanced electric motor.

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices. As shown in Figure 1A, a small, relatively low-power electric motor 102 rotates a cylindrical shaft 104 onto which a weight 106 is asymmetrically or mounted. Figure 1B shows the weight asymmetrically mounted to the shaft, looking down at the weight and shaft in the direction of the axis of the shaft. As shown in Figure 1B, the weight 106 is mounted off-center on the electric-motor shaft 104. Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B. As shown in Figures 2A-B, the asymmetrically-mounted weight creates an elliptical oscillation of the end of the shaft, normal to the shaft axis, when the shaft is rotated at relatively high speed by the electric motor. Figure 2A shows displacement of the weight and

shaft from the stationary shaft axis as the shaft is rotated, looking down on the weight and shaft along the shaft axis, as in Figure 1B. In Figure 2A, a small mark 202 is provided at the periphery of the disk-shaped end the of electric-motor shaft to illustrate rotation of the shaft. When the shaft rotates at high speed, a point 204 on the edge of the weight traces an ellipsoid 206 and the center of the shaft 208 traces a narrower and smaller ellipsoid 210. Were the shaft balanced, the center of the shaft would remain at a position 212 in the center of the diagram during rotation, but the presence of the asymmetrically-mounted weight attached to the shaft, as well as other geometric and weight-distribution characteristics of the electric motor, shaft, and unbalanced weight together create forces that move the end of the shaft along the elliptical path 210 when the shaft is rotated at relatively high speed. The movement can be characterized, as shown in Figure 2B, by a major axis 220 and minor axis 222 of vibration, with the direction of the major axis of vibration equal to the direction of the major axis of the ellipsoids, shown in Figure 2A, and the length of the major axis corresponding to the amplitude of vibration in this direction. In many applications, in which oscillation back and forth along a defined path is desired, designers seek to force the major-axis-amplitude/minor-axis-amplitude ratio to be as large as possible, to approach a linear path, but, because the vibration is produced by a rotational force, it is generally not possible to achieve oscillation back and forth along a defined path. In many cases, the path traced by the shaft center may be close to circular. The frequency of vibration of the unbalanced electric motor is equal to the rotational frequency of the electric-motor shaft, and is therefore constrained by the rate at which the motor can rotate the shaft. At low rotational speeds, little vibration is produced.

While effective in producing vibrations, there are many problems associated with the unbalanced-electric-motor vibration-generating units, such as that shown in Figure 1A, commonly used in the various devices, systems, and applications discussed above. Unbalancing the shaft of an electric motor not only produces useful vibrations that can be harnessed for various applications, but also produces destructive, unbalanced forces within the motor that contribute to rapid deterioration of motor parts. Enormous care and effort is undertaken to precisely balance rotating parts of motors, vehicles, and other types of machinery, and the consequences of unbalanced rotating

parts are well known to anyone familiar with automobiles, machine tools, and other such devices and systems. The useful lifetimes of many devices and appliances, particularly hand-held devices and appliances, that employ unbalanced electric motors for generating vibrations may range from a few tens of hours to a few thousands of hours of use, after which the vibrational amplitude produced by the devices declines precipitously as the electric motor and other parts deteriorate. Unbalanced electric motors are relatively inefficient at producing vibrational motion. A far greater amount of power is consumed by an unbalanced electrical motor to produce a given vibrational force than the theoretical minimum power required to produce the given vibrational force. As a result, many hand-held devices that employ unbalanced electric motors for generating vibrations quickly consume batteries during use. Unbalanced electric motors, as discussed above, oscillating motion back and forth along a predefined path, or space curve, cannot generally be produced by unbalanced electric motors. Unbalanced electric motors generate vibrations in only a very limited portion of the total vibrational-force/frequency space. Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors. The graph is shown as a continuous hypothetical curve, although, of course, actual data would be discrete. As shown in Figure 3, for relatively low-power electric motors used in hand-held appliances, only a fairly narrow range of frequencies centered about 80 Hz (302 in Figure 3) generate a significant vibrational force. Moreover, the vibrational force is relatively modest. The bulk of energy consumed by an unbalanced electric motor is used to spin the shaft and unbalanced weight and to overcome frictional and inertial forces within the motor. Only a relatively small portion of the consumed energy is translated into desired vibrational forces.

Because of the above-discussed disadvantages with the commonly employed unbalanced-electric-motor vibration-generation units, designers, manufacturers, and, ultimately, users of a wide variety of different vibration-based devices, appliances, and systems continue to seek more efficient and capable vibration-generating units for incorporation into many consumer appliances, devices, and systems.

SUMMARY

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices.

Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B.

Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors.

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document.

Figures 5A-G illustrate one particular type of ORM.

Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs.

Figure 10 shows a plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by ORMs.

Figures 11-18 show a variety of different alternative implementations of ORMs.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17.

Figure 20 illustrates a first coil layer.

Figure 21 illustrates a second coil layer.

Figure 22A illustrates a cross-section of a stator having two coil layers.

Figure 22B illustrates a cross-section of a stator having four coil layers.

Figure 22C illustrates a cross-section of a stator having two coil layers.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate.

Figure 23B illustrates the motor with a magnetic armature in an upward position.

Figure 23C illustrates the motor with a magnetic armature in a downward position.

Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation.

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration.

Figures 26A-B illustrate multiple resonant frequencies within a device or system.

Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response.

Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device.

Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figures 37A-D illustrate pulse-width modulation control of an ORM.

Figure 38A illustrates a control pattern that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806.

Figure 38B illustrates the actual vibration response of the ORM.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f.

Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs.

Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM.

Figures 46A-B illustrate several possible direct-sensing approaches.

DETAILED DESCRIPTION

The current document is directed to various oscillating resonant modules ("ORMs"), including various types of linear oscillating resonant modules ("linear ORMs"), that can be used within a wide variety of different types of appliances, devices, and systems, to generate vibrational forces. ORMs produce vibrational forces by oscillation of a weight or component within the ORM along a segment of a space curve, rather than as a by-product of an unbalanced rotation, as in the case of unbalanced electric motors. The oscillatory nature of the ORM vibration-inducing motion effectively addresses many problems associated with unbalanced electric motors. Combining an ORM with feedback control, so that the driving frequency produced by the ORM falls close to the resonant frequency of a device in which the ORM is included, results in optimal power consumption with respect to the amplitude and frequency of vibration produced by the ORM as well as maximal vibration energy of the device. Oscillation within a ORM may translate into highly directional driving forces produced by the ORM to drive a vibration response in an appliance or device that incorporates the ORM. The current document includes a first subsection, in which various types of ORMs are described, a second subsection on which an ORM controller is discussed, and a third subsection in which accurate methods for ORM control, to which the current document is directed, are described in detail.

ORMs

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document. In contrast to the above-discussed unbalanced electric motors often used to generate vibrations in vibration-driven appliances, an oscillating resonant module contains a weight, or mass, that oscillates back and forth along a path. The path may be a linear path, or line segment, but, in the general case, can be potentially any particular segment of a space curve. Figure 4A illustrates operation of a linear oscillating resonant module. In a first diagram 402, labeled with the time "0," the linear ORM is depicted at time 0 (404 in Figure 4A), with the mass or weight 406 centered within a linear path 408 bounded by two stops 410 and 412. When the linear ORM is activated, the weight begins moving to the left, as shown in diagram 414. The small arrow 415 within the disk-like mass 406 indicates

the direction of movement. The mass continues to move, as shown in diagram 416, until the mass strikes the left-hand stop 410, at which point the direction of travel of the mass reverses and the mass begins moving back in the opposite direction, as shown in diagram 418. In diagrams 419 and 420, the mass continues in its rightward direction of travel during time intervals 4 and 5. At time 6, as shown in diagram 421, the mass strikes the right-hand stop 404 and reverses direction, traveling back in the leftward direction, as shown in diagram 422. Ellipses 424 indicate that this process continues indefinitely during operation of the linear ORM. The mass oscillates back and forward along the linear path. The period of oscillation and the maximum amplitude of oscillation can generally be controlled by control signals input to an ORM.

Figure 4B illustrates a mapping of a continuous logical movement of the weight along a circle to the actual linear motion of the weight within a linear ORM, as discussed above with reference to Figure 4A. In Figure 4B, the position of the weight is plotted along a circle 430. At time 0, represented by point 432, the weight position is vertically mapped, as indicated by dotted line 434 as well as by the solid line 436 within the circle 430, to a central point 438 on the linear path 440 shown below the circle. The position of the weight travels along the circle, in a counter-clockwise direction, as long as the linear ORM operates, as indicated by the dashed circular arrow 442. At time 1, indicated by point 444 on circle 430, the position of the mass is mapped, by vertical dashed line 446, to point 448 on linear path 440. At time 2, represented by point 450, the position of the mass on the linear path 440 is point 452. At time 3, represented by point 454 along the circle, the position of the mass is again point 448. Thus, as the position of the mass plotted along the circle has moved from point 444 to point 454, the direction of movement of the mass has reversed and the mass is now continuing in the opposite direction from the direction in which it originally moved. Small horizontal arrows, such as arrow 456, shown below the linear path 440, illustrate the linear motion of the mass of the linear ORM between each pair of adjacent time points. Thus, the back-and-forth oscillation of the mass in a linear ORM can be described by a logical revolution of a mass about a circle. If the circle has a radius of 1, then the position x at time t of the mass along the actual path of travel can be expressed as:

$$x(t) = \cos\left(\omega t - \frac{\pi}{2}\right),$$

where ω is the angular velocity at which the point representing the mass moves around the circle.

Figure 4C illustrates a general space-curve segment path. In Figure 4C, a short space-curve segment 460 is shown plotted in a three-dimensional Cartesian coordinate system 462. The weight or mass of an oscillating resonant module ("ORM") may oscillate back and forth along such a space-curve-segment path. In the first plot in Figure 4C 458, the weight or mass moves from left to right along the path, as indicated by the small curved arrows, such as curved arrow 460. As shown in the second plot 462 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it reverses directions and move to the left. As shown in the third plot 464 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it again reverses direction and moves to the right. Ellipses 466 indicate that this back-and-forth oscillation continues while the ORM operates. The space-curve-segment path of the weight in an ORM is defined by the physical implementation and operation of the ORM.

Figure 4D illustrates two additional example paths along which the weight or mass of an ORM may oscillate. The first path is a circular arc 470 and the second path is a partially elliptical arc-like path 472. As mentioned above, many additional different types of space-curve-segment paths for ORMs are possible.

Figures 5A-G illustrate one particular type of ORM. Figures 5A-G all use the same illustration conventions, next discussed with reference to Figure 5A. The ORM includes a cylindrical housing 502 within which a solid, cylindrical mass 504, or weight, can move linearly along the inner, hollow, cylindrically shaped chamber 506 within the cylindrical housing or tube 502. The weight is a magnet, in the described an implementation, with polarity indicated by the "+" sign 510 on the right-hand end and the "-" sign 512 on the left-hand end of the weight 504. The cylindrical chamber 506 is capped by two magnetic disks 514 and 516 with polarities indicated by the "+" sign 518 and the "-" sign 519. The disk-like magnets 514 and 518 are magnetically oriented opposite from the magnetic orientation of the weight 504, so that when the

weight moves to either the extreme left or extreme right sides of the cylindrical chamber, the weight is repelled by one of the disk-like magnets at the left or right ends of the cylindrical chamber. In other words, the disk-like magnets act much like springs, to facilitate deceleration and reversal of direction of motion of the weight and to minimize or prevent mechanical-impact forces of the weight and the end caps that close off the cylindrical chamber. Finally, a coil of conductive wire 520 girdles the cylindrical housing, or tube 502 at approximately the mid-point of the cylindrical housing.

Figures 5B-G illustrate operation of the ORM shown in Figure 5A. When an electric current is applied to the coil 520 in a first direction 522, a corresponding magnetic force 524 is generated in a direction parallel to the axis of the cylindrical chamber, which accelerates the weight 504 in the direction of the magnetic force 524. When the weight reaches a point at or close to the corresponding disk-like magnet 514, as shown in Figure 5C, a magnetic force due to the repulsion of the disk-like magnet 514 and the weight 504, 526, is generated in the opposite direction, decelerating the weight and reversing its direction. As the weight reverses direction, as shown in Figure 5D, current is applied in an opposite direction 530 to the coil 520, producing a magnetic force 532 in an opposite direction from the direction of the magnetic force shown in Figure 5B, which accelerates the weight 504 in a direction opposite to the direction in which the weight is accelerated in Figure 5B. As shown in Figure 5E, the weight then moves rightward until, as shown in Figure 5F, the weight is decelerated, stopped, and then accelerated in the opposite direction by repulsion of the disk-like magnet 516. An electrical current is then applied to the coil 520 in the same direction 534 as in Figure 5B, again accelerating the solid cylindrical mass in the same direction as in Figure 5B. Thus, by a combination of a magnetic field with rapidly reversing polarity, generated by alternating the direction of current applied to the coil, and by the repulsive forces between the weight magnet and the disk-like magnets at each end of the hollow, cylindrical chamber, the weight linearly oscillates back and forth within the cylindrical housing 502, imparting a directional force at the ends of the cylindrical chamber with each reversal in direction.

Clearly, the amplitude of the vibration and other characteristics of the vibrational forces produced within the ORM are related to the length of the hollow chamber in which the weight oscillates, the current applied to the coil, the mass of the weight, the acceleration of the weight produced by the coil, and the mass of the entire ORM. All of these parameters are essentially design parameters for the ORM, and thus the ORM can be designed to produce a wide variety of different amplitudes.

The frequency of the oscillation of the solid, cylindrical mass is determined by the frequency at which the direction of the current applied to the coil is changed. Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM. Figures 6A-B both use the same illustration conventions, described next with respect to Figure 6A. The H-bridge switch receives, as input, a directional signal *d* 602 and direct-current ("DC") power 604. The direction-control signal *d* 602 controls four switches 606-609, shown as transistors in Figure 6A. When the input control signal *d* 602 is high, or "1," as shown in Figure 6A, switches 608 and 609 are closed and switches 606 and 607 are open, and therefore current flows, as indicated by curved arrows, such as curved arrow 610, from the power-source input 604 to ground 612 in a leftward direction through the coil 614. When the input-control signal *d* is low, or "0," as shown in Figure 6B, the direction of the current through the coil is reversed. The H-bridge switch, shown in Figures 6A-B, is but one example of various different types of electrical and electromechanical switches that can be used to rapidly alternate the direction of current within the coil of an ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G. The ORM, in addition to the cylindrical housing, coil, and internal components shown in Figure 5A, includes a power supply, a user interface, generally comprising electromechanical buttons or switches, the H-bridge switch, discussed above with reference to Figures 7A-B, a central processing unit ("CPU"), generally a small, low-powered microprocessor, and one or more electromechanical sensors. All of these components are packaged together as an ORM within a vibration-based appliance, device, or system.

As shown in Figure 7, the ORM 700 is controlled by a control program executed by the CPU microprocessor 702. The microprocessor may contain sufficient on-board memory to store the control program and other values needed during execution of the control program, or, alternatively, may be coupled to a low-powered memory chip 704 or flash memory for storing the control program. The CPU receives inputs from the user controls 706 that together comprise a user interface. These controls may include any of various dials, pushbuttons, switches, or other electromechanical-control devices. As one example, the user controls may include a dial to select a strength of vibration, which corresponds to the current applied to the coil, a switch to select one of various different operational modes, and a power button. The user controls generate signals input to the CPU 708-710. A power supply 712 provides power, as needed, to user controls 714, to the CPU 716 and optional, associated memory, to the H-bridge switch 718, and, when needed, to one or more sensors 732. The voltage and current supplied by the power supply to the various components may vary, depending on the operational characteristics and requirements of the components. The H-bridge switch 720 receives a control-signal input *d* 722 from the CPU. The power supply 712 receives a control input 724 from the CPU to control the current supplied to the H-bridge switch 718 for transfer to the coil 726. The CPU receives input 730 from one or more electromechanical sensors 732 that generate a signal corresponding to the strength of vibration currently being produced by the linearly oscillating mass 734. Sensors may include one or more of accelerometers, piezoelectric devices, pressure-sensing devices, or other types of sensors that can generate signals corresponding to the strength of desired vibrational forces.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM. Figure 8A provides a control-flow diagram for the high-level control program. The program begins execution, in step 802, upon a power-on event invoked by a user through a power button or other user control. In step 802, various local variables are set to default values, including the variables: (1) *mode*, which indicates the current operational mode of the device; (2) *strength*, a numerical value corresponding to the current user-selected strength of operation, corresponding to the electrical current applied to the coil; (3)

lvl0, a previously sensed vibrational strength; (4) *lvl1*, a currently sensed vibrational strength; (6) *freq*, the current frequency at which the direction of current is alternated in the coil; (6) *d*, the control output to the H-bridge switch; and (7) *inc*, a Boolean value that indicates that the frequency is currently being increased. Next, in step 804, the control program waits for a next event. The remaining steps represent a continuously executing loop, or event handler, in which each event that occurs is appropriately handled by the control program. In certain implementations of the control program, events may be initiated by interrupt-like mechanisms and stacked for execution while, in more primitive implementations, certain events that overlap in time may be ignored or dropped. In the implementation illustrated in Figures 8A-C, two timers are used, one for controlling the change in direction of the current applied to the coil, at a currently established frequency, and the other for controlling a monitoring interval at which the control program monitors the vibrational force currently produced. Rather than using a formal timer mechanism, certain implementations may simply employ counted loops or other simple programming techniques for periodically carrying out tasks. When an event occurs, the control program begins a series of tasks, the first of which is represented by the conditional step 806, to determine what event has occurred and appropriately handle that event. When the frequency timer has expired, as determined in step 806, the value of the output signal *d* is flipped, in step 808, and output to the H-bridge switch, with the frequency timer being reset to trigger a next frequency-related event. The frequency-timer interval is determined by the current value of the variable *freq*. Otherwise, when the event is a monitor timer expiration event, as determined in step 810, then a routine "monitor" is called in step 812. Otherwise, when the event corresponds to a change in the user input through the user interface, as determined in step 814, the routine "control" is called in step 816. Otherwise, when the event is a power-down event, as determined in step 818, resulting from deactivation of a power button by the user, then the control program appropriately powers down the device, in step 820, and the control program terminates in step 822. Any other of various types of events that may occur are handled by a default event handler 824. These events may include various error conditions that arise during operation of the device.

Figure 8B provides a control-flow diagram for the routine "monitor," called in step 812 of Figure 8A. In step 830, the routine "monitor" converts the sensor input to an integer representing the current vibrational force produced by the ORM and stores the integer value in the variable *lvl1*. Next, in step 832, the routine "monitor" determines whether or not the ORM is currently operating in the default mode. In the default mode, the ORM uses continuous feedback control to optimize the vibrational force produced by the ORM by continuously seeking to operate the ORM at a frequency as close as possible to the resonant frequency for the ORM. Other, more complex operational modes may be handled by various more complex routines, represented by step 834 in Figure 8B. More complex vibrational modes may systematically and/or periodically alter the frequency or produce various complex, multi-component vibrational modes useful in certain applications, appliances, devices, and systems. These more complex modes are application dependent, and are not further described in the control-flow diagrams. In the case that the operational mode is the default mode, in which the control program seeks to optimize the vibrational force generated by the device, in step 836, the routine "monitor" determines whether the local variable *inc* is set to TRUE. If so, then the control program is currently increasing the frequency at which the device operates in order to obtain the resonance frequency. When *lvl1* is greater than *lvl0*, as determined in step 838, then the vibrational force has been recently increased by increasing the frequency, and so the routine "monitor" increases the frequency again, in step 840, and correspondingly resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 842, then the control program has increased the frequency past the resonance frequency, and therefore, in step 844, the control program decreases the frequency, sets the variable *inc* to FALSE, and correspondingly resets the frequency timer. In similar fashion, when the variable *inc* is initially FALSE, as determined in step 836, and when *lvl1* is greater than *lvl0*, as determined in step 846, the routine "monitor" decreases the value stored in the variable *freq*, in step 848 and resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 860, then the routine "monitor" increases the value stored in the variable *freq*, sets the variable *inc* to TRUE, and resets

the frequency timer in step 862. Finally, the value in *lvl1* is transferred to *lvl0* and the monitor timer is reset, in step 864.

Figure 8C provides a control-flow diagram for the routine "control," called in step 816 in Figure 8A. This routine is invoked when a change in the user controls has occurred. In step 860, the variables *mode* and *strength* are set to the currently selected mode and vibrational strength, represented by the current states of control features in the user interface. Next, in step 862, the routine "control" computes an output value *p* corresponding to the currently selected strength, stored in the variable *strength*, and outputs the value *p* to the power supply so that the power supply outputs an appropriate current to the coil. Finally, in step 864, the routine "control" computes a new monitor timer interval and resets the monitor timer accordingly.

The control program described with reference to Figures 8A-C is one example of many different implementations of the control program that can be carried out, depending on requirements of the ORM, the parameters and characteristics inherent in a particular ORM, the types of control inputs received from a particular user interface, the nature of the power supply, and the types of operational modes that are implemented for the ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs. Figure 9 has the same axes as the graph shown in Figure 3. However, unlike Figure 3, Figure 9 includes many different curves, such as curve 902, each representing the vibrational forces and frequencies that can be obtained from a particular ORM implementation. Again, an ORMs generally has at least one resonant frequency that is characteristic of the geometry and weights of various components of the ORM, and each ORM is naturally operated at a frequency close to this resonant frequency in order to achieve maximum vibrational force. Thus, rather than being restricted, over all possible implementations, to a relatively narrow range of frequencies and vibrational forces, as in the case of unbalanced electrical motors, ORMs can be designed and implemented to produce desired vibrational forces over a wide range of vibrational frequencies, and desired vibrational frequencies over a wide range of desired vibrational forces. The contrast is perhaps best seen in Figure 10. Figure 10 shows a

plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by linear ORMs. Unbalanced electric motors can be implemented to produce amplitude/frequency combinations roughly within the cross-hatched square region 1002 within amplitude/frequency space. By contrast, linear ORMs can be designed and implemented to produce amplitude/frequency combinations underlying curve 1004. Thus, linear ORMs can achieve much higher operational frequencies and much lower operational frequencies than can be practically obtained by unbalanced electric motors, and can produce much higher amplitudes and vibrational forces than can be achieved by relatively low-powered unbalanced electrical motors used in hand-held appliances and other commonly encountered devices and systems. Furthermore, when larger vibrational forces are needed, balanced electrical motors are generally impractical or infeasible, due to the destructive forces produced within the electrical motors. In general, a single implemented linear ORM can access a much larger region of amplitude/frequency space than currently available vibration modules, which generally operate at fixed amplitudes and/or fixed frequencies, as further discussed below.

Figures 11-18 show a variety of different alternative implementations of ORMs. Figure 11 provides a schematic illustration of an ORM similar to that discussed above with reference to Figure 4A. Note that, in place of the end magnets 1102 and 1104, mechanical springs may alternatively be used. These may be traditional helical springs made from metal or springs made from a compressible and durable material or mechanical device that seeks to restore its initial shape when depressed or compressed. Note that the weight and chamber may be cylindrical, in cross section, as discussed above with reference to Figure 5A, or may have other shapes, including rectangular or hexagonal cross-sections.

Figure 12 shows a similar implementation in which the control unit and power supply are incorporated into the moving mass 1202. In this implementation, the relative masses of the moving mass 1202 and remaining components of the ORM is maximized, thus maximizing the vibrational forces produced at a given level of power consumption.

Figure 13 shows yet an alternative ORM. In this alternative implementation, additional coils 1302 and 1304 are incorporated in the moving mass, and a centering magnet or coil 1306 is positioned in a fixed location on the housing so that, when the direction of the current applied to the coils 1302 and 1304 is alternated, an oscillating rotational force is generated to cause the movable weight to oscillate both in a plane perpendicular to the axis of the chamber as well as linearly oscillating the direction of the chamber.

Figure 14 illustrates an ORM in which multiple electromagnetic coils are employed. In Figure 14, two coils 1402 and 1404 are placed in two different positions on the housing. The first coil 1402 may be used to drive linear oscillation of the moving mass 1406, while the second coil may be activated in order to shorten the length of the chamber within which the moving mass linearly oscillates, essentially serving as a second repelling magnet. In this implementation of the ORM, the moving mass may linearly oscillate with at least two different amplitudes, depending on whether or not the second coil 1404 is activated to repel the moving mass. Additionally more complex patterns of current reversal in the two coils can be employed to produce complex multi-component vibrational modes of the moving mass.

When the housing is fully enclosed, air within the chamber serves to dampen oscillation of the moving mass. This dampening may be minimized by providing channels, on the sides of the moving mass, to allow air to pass from one side of the moving mass to the other, by channels through the moving mass, or by providing openings in the housing to allow air to be forced from the housing and drawn into the housing. Additionally, different fluids or liquids may be employed within the chamber to change the dampening effect produced by displacement of the fluids and gasses as the moving mass linearly oscillates.

Figure 15 illustrates an alternative ORM an implementation of the linear resonant vibration module to which current document is directed in which a plunger linearly oscillates to produce a vibration. The plunger 1502 is slideably contained within a moveable-component track orthogonal to a long axis of the main housing 1504 of the ORM that includes the power supply, microcontroller, and other control components. The plunger is girdled by, or includes, a driving magnet 1506 that

is attracted to, and seeks to be positioned in alignment with, a centering magnet 1508 mounted within the housing. Applying current to one of two driving coils 1512 and 1514 forces the driving magnet away from the equilibrium position shown in Figure 15. By rapidly switching the direction of current applied to the driving coils, the microcontroller can control the plunger to linearly oscillate in an up-and-down fashion, as indicated by arrow 1520.

Figure 16 shows yet another ORM an implementation of the linear-resonant vibration module to which current document is directed. In this an implementation of the linear-resonant vibration module to which current document is directed, a spring-like member 1602 is clamped at one end 1604 to the housing. Driving magnets 1606 and 1608 are fixed to the spring-like member 1602, and when current is rapidly reversed in a coil 1610, the spring-like member 1602 is induced to vibrate at a relatively high frequency.

Figure 17 shows another ORM similar to the ORM shown in Figure 16. In this ORM, the spring member 1702 is extended to provide an external massage arm 1704 that extends out from the housing to provide a linearly oscillating massage-foot member 1706 for massaging human skin or some other substrate, depending on the application.

Figure 18 shows a mechanical vibration adjustment feature that can be added to either of the ORMs shown in Figures 16 and 17. An adjustment screw 1802 can be manipulated to alter the position of a movable spring clamp 1804 that acts as a movable clamping point for the spring-like member 1806. Moving the movable spring clamp 1804 leftward, in Figure 18, shortens the length of the spring-like member and thus tends to increase the resonant frequency at a particular power-consumption level. Conversely, moving the movable spring clamp rightward, in Figure 18, lengthens the spring-like member and decreases the vibrational frequency.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17. In this implementation, the massage foot is enhanced to include elastomer bristles 1902-1906 to transfer the linear oscillation of the massage foot to human skin or another substrate. The elastomeric bristles, or pad or brush comprising numerous elastomeric bristles, allow transmission of vibration to a surface even at low

operational powers, when a rigid or even semi-compliant massage foot would instead simply stop moving for inability to overcome frictional forces.

Figure 20-23C illustrate a different type of ORM. This ORM comprises a motor incorporated within a printed circuit board ("PCB"). The motor includes moving and non-moving components that interact via electromagnetic forces to produce motion. The non-moving components include a stator that generates a magnetic field. A stator can be created by using one or more coils. In certain implementations, a stator adapted to integration with a planar substrate is produced using combinations of one or more spiral-shaped conductive traces.

Figure 20 illustrates a first coil layer. The first coil layer 2000 includes a substrate 2002 and a spiral-shaped trace 2004 that is wound in a clockwise direction from the outside of the spiral to the inside of the spiral. The spiral-shaped trace 2004 surrounds a central core and overlays the substrate 2002. In some implementations, the substrate 2002 is a printed circuit board. The width and thickness of the trace influence the conductivity of the resulting coil. In general, thicker and wider traces have lower electrical resistance and result in coils with lower resistance and higher current carrying capacity. Spirals with a larger core diameter and spirals having a larger number of turns produce coils with correspondingly higher inductance. The inductance of the spiral-shaped trace 2004 with an air core at the center of the spiral is expressed as:

$$L(uH) = \frac{r^2 N^2}{8r + 11W}$$

where:

r is the core radius in inches;
N is the number of turns; and
W is the total width of the windings in inches.

The inductance of the resulting coil can be adjusted by altering the above parameters, as well as through the selection of core materials.

A first connection pad 2006 and a second connection pad 2008 terminate the ends of the spiral-shaped trace 2004. In certain implementations, the first

connection pad 2006 and/or the second connection pad 2008 are incorporated into one or more conductive vias connecting the first coil layer to other coil layers or to electrical circuits constructed on the substrate. Additional connection pads 2010, 2012, 2014, and 2016 can provide connection points or can be incorporated into vias that connect multiple layers of traces.

Figure 20 additionally illustrates the placement of a number of motor elements in a particular motor implementation. At the center of the spiral-shaped trace 2004 is a circular opening 2018. The circular opening provides a space for an armature 2020. The armature 2020 can be made from a ferrous metal or a magnetic material and moves in a direction substantially perpendicular to the surface of the substrate 2002 in response to a drive current applied to the coil layer. A centering spring 2022 retains the armature 2020 in the circular opening 2018 in the substrate 2002, and allows limited movement perpendicular to the substrate.

In certain implementations, the traces and connection pads are made from conductive material, such as metal, copper, aluminum, or conductive alloys. The traces and connection pads on the first coil layer 2000 can be fabricated using printed-circuit-board manufacturing techniques. In some implementations, foil decals are created and laminated onto the substrate 2002. The construction of multi-layer coils is achieved using a number of techniques, including: multi-layer PCB construction; laminated foil decals separated by insulating layers; and 2-sided PCB construction. In some implementations, the traces and connection pads are embedded into the substrate 2002.

Figure 21 illustrates a second coil layer. The second coil layer 2100 is constructed using techniques already described for the construction of the first coil layer 2000. A spiral-shaped trace 2102 winds in a clockwise direction from the starting connection pad 2104 to the ending connection pad 2106. The coil layer of Figure 20 is positioned over the coil layer of Figure 21 and the two layers are aligned with one another so that the second connection pad 2008 in Figure 20 overlays the starting connection pad 2104 in Figure 21, and the connection pad 2010 in Figure 20 aligns with the ending connection pad 2106 in Figure 21. PCB vias form electrical connections between the second connection pad 2008 in Figure 1 and the starting

connection pad 2104. When the first coil layer 2000 in Figure 20 and the second coil layer 2100 in Figure 21 are connected in this way and energized, the inductance of the layers is additive. In one mode of operation, current flows into the coil layer of Figure 20 starting at the first connection pad 2006, clockwise around the coil to the second connection pad 2008, through a via to the starting connection pad 2104, and clockwise to the ending connection pad 2106. Adding additional coil layers increases the total inductance of the resulting coil. Additional connection pads 2108, 2110, 2112, and 2114 provide connection points and support for vias that connect to additional coil layers. In certain implementations, additional coil layers can be added to the coil using similar methods to those described above. The additional coil layers are separated by insulating layers or placed on opposite sides of an insulating substrate. In certain implementations, the multi-layer coil is used as a stator in a motor.

Figure 22A illustrates a cross-section of a stator having two coil layers. A first coil layer 2202 and a second coil layer 2204 are laminated onto an insulating planar substrate 2206, such as a PCB. The first and second coil layers 2202 and 2204 are separated by an insulating layer and electrically connected to each other with a via 2208. The stator is driven by a first connection pad 2210 and a second connection pad 2212. In certain implementations, the second connection pad 2212 is routed to the front surface of the PCB using a via. An opening 2214 is provided for an armature that moves perpendicularly to the surface of the substrate in response to energizing the stator. The first and second coil layers can be constructed using the coil layers illustrated in Figures 20 and 21, or with similar trace patters arranged so that the coil layers produce a single direction of rotation around the opening 2214. The implementations illustrated in Figure 22A can be extended to include additional coil layers laminated to both sides of a planar substrate.

Figure 22B illustrates a cross-section of a stator having four coil layers. A first-front coil layer 2250 and a second-front coil layer 2252 are laminated onto a front surface of an insulating planar substrate 2254, such as a PCB. A first-back coil layer 2256 and a second-back coil layer 2258 are laminated onto a back surface of the insulating planar substrate 2254. A first via 2260 electrically connects the end of the first-front coil layer 2250 to the beginning of second-front coil layer 2252. A second

via 2262 electrically connects the end of the first-back coil layer 2256 to the beginning of second-back coil layer 2258. Cross-substrate via 2264 connects the end of first-front coil layer 2250 to the end of first-back coil layer 2256. When current enters at an entry connection pad 2266 and passes through the four coil layers, the current travels with a single direction of rotation until the current exits at an exit connection pad 2268. The inductance of the stator in Figure 22B is approximately double that of the stator shown in Figure 22A.

Figure 22C illustrates a cross-section of a stator having two coil layers. A front coil layer 2280 and a back coil layer 2282 are laminated onto opposing sides of an insulating planar substrate 2284, such as a PCB. A via 2288 electrically connects the front coil layer 2280 to the back coil layer 2282 forming a coil wound in a single direction around the opening 2290. Connection pads 2292 and 2294 provide electrical contacts for connecting the coil to a drive current.

In some implementations, the coil layers that make up the stator are not interconnected to form a single coil. For example, cross-substrate via 2264 may be omitted, and the two front coil layers 2250 and 2252 are electrically driven independently from the two back coil layers 2256 and 2258. In other implementations, the two front coil layers 2250 and 2252 are counter-wound with respect to the two back coil layers 2256 and 2258. In this configuration, the magnetic fields generated in the opening 2270 by the two front coil layers oppose the magnetic field generated by the two back coil layers.

PCBs are suitable substrates for making the coils and motors described in the current document. A PCB can be constructed using a PCB process where layers of printed copper are separated by a hard laminate core, for example, using FR-4 glass-reinforced epoxy. A PCB made from polyimide can support a greater density of coils and increased mechanical flexibility. A PCB made from a ceramic, such as aluminum oxide, provides increased heat resistance. The stators described above can be constructed with any of these PCB materials.

In certain implementations, the coil layers described above are arranged to form one or more coils that overlay the front and/or back surfaces of a PCB. The coils form a stator that drives the armature of a motor.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate. The motor 2300 is constructed on a substrate 2302 , such as a PCB. A first front coil layer 2304 and a second front coil layer 2306 overlay the front surface of the substrate 2302. A first back coil layer 2308 and a second back coil layer 2310 overlay the back surface of the substrate. A first via 2312 electrically connects the first front coil layer 2304 to the second front coil layer 2306 to form a front coil, and a second via 2314 electrically connects the first back coil layer 2308 to the second back coil layer 2310 to form a back coil. Front coil connections 2316 and 2318 provide electrical connectivity for driving the front coil. and back coil connections 2320 and 2322 provide electrical connectivity for driving the back coil.

A magnetic armature 2324 having a north pole 2326 and a south pole 2328 is positioned in an opening in the substrate 2302 through the center of the front and back coils. In order to drive the magnetic armature 2324 into vibration, a first oscillating current is applied to the front coil connections 2316 and 2318, and a second oscillating current is applied to the back coil connections 2320 and 2322. When the motor is operated, the current that flows through the front coil and the current that flows through the back coil flow with opposite directions of rotation. In certain implementations, this is accomplished by applying the same oscillating current to both front and back coils provided the coils are counter-wound. In an alternative implementation, where the coils are not counter-wound, the second oscillating current is 180 degrees out of phase with the first oscillating current. The resulting oscillating magnetic field provides a magneto-motive force to the north pole 2326 and the south pole 2328 in synchrony, driving the magnetic armature 2324 into vibration at a frequency proportional to the frequency at which the oscillating current is applied. In an alternative implementation, the second front coil layer 2306 is connected to the first back coil layer 2308 with a third conductive via to form a single-drive counter-wound stator that is driven with a single oscillating current to produce vibratory motion of the armature.

The magnetic armature is constructed from an axially polarized magnet. In one implementation, the magnet is a neodymium grade N-42 disk magnet. The size

and shape of the magnet is adapted based, in part, on the desired vibration profile of the motor.

Figure 23B illustrates the motor with the magnetic armature in an upward position. When a first driving current is applied to a front coil 2330, the front coil 2330 generates a downward magnetic flux 2332. In response to the downward magnetic flux 2332, an upward vertical force is exerted on the north pole 2336. As the first driving current is applied, a second driving current is applied to a back coil 2338 and an upward magnetic flux 2340 is generated. In response to the upward magnetic flux 2340, an upward vertical force is exerted on the south pole 2342 of the magnet. In response to the upward forces, the magnetic armature 2334 moves upwards as illustrated in Figure 23B.

Figure 23C illustrates the motor with the magnetic armature in a downward position. When the direction of the first and second driving currents is reversed, the forces on the north pole 2360 and south pole 2362 are reversed. When the first reversed current is applied to a front coil 2364, the front coil 2364 generates an upward magnetic flux 2366, and a downward vertical force is exerted on the north pole 2360. When the second reversed current is applied to a back coil 2368 a downward magnetic flux 2370 is generated. A downward vertical force is exerted on the south pole 2362 of the magnetic armature 2372. In response to these two forces, the magnetic armature 2372 moves downwards as illustrated in Figure 23C.

The drive currents are alternated to cause the magnetic armature to vibrate perpendicularly to the surface of the substrate at a chosen frequency. In one implementation, the front coil and back coil are counter-wound with respect to each other. The front and back coils are connected with a conductive via or wire and driven with one drive current. This arrangement causes the front and back coils to generate simultaneous magnetic flux signals in opposing directions, which, in turn, acts on the north and south poles of the magnetic armature to drive the magnetic armature into vibration.

In alternative implementations, additional coil layers are employed. For example, an 8-layer PCB can have four front coil layers and four back coil layers. The four front coil layers are connected to form a front coil, and the four back coil layers

are connected to form a back coil. In certain implementations, the front coil and back coil are counter wound, and driven with a single drive current as explained above.

Next, a slightly more mathematically descriptive explanation of oscillation, resonance, and the Q factor is provided. Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation. Great insight into harmonic oscillators can be provided by considering a simple, one-dimensional spring. Figure 24A illustrates a spring that can be extended in the x direction. In a first diagram 2402, the spring is shown in an equilibrium, resting state with a point or mass 2404 at the end of the spring located at the position $x = 0$. In a second diagram 2406, the spring has been pulled rightward, along the x direction, with the mass 2404 now located at a position x. As is well known, the extended spring has potential energy that results in a force F_x 2408 that points in the opposite direction. In other words, were the spring released, the mass would travel leftward, oscillate back and forth, and eventually settle back to the 0 position shown in diagram 2402. Were the spring frictionless, however, the mass would continue to oscillate back and forth, in a manner similar to the linear ORM described in Figures 4A-B, indefinitely.

The frictionless spring can be mathematically modeled as follows:

$$F_s(x) = -kx,$$

where $F_s(x)$ is the force exerted by the spring;
x is the position of the spring end; and
k is the force constant.

The force constant k is a property of the spring, including all of the parameters that contribute to its elasticity, compressibility, and other physical characteristics of the spring. In more complex, realistic situations, many different factors may contribute to the force constants associated with harmonic oscillators, including interaction with other harmonic-oscillation modes within a physical device or module.

The potential energy of the spring system illustrated in Figure 24A can be modeled as:

$$U(x) = \frac{1}{2}kx^2,$$

where $U(x)$ is the potential energy of the spring system.

Using Newton's second law, the equation that models the force exerted by the spring when it is extended or compressed can be modeled as a simple, second-order differential equation:

$$m\ddot{x} = Fx = -kx,$$

where m = mass of oscillator; and

$$\ddot{x} = \frac{d^2x}{dt^2}.$$

This differential equation can be simplified as:

$$\ddot{x} = \frac{-k}{m}x = -\omega^2 x,$$

where $\omega = \sqrt{\frac{k}{m}}$.

The general solution for this simple, second-order differential equation is, in one form:

$$x(t) = C_1 e^{i\omega t} + C_2 e^{-i\omega t}.$$

In this equation, C_1 and C_2 are arbitrary constants that are determined by the initial conditions of a particular spring system. This solution can be recast as:

$$x(t) = B_1 \cos(\omega t) + B_2 \sin(\omega t).$$

where $B_1 = C_1 + C_2$; and

$$B_2 = i(C_1 - C_2).$$

A final, perhaps most elegant form of the solution is:

$$x(t) = \mathrm{Re}[Ae^{i(\omega t - \delta)}],$$

where $Ae^{-i\delta} = B_1 - iB_2 = C$.

In this equation, A is the amplitude of the oscillation, ω is an angular velocity of the oscillation, as discussed above with reference to Figure 24B, and δ is an initial phase offset. This final expression describes the mapping of a rotation to linear harmonic oscillation, as discussed above with reference to Figure 4B, shown again, in Figure 24B, with annotations taken from final expression for the solution to the differential equation.

As mentioned above, a frictionless spring would continue to oscillate indefinitely after being released from an extended position. However, in actual systems, there are always resistive forces, such as friction, that dampen the oscillation so that, over time, the amplitude of the oscillation decreases and the oscillation finally stops. This more complex and more realistic scenario can be modeled by including a resistive-force term in the second-order differential equation:

$$m\ddot{x} + b\dot{x} + kx = 0,$$

where $-b\dot{x}$ is a resistive force; and

$$\dot{x} = \frac{dx}{dt}.$$

Defining several new constants as follows:

$$\beta = \frac{b}{2m} = \text{ damping constant, and}$$

$$\omega_0 = \sqrt{\frac{k}{m}} = \text{ natural frequency}$$

and solving the above modified second-order ordinary differential equation, the following result is obtained:

$$x(t) = Ae^{-\beta t}\cos(\omega_1 t - \delta)$$

where $\omega_1 = \sqrt{\omega_0^2 - \beta^2}$; and

$\beta < \omega_0$.

when, as indicated above, the damping constant β has a value less than the value of the natural frequency ω_0, the system in under-damped and the amplitude of the oscillations decrease non-linearly, as shown in Figure 24C. When β is greater than ω_0, the system is over-damped, in which case only a single oscillation may occur, as shown in Figure 24D.

Most physical systems have one or more natural frequencies at which they oscillate, when mechanically perturbed from their equilibrium states. In ORMs, a motor is used to continuously perturb the system in order to drive the ORM to oscillate and generate vibration. A device in which an ORM is incorporated vibrates in response to a driving vibration generated by the ORM. In this case, an external

driving force $F(t)$ is applied by the ORM to drive continuous oscillation of the device in which it is included. An external-force-driven linear oscillator can be modeled by the following expression:

$$m\ddot{x} + b\dot{x} + kx = F(t),$$

where $F(t)$ is an external driving force.

With the definition:

$$f(t) = \frac{F(t)}{m},$$

the mathematical model becomes:

$$\ddot{x} + 2\beta\dot{x} + \omega_0^2 x = f(t).$$

A solution for this expression is:

$$x(t) = A\cos(\omega t - \delta)$$

where $f(t) = f_0\cos(\omega t)$;

$$A^2 = \frac{f_0^2}{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2} \text{ ; and}$$

$$\delta = \arctan\left(\frac{2\beta\omega}{\omega_0^2 - \omega^2}\right).$$

In this expression, the constant ω is the driving frequency of the driving force, which is somewhat less than the natural frequency ω_0. As can be seen in the expression for the square of the amplitude, which is proportional to the energy of the vibration, the amplitude is maximized when the denominator of this expression is a value approaching 0. Maximizing the expression can be carried out either by varying the physical device in order to vary the natural frequency ω_0, while the external-driving-force frequency remains fixed ω, or by varying the driving frequency ω when the natural frequency ω_0 is fixed. When ω_0 varies and ω is fixed, A is maximum when $\omega_0 = \omega$; and when ω varies and ω_0, A is maximum when $\omega = \sqrt{\omega_0^2 - 2\beta^2}$. This is where the term "resonance" arises. The resonant frequency is the frequency at which the amplitude A is maximized. As can be seen, this occurs, in general, when the driving frequency of the motor or other mechanical-force-input mechanism has a frequency

close to or equal to the natural frequency ω_0 of the physical system. A quality factor Q can be expressed, in terms of the natural frequency and damping factor, as:

$$Q = \frac{\omega_0}{2\beta}.$$

This is the reciprocal of the ratio of the width of the amplitude peak at half its maximum value to the natural frequency ω_0.

An ORM Controller

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration. The vibration may be generated for application to people, animals, or objects for various purposes, including therapeutic purposes, or may instead be generated to provide haptic feedback, such as vibration in mobile phones, vibration-based notification, or vibration-based communications. Thus, the current document is directed to particular features of a generic ORM-containing device or system that may be used in a wide variety of different types of applications or included in larger devices and systems. In Figure 25, the device, appliance, or system is represented by an outer rectangle 2502. The device includes four ORMs 2504-2507. The ORMs may be of any of many different types, including the types of ORM discussed above. In general, the ORMs convert input energy, such as an electrical current, to mechanical vibration. The device also includes several vibration sensor 2510-2511. There are a variety of different types of vibration sensors, including piezoelectric accelerometers that measure acceleration in one, two, or three different orthogonal directions. Other types of sensors may include membranes attached to moving coils that generate electronic signals when the membrane vibrates, similar to a reverse audio speaker. In addition, the device or system contains a controller 2516. The controller includes ORM control logic 2418 that transmits control signals, in certain cases electrical signals that also serve to power the ORMs. The ORM control logic may be implemented as a sequence of processor instructions, when the controller 2516 is a processor or processor-controlled controller subsystem. In many of the ORM devices and systems, the controller accesses some type of electronic memory 2520, which stores processor instructions and other types of data for

implementing ORM control logic 2518. Not shown in Figure 25 are various standard components and signal lines, including a power supply and power-transmitting circuitry, display screens, push buttons, other user-interface-related components, and other types of logic and logic-controlled subcomponents particular to particular types of devices, such as transceivers and communications subsystems within mobile phones. A set of double-headed arrows, such as double-headed arrow 2522, represent the fact that the controller may control many other subcomponents and features of the device or system in addition to the ORMs.

In the previous discussion of oscillation, vibration, and resonance, simple mathematical models for one-dimensional harmonic oscillation were developed. However, in the generic ORM-containing device or system, there may be multiple ORMs, activation of which produce very complex three-dimensional spatial vibration. Vibration modes of individual ORMs may couple to produce a large number of complex spatial-vibration modes. The physical characteristics of these vibration modes may be highly dependent on the exact geometry, weight and balance, and the material type of the housing and internal components of a particular device or system. As a result, there may be numerous different natural resonant frequencies for the device or system.

Figures 26A-B illustrate multiple resonant frequencies within a device or system. In Figure 26A, the vibrational energy, or square of the amplitude of the vibration, is plotted with respect to frequency. The vertical axis represents the energy and vibration 2602 and the horizontal axis represents the frequency of vibration 2604. The plotted curve 2606 shows numerous different vibration-energy peaks 2610-2615. The heights and positions of these peaks along the frequency axis 2604 may vary considerably with slight changes to the physical characteristics of a device or system that is vibrated by ORM components.

Figure 26B shows a more complex type of vibration-response plot. The vibration response is represented by a surface 2620 in the plot shown in Figure 26B. Measured amplitudes or vibration energies produce a surface 2620 in a three-dimensional Cartesian coordinate system that includes an x-direction vibration frequency axis 2522, a y-direction frequency axis 2624, and a vibration-energy axis

2626. The device or system for which the vibration-response surface 2620 is obtained includes two ORMs, one of which generates vibrations in the x direction and one of which generates vibrations in the y direction. The two ORMs can be independently controlled to generate vibrations in their respective directions at different frequencies. The x, y plane 2628 below the plotted vibration-energy surface 2620 represents all possible x-direction vibration frequencies and y-direction vibration frequencies that can be generated by the two ORMs within the device or system. As shown in Figure 26B, the surface includes three local vibration-energy maxima 2630-2632. These three local maxima are each associated with x-direction frequency and y-direction frequency components 2634. Thus, in the case shown in Figure 26B, two ORMs which generate vibrations in two different directions within the device or system may generate a complex vibration-response surface with respect to the frequencies at which the two ORMs are operated. Depending on the types and numbers of ORMs, the vibration response may be a hyper-dimensional surface in a much higher dimensional frequency space. In all cases, however, the device or system generally has some number of characteristic resonant frequencies that represent maximal vibration energy or amplitude with respect to the frequencies at which individual ORMs are driven with the device or system. In general, the number of resonant frequencies is equal to the number of vibrational degrees of freedom in the device, appliance, or system.

A vibration-response obtained for a device or system by measuring sensor output can be used to identify and tabulate the natural resonant frequencies for the device or system. Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25. Each row in the resonant-frequency table 2702, such as row 2704, represents a local maxima, or peak, in the vibration response for the generic device. In the example table shown in Figure 27, each peak is characterized by an amplitude in the x 2706, y 2707, and z 2708 directions as well as by the frequency of vibration represented by the peak ω 2710 and by the frequency at which each of the four ORMs are driven by the ORM control logic 2712-2715. Thus, to achieve maximum vibration energy of the vibration of the generic device at any of the resonant frequencies for the device, the ORMs are driven at the control frequencies for that resonant frequency.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response. Figure 28A shows the vibration-response for a simple device, vibration of which is stimulated by a single ORM. There is a single natural frequency ω_1 2802 corresponding to the vibration-energy peak 2804 in the vibration-response plot of vibration energy with response to frequency. Figure 28B shows a plot of the frequency of vibration generated by an ORM with respect to time over a time interval that represents an ORM control scheme. In Figure 28B, the vertical axis 2810 represents the frequency at which the ORM is driven by ORM-control input and the horizontal axis 2812 represents time. The control curve 2814 indicates that the ORM is non-linearly driven over an initial time period 2816 to the natural frequency ω_1 2818 for the device in which the ORM is included. At a final point in time t_f 2820, input to the ORM is discontinued. Figure 28C shows a vibration-response curve for the device containing the ORM when the ORM is operated according to the control curve 2814 discussed above with reference to Figure 28B. As shown in the vibration-response curve 2822, there is an initial lag time 2824 following initiation of the control scheme before a perceptible device vibration occurs, at time t_i 2826. The vibrational energy, or amplitude of vibration, very steeply increases from this point on as the ORM is controlled to approach and equal the natural frequency ω_1 for the device. At time t_f 2820, the vibrational energy of the device relatively steeply falls, since the ORM is no longer being driven. However, the vibrational energy does not immediately fall to 0, as in the control curve, but over a short period of time 2828 after the ORM ceases to be driven.

The generic device, as discussed above, contains a memory that may store various types of control schemes, or control patterns, for the ORMs that are controlled by the ORM control logic. Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device. The example patterns include a linear ramp-up and ramp-down pattern 2802, a constant control over a specified duration of time 2904, and an oscillating control 2906. The patterns may be parameterized by the duration of the pattern 2908 and the maximum input to the ORM 2910. The input may be specified as the current or voltage, for certain types of ORMs. Other ORMs may be controlled by digital control signals in

which numerically encoded commands are transmitted to the ORM. The control patterns can be scaled in both time and frequency in order to generate a variety of equivalent vibration responses for the ORM with similar forms, but different maximum amplitudes and over different periods of time.

A set of scalable control patterns, such as those shown in Figure 29, and a table of resonant frequencies, such as that shown in Figure 27, can be used to generate a table of different types of vibration that can be generated in the generic device by controlling the ORMs within the device according to scaled control patterns. Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25. Each row in the table, such as row 3004, represents a different vibration type that can be produced in the generic device by controlling the ORMs within the device. For example, a cell phone may use a variety of different haptic vibration signals to alert the cell phone user of many different types of events. Each different vibration signal corresponds to a different vibration- type. Each vibration type is characterized by a vibration-type identifier 3006, an amplitude range for the vibration 3008, a reference duration for the vibration 3010, and the control pattern and scaling parameters for the pattern for each of the ORMs 3012-3015. Each vibration type can be scaled within the amplitude range and may also be scaled for a desired duration.

By using either external or internal sensors to characterize the natural resonant frequencies for a physical device or system that contains ORMs, a large number of different vibration responses for the physical device or system can be compiled based on the resonant frequencies as well as a set of ORM control patterns. In alternative vibration-control approaches, the different types of vibration responses may be computed, on the fly, rather than tabulated based on a set of control patterns. However, in all cases, characterization of the resonant frequencies of the device or system that is vibrated by the ORMs contained within the device or system is a necessary step in producing predictable vibration responses via ORM control.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figure 31 illustrates the inner control loop of the control logic within the physical device shown in Figure 25. The inner control loop waits, in step 3102, for a next event and then handles the event that occurs. When the event is a characterize-vibration event, as determined in step 3104, the routine *characterize vibration* is called to handle the event in step 3106. When the event is a generate-vibration event, as determined in step 3108, a generate-vibration routine is called in step 3110 to generate a vibration in response to the generate-vibration event. When the next event is a user-input event, as determined in step 3112, a process-input routine is called, in step 3114, to handle the input from the user. Ellipses 3116 are used in Figure 31 to indicate that many other types of events are handled by the inner event loop of the control logic. When, after handling the most recently occurring event, there are other events that are queued for handling which arose while handling the most recently handled event, as determined in step 3118, then a next event is dequeued in step 3120 with control flowing back to step 3104. Otherwise, control flows back to step 3102 where the inner event loop waits for a next event to occur.

The characterize-vibration event 3104 is an event that is raised by control-logic routines, timer-expiration handlers, and by other control logic in order to control the ORMs and sensors within the generic device to carry out a re-characterization of the vibration-response for the physical device, as discussed above with reference to Figures 26A-B, in order to update the resonant-frequency table, such as the resonant-frequency table discussed above with reference to Figure 27. In devices that employ a vibration-type table, such as the vibration-type table discussed with reference to Figure 30, the vibration-type table is also updated following update of the resonant-frequency table.

A generate-vibration event is raised by control logic in order to vibrate the generic device for a variety of different reasons. As one example, the device may be vibrated in response to user input. As another example, the device may be vibrated when the control logic determines that any of various alert conditions have arisen. As yet another example, generate-vibration events may be raised in order to communicate information to a device user.

Figure 32 provides a control-flow diagram for the characterize-vibration event handler, called in step 3106 of Figurer 31. In step 3202, the routine calls a subroutine *sweep* in order to generate a sampling of a vibration-response curve, surface, or hyper-dimensional surface. In step 3204, the routine calls a store-vibration-maxima subroutine in order to identify the resonant frequencies from the curve or surface sampled in step 3202. Finally, in step 3206, the routine calls a compute-and-store-vibration-type-control subroutine in order to update the vibration-type table based on the new resonant-frequency determination made in steps 3202 and 3204.

Figure 33 provides a control-flow diagram for the subroutine *sweep*, called in step 3202 of Figurer 32. In step 3302, the subroutine *sweep* initializes a data structure for storing a vibration response. As discussed above, the vibration response may be a sampled curve, sampled surface, or sampled hyper-dimensional surface. In the *for*-loop of steps 3304-3306, a frequency sweep of each ORM is initiated. A frequency sweep is a control pattern that continuously sweeps each ORM over a wide range of driving frequencies. Each ORM repeats a single frequency sweep over a different time interval, so that following a number of iterations, the multi-dimensional ORM-driving-frequency space can be sampled. Then, in the *for*-loop of steps 3308-3312, the *sweep* routine continuously samples the vibration amplitude or vibrational energy produced in the device, using sensor output, while the driving-frequency sweeps take place. There are, of course, many alternative methods for sampling the multi-dimensional driving-frequency space in order to generate a sampled vibration-response curve, surface, or hyper-surface.

Figure 34 provides a control-flow diagram for the store-variation-maxima subroutine called in step 3204 of Figure 32. In step 3402, the routine identifies local maxima in the vibration-response curve or surface produced by the *sweep* routine. There are many well-known mathematical techniques for identifying local maxima within a curve, surface, or hyper-surface. Then, in the *for*-loop of steps 3404-3406, data that characterizes each of the local maxima are tabulated in the resonant-frequency table.

Figure 35 provides a control-flow diagram for the compute-and-store-vibration-type-control subroutine called in step 3206 of Figure 32. In a *for*-loop of

steps 3503-3509, each possible set of ORM/control-pattern/resonant-frequency triples is considered. The currently considered triple is used to estimate the vibration mode and intensity of the resulting device vibration, in step 3504. In step 3505, the nearest vibration-type to the estimated vibration mode is identified, if there is one. If a nearest vibration type is found, as determined in step 3506, and when the current ORM/control-pattern/resonant-frequency triple provides a device response closer to the vibration type than the control parameters currently associated with the vibration-type, as determined in step 3507, then, in step 3508, the vibration-type table entry for the found vibration type is updated with the current control parameters represented by the currently considered ORM/control-pattern/resonant-frequency triple. Of course, in certain cases, there may be too many possible ORM/control-pattern/resonant-frequency triples to consider in a reasonable amount of time, in which case the resonant-frequency data may be used in other ways to find the best control parameters for the vibration types in the vibration-type table.

Figure 36 provides a control-flow diagram for the generate-vibration handler called in step 3110 of Figure 31. In step 3602, the handler receives a vibration type, duration, and amplitude associated with the generate-vibration event that is being handled. In step 3604, the appropriate ORM control parameters and patterns are selected from the vibration-type table. In step 3606, the ORM control parameters are scaled according to the received duration and amplitude. In step 3608, a stop time at which the vibration will finish is determined from the received duration. Then, in the *for*-loop of steps 3610-3613, the generate-vibration handler continuously adjusts inputs to each ORM according to the scaled ORM control parameters produced in step 3606.

Precise and Accurate Control of ORMs

The current document is directed to various approaches used within the control logic of an ORM-containing device, appliance, or system, to accurately and precisely control the ORMs to produce time-dependent driving oscillations in conformance with desired control patterns. As discussed above, the combination of controlling ORMs in accordance with control patterns and the accurate characterization

of the resonant frequencies of the device, appliance, or system together allow for reproducible generation of many different types of vibration responses of the device, appliance, or system to the driving oscillations of control-pattern-controlled ORMs.

As further discussed below, many current control regimes fail to accurately reproduce the desired driving time-dependent oscillations in each ORM within a device, appliance, or system. As a result, the vibration response of the device, appliance, or system may vary significantly from a desired vibration response and, perhaps more importantly, may not be accurately reproduced at different points in time, due to the inability to accurately and deterministically control the ORMs to produce driving oscillations in conformance with desired control patterns.

A first approach to more accurately controlling ORMs is to use pulse-width modulation control signals rather than conventional constant-duration control pulses. Figures 37A-D illustrate pulse-width modulation control of an ORM. Figure 37A shows a desired vibration response for an ORM that represents a desired time-dependent driving oscillation for inducing at least a portion of the vibration response of a device, appliance, or system in which the ORM is included. The desired vibration response of the ORM is a sine-wave-like 3702 oscillation that is plotted, in Figure 37A, on an amplitude versus time coordinate system 3704. Figure 37B illustrate a hypothetical control regime that attempts to produce the desired driving oscillation discussed above with reference to Figure 37A in a hypothetical ORM. Constant-width voltage pulses, such as voltage pulse 3706, are input to the ORM to drive the weight or mass in forward and backward directions along the oscillation path. These pulses are plotted in Figure 37B in a voltage versus time coordinate system 3708. Because the constant-width pulses are a rather crude approximation of the desired sine-wave-like vibration response, the control regime shown in Figure 37B comprises a series of positive-voltage, 0-voltage, and negative-voltage constant-width pulses 3706 and 3710-3713 that produce a vibration response, superimposed in Figure 37B over the control pulses, as curve 3716. In general, the pulse widths are controlled by an oscillating clock or clock-based timing signal. The vibration-response curve 3716 differs significantly from the desired driving oscillation shown in Figure 37A. Figure 37C shows the desired vibration response 3702 plotted together with the vibration

response produced by the constant-width voltage-pulse control 3716. In fact, this is actually a relatively favorable case, because the sequence of positive, 0-voltage, and negative voltage pulses shown in Figure 37B has a period close to the period of the desired sine-wave-like vibration response. Otherwise, the actual vibration response would differ even more greatly from the desired vibration response, often having irregularly shaped wave forms.

Figure 37D illustrates pulse-width-modulation control of the ORM. In pulse-width-modulation control, rather than using constant-width voltage pulses to control the ORM, the controller instead uses variable-width pulses. Moreover, much shorter pulses can be used to more precisely control the vibration response of the ORM. In essence, pulse-width modulation allows a variable-frequency control signal to be used, rather than a constant-frequency control signal. Because a variable-frequency control signal can contain a much greater amount of information than a constant-frequency control signal, the pulse-width-modulation control signals can be used to much more precisely steer the vibration response of the ORM towards a desired wave form. As shown in Figure 37D, many more voltage pulses are used in order to achieve the sine-wave-like vibration response of the ORM. For example, in the constant-width-pulse control shown in Figure 37B, a positive-voltage pulse 3706, a 0-voltage pulse, and a negative-voltage pulse 3710 are used to attempt to approximate the first period of the desired vibration response. By contrast, as shown in Figure 37D, four positive-voltage pulses 3720-3722 and 3726 and three negative-voltage pulses 3723-3725 are employed to produce the first period of the desired vibration response. Moreover, these seven pulses have varying pulse widths and are irregularly spaced along the time axis.

Another problem associated with conventional control of ORMs is that the vibration response produced by a control pattern is often very different from the vibration response that might be predicted from the control pattern or desired. For example, in Figure 38A, a control pattern is shown that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806. Of course, this control pattern may correspond to a large number of positive-voltage pulses in the time interval t_i to t_f. The vibration response of the ORM is shown in Figure 38B. In this figure, the horizontal time axis 3808 has been rescaled to show more detail. The control

pattern 3802 shown in Figure 38A might be initially assumed to produce a pulse of constant-amplitude vibrations over the time interval t_i to t_f. However, as shown in Figure 38B, the actual vibration response of the ORM, shown as curve 3810, includes an initial ramp-up interval 3812 in which the amplitude of the vibration response steadily increases to the desired amplitude, a middle period 3814 in which the ORM is oscillating at the desired amplitude, a short period 3816 at the end of the time interval t_i to t_f during which, in anticipation of the sharp control-pattern edge at time t_f, the control voltage is dropped to 0 so that the vibration will fall to a low level at time t_f, and a fourth undesired ramp-down interval 3818, extending well past the time t_f, during which vibration of the ORM continues at increasingly smaller amplitudes.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f. In a first plot 3902, the naïve control pattern is shown. In a second plot 3904, the naïve control pattern is modified in order to produce the constant-amplitude oscillation that is desired. First, a large-voltage input 3906 occurs prior to time t_i in order to quickly force the ORM to begin vibrating. From time t_i to a time prior to time t_f, a lower-voltage input 3908 is provided in order to control the ORM to oscillate at the desired amplitude. Prior to time t_f, a negative-voltage control signal 3910 is input to the ORM in order to sharply drive the ORM towards oscillation out of phase with the desired driving oscillation during the time interval t_i to t_f. This negative-voltage control signal is then relaxed linearly 3912 in order to stop ORM vibration in a relatively short period of time. As shown in plot 3914 in Figure 39, the vibration response of the ORM much more closely approximates a desired constant-amplitude vibration between time intervals t_i and t_f.

Many different types of control inputs can be used to shape the vibration response of an ORM. For example, short control pulses can push the vibration to a different phase, resulting in cancellation of the previously established oscillation. The various types of inputs depend on the type and form of control signals that can be transmitted to the ORM, which, in turn, depends on the type of ROM, the driving force used to induce oscillation of the moving mass within the ORM, and the type of logic circuitry that receives input signals and translates them into oscillations.

Thus, in addition to pulse-width modulation, a wide variety of different types of complex control signals may be devised in order to achieve the vibration response desired from the simple control patterns discussed above, including control pattern 3802 shown in Figure 38A. Many different control-signal parameters may be varied in order to control an ORM to provide a desired vibration response, including varying the voltage of the control signal, using pulse-width modulation to finely tailor the control signal to produce a desired vibration response, and adjusting the control signal to include pre-response and post-response signals to remove undesired ramp-up and ramp-down periods in the vibration response.

In addition to varying the input control to an ORM, an ORM may be designed to include a variety of different mechanical controls to further increase the range of vibration responses of the ORM. Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs. Equivalent electromagnetic features may be included in other types of ORMs. Figure 40A illustrates a first type of ORM. In a first diagram 4002, the ORM is shown in an equilibrium, non-vibrating position. The ORM includes a moveable weight or mass 4002 that is connected to two ends of the ORM 4004 and 4006 by springs 4008 and 4010. Diagram 4012 shows the ORM when the movable mass 4002 has been moved, by application of a translational force, such as an electromagnetic force, to the furthest position in the leftward direction along the oscillation path. In this position, spring 4010 is compressed and spring 4008 is extended. In both cases, the springs have potential energy that produces forces that force the movable mass 4002 back in the rightward direction towards stop 4012. Diagram 4014 shows the ORM with the movable mass in the furthest rightward direction.

Figure 40B shows the equilibrium and largest-amplitude positions of a movable mass in a different type of ORM. In a first diagram 4016, the ORM is shown in an equilibrium position. The ORM features an arc-like oscillation path 4018 along which the moving mass 4020, attached to a rotor 4022, oscillates. The moving mass 4020 is attached to the rotor 4022 by a flexible support 4024. Diagram 4026 shows the ORM with the movable mass in the furthest leftward position and diagram 4028 shows

the ORM with the movable mass in the furthest rightward direction, similar to the positions shown for the ORM of Figure 40A in diagrams 4012 and 4014.

Figure 40C illustrates movable mechanical stops included in the ORM discussed above with reference to Figure 40A. The movable stops are depicted by features 4030 and 4032 in a first diagram 4034. Of course, the depictions do not necessarily reflect the shape, size, and structure of mechanical stops needed to stop motion of the moveable mass in the various different types of ORMs, but are instead used to illustrate positioning of the moveable stops and their deployment. In a second diagram 4036, the movable stops have been repositioned 4038 and 4040 in order to limit the length of travel of the moving mass 4002. The second diagram 4036 shows the leftward extent of motion of the moving mass 4002 with the movable stops deployed and diagram 4042 shows the rightward extent of travel of the moving mass when the movable stops are deployed. Similar illustration conventions are used, in Figure 40D, to illustrate deployment of movable stops in the ORM discussed above with reference to Figure 40B. Use of movable stops can significantly alter the vibration response of the ORM to a given control input. This may include changing the amplitude of the vibration response, the frequency of the vibration response, and changing the force imparted by the moving mass to the ORM when the moving mass strikes the stops versus the original end stops 4002 and 4004. In general, the vibration-response alterations are complex functions of the geometry, material composition, and driving forces used in the ORM.

Figures 40E-F illustrate use of the movable stops, discussed above with reference to Figures 40C and 40D, as latches. As shown in a first diagram 4048 in Figure 40E, the movable stops have been repositioned 4050 and 4052 closer to the center of the oscillation path. As shown in diagram 4054, the left-hand movable stop 4056 has been deployed when the moving mass 4002 has just reached its leftward, stopped position. As a result, motion of the moving mass is stopped, resulting in an immediate cessation of the driving oscillation produced by the ORM and a higher force exerted in the last oscillation on the left-end stop 4004 of the ORM. Diagram 4058 shows the right-hand movable stop 4052 deployed to latch the moving mass 4002 at its furthest right-hand position. Figure 40F shows similar deployment of the movable

stops, in the ORM discussed above with reference to Figure 40B, to latch the moving mass at its leftward and rightward extents. Latching of the moveable mass may trap the moveable mass in a high-potential-energy state, so that immediate, rapid oscillation may ensue when the latch is released. Latching may also significantly alter the relaxation of the oscillation at the end of control-pattern execution.

The current document is directed to employing the various different types of alternative control of ORMs to more accurately generate desired vibration responses. This involves use of a much greater amount of information about the ORM than used in the vibration response table discussed above. Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document. The information is stored in five different tables. An ORM table 4102 stores control information for each different ORM in a device, appliance, or system. This information includes an identifier for the ORM 4104, an indication of the ORM type 4105, an indication of the minimum pulse width that can be input in a control signal 4106, an indication of the minimum amplitude 4107 and maximum amplitude 4108 of an input control signal, indications of whether or not mechanical or electromagnetic latches are available in the ORM 4110 and 4112, the oscillation path length within the ORM 4114, the number of movable stops, or path blocks, included in the ORM 4115, and the positioning range for each moveable stop 4116-4117. An event-types table 4120 includes various different types of control events. These may include deployment of latches, movement of movable stops, and output of control pulses of various different widths and amplitudes. An events table 4122 includes ordered pairs of event types and relative times that each represents one of the many different types of control events that can be input to ORMs. Each control event includes an event ID 4123, an event type 4124, and a relative time that specifies a time point within a control pattern 4126 at which the event occurs. Table 4128 includes the actual control actions that a logic controller employs to initiate each type of event in each type of ORM. For each type of control, the table includes an indication of the event type 4130, the ORM type 4131, a control ID 4132, a signal type 4133, a signal strength 4134, and any of many different other characterizations of the type of control 4135 executed by the control logic in order

to control an ORM to produce a particular type of event. Finally, table 4140 lists all of the different types of control patterns that can be used to control ORMs. These are equivalent to the previously discussed control patterns. Each control pattern includes a control-pattern identifier 4142, an indication of the number of events in the control pattern 4144, and the event identifiers for those events 4146-4149.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36. The alternative information incorporates more accurate control of ORMs using the information and techniques discussed above with reference to Figures 37A-41. In step 4202, the routine receives a vibration type, duration, amplitude, and start time for a desired device, appliance, or system vibration response. Then, in the *for*-loop of steps 4204-4212, the routine prepares for controlling each of the ORMs in the device, appliance, or system. In step 4205, a control-pattern ID is selected from the vibration-type table for the ORM, modified with respect to the previously described vibration-type table to include the identifiers of control patterns that are tabulated in the control-patterns table 4149. In step 4206, the identified control pattern is selected from the control-patterns table. In the inner *for*-loop of steps 4207-4212, each event is selected from the control pattern selected in step 4206. For each event, a corresponding event control entry is selected from the event-control table, in step 4208. The controls are scaled, in step 4209, according to the desired duration and amplitude for the vibration response. In step 4210, the time associated with the event, selected from the events table, is also scaled. In step 4211, the scaled controls and times are added to a list of time-ordered events, the controls for which are issued to the ORM during generation of the desired vibration response. In step 4214, the routine waits until the desired start time for the vibration response. Note that the desired start time takes into consideration any pre-vibration-response controls needed to produce the desired vibration response. Then, in the *while*-loop of steps 4216-4222, the routine carries out ORM control over a set of time points spanning the desired vibration-response duration. In the inner *for*-loop of steps 4217-4220, the routine initiates a control sequence for each of the time-ordered events for each of the ORMs at the points in time in which the control sequence is specified for issuance. Then, in step 4221, the routine waits for a next update-control time point.

The above-discussed methods for more accurate and reliable control of ORMs provide increased opportunities for generating increasingly complex vibration responses in devices, appliances, and systems that contain ORMs. However, with increasing complexity, attention is needed to simplifying and increasing the efficiency of driving-oscillation sensing in order to provide feedback-based control to ORMs. In addition, with more accurate control, it is possible to increase the complexity of ORM time-dependent driving oscillations, significantly increasing the types of time-dependent driving oscillations that can be encoded in control patterns and thus increasing the device, appliance, and system vibration responses to controlled ORM driving oscillations.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control. Figure 43 provides a simplified ORM-containing device architecture similar to that provided by Figure 25, discussed above. However, as shown in Figure 43, each of the ORMs, such as ORM 2504, is coupled to an additional passive oscillator, such as passive oscillator 4302. In various different implementations, a given ORM may be coupled to one, two, or more passive oscillators. When an ORM is mechanically coupled to one or more additional passive oscillators, the passive oscillators greatly increase the number of degrees of freedom for vibration of the combined ORM and one or more passive oscillators. The mathematical models for the vibration modes and resonant frequencies become far more complex, involving eigenvalue problems arising from coupled differential equations. As discussed above, the number of resonant frequencies for a system is generally proportional to the number of vibrational degrees of freedom. Furthermore, coupling passive oscillators to ORMs may provide new, complex vibrational modes with different frequencies and amplitudes. Thus, vibration components comprising an ORM and one or more passive oscillators can significantly increase the complexity of the time-dependent driving oscillations produced by these vibration components, and therefore greatly expand the types, frequencies, and modes of vibration responses produced in a device, appliance, or system containing the complex vibration components.

In the simpler system shown in Figure 25, two vibration sensors 2510 and 2511 were included. These vibration sensors detected vibration in one, two, or three orthogonal directions of the device, appliance, or system 2502 in which multiple ORMs are included. However, as shown in Figure 43, sensors that provide information regarding the driving oscillations produced by ORMs and passive oscillators, such as sensors 4304 and 4305 in ORM 2504 and passive oscillator 4302, respectively, may also provide information to local control logic, such as control logic 4306, within ORMs as well as the controller 2516 that controls one or more ORMs within the device, appliance, or system 2502. The sensors local to ORMs and passive oscillators may be designed to sense driving-oscillation characteristics while vibration sensors 2510 and 2511 are designed to sense the vibration response of the entire device, appliance, or system 2502.

By including a variety of different types of sensors within different positions and components of an ORM-containing device, appliance, or system, an opportunity is provided for hierarchical sensing and corresponding feedback control within a device, appliance, or system. In many cases, the output from a vibration sensor may be difficult to translate into accurate feedback information and corresponding control signals. For example, the vibration sensed by the vibration sensors 2510-2511 may be rather indirectly related to the individual driving oscillations produced by the ORM-based vibration components, such as the vibration component comprising ORM 2504 and mechanically coupled passive oscillator 4302. In such cases, a significant amount of inference may be necessary to logically infer the driving oscillations of the vibration components producing the vibration-sensor signals and to compute corresponding adjustments to ORM control. Furthermore, there may be significant temporal lags between sensor vibration and the driving oscillations that produce the sensor vibration. Many of the common techniques for sensing ORM driving oscillations in order to provide local feedback to ORMs may suffer similar problems. Furthermore, there may be many different types of interferences and couplings between electromechanical driving forces, electromagnetic sensors, and other device components that mask or entirely prevent accurate inference of the real-time characteristics of ORMs and the vibration-response of the entire device, appliance, or

system. For this reason, simpler and more direct types of sensing and control can provide enormous benefits in achieving desired vibration responses of the entire device, appliance, or system, particularly in devices, appliances, and systems that include multiple vibration components, each consisting of an ORM and one or more passive oscillators as well as various types of vibration sensors external to ORMs and passive oscillators as well as sensors within, or coupled to, ORMs and passive oscillators.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control. In Figure 44, a linear ORM 4402, used in previous examples, is again shown as an example ORM. The linear ORM includes a mass or weight 4404 that is driven electromagnetically by a drive coil 4406 to oscillate along a linear tube 4408. In this ORM, two sensor coils 4410 and 4412 are additionally included in order to detect motion of the weight or mass 4404 within the ORM as it is driven to oscillate. The sensor information may be provided to an internal ORM control logic 4414 or to the controller 2516 within the device, appliance, or system that includes the ORM. In certain cases, both the internal ORM control logic as well as the device controller may receive sensor information, for various different types of feedback-based control purposes. In the lower portion 4420 of Figure 44, a small control-flow diagram is provided to indicate how the sensor information is used. When a controller receives a target frequency ω_t at which the ORM is to oscillate, in step 4422, the control logic or controller initiates oscillation of the weight or mass, in step 4424, and then, in the *while*-loop of steps 4426-4430, continues to monitor the sensor output and modify control input to the ORM in order that the ORM oscillates at the target frequency ω_t. This involves reading the sensor data to determine the actual frequency of oscillation ω_a, in step 4427, then determining a difference between the target and actual frequencies in step 4428, using the determined difference to compute modifications to the current control of the ORM and modify the control in a way estimated to result in the ORM achieving the target frequency ω_t, in step 4429, and executing the modified control in step 4430. In many cases, the computations are sufficiently complex that the feedback-based control needs to be implemented by control routines running on a processor. Furthermore, because

the sensors 4410 and 4412 are essentially external to the actual oscillating mass or weight and oscillation path, the data that they output does not directly correspond to position and velocity data for the moving mass or weight, but is instead a signal proportional to the current induced in the sensor coils by the moving mass. A fair amount of interpretation is required to convert the sensor information into velocity and position information, or even into information related to the actual frequency ω_a of oscillation. Moreover, there may be significant electromagnetic interference between the drive coil 4406 and the sensor coils 4410 and 4412, limiting the accuracy at which the actual frequency ω_a or mass position and velocity can be determined. Sensor-coil-based inferences may also suffer from significant lag times between passing of the moving weight through the sensor coil and generation of a corresponding signal. In a complex system in which many different sensors are being monitored for many different ORMs, as well as sensors that detect the vibration response for a device, appliance, or system containing the ORMs, use of inferential feedback information, such as that provided by the sensor coils shown in Figure 44, may be problematic, at best.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the direct sensor data. When a target frequency ω_t is received in step 4512, the control initiates oscillation of the mass in step 4514. In addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the sensor and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the

difference and position with time over several readings, but because of the direct nature of the position sensing, is generally far less inferential and computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

Although the present invention has been described in terms of particular embodiments, it is not intended that the invention be limited to these embodiments.

Modifications will be apparent to those skilled in the art. For example, any of many different design and implementation parameters may be varied in order to provide different implementations of the ORM control logic discussed above, including choice of type of logic control, programming language, in the case of a processor-controlled controller, modular organization, data structures, control structures, logic circuitry, processor type, and many other such design and implementation parameters. Many different types of direct sensors that relatively directly determine the velocity and position of the oscillating mass within an ORM can be used in different types of ORMs. Various types of electromagnetic sensors that sense position, precious-metal brush-contact sensors, and Reed switches are examples of the many types of sensors that can be used to directly determine oscillating-mass position and velocity and induce direct, corresponding control of the ORM.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. The foregoing descriptions of specific embodiments of the present invention are presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments are shown and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents:

SUBSTITUTE SPEC

OSCILLATING-RESONANT-MODULE CONTROLLER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of Application No. 15/043,584, filed February 14, 2016, which claims the benefit of Provisional Patent Application No. 62/116,144, filed February 13, 2015.

TECHNICAL FIELD

The current document is related to vibration-generating devices and, in particular, to vibration modules that can be incorporated into a wide variety of different types of electromechanical devices and systems to produce predetermined vibration responses.

BACKGROUND

Vibration-inducing motors and mechanisms have been used for many years in a wide variety of different consumer appliances, toys, and other devices and systems. Examples include vibration signals generated by pagers, smart phones, vibration-driven appliances, such as hair-trimming appliances, electric toothbrushes, electric toy football games, and many other appliances, devices, and systems. The most common electromechanical system used for generating vibrations is an intentionally unbalanced electric motor.

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices. As shown in Figure 1A, a small, relatively low-power electric motor 102 rotates a cylindrical shaft 104 onto which a weight 106 is asymmetrically or mounted. Figure 1B shows the weight asymmetrically mounted to the shaft, looking down at the weight and shaft in the direction of the axis of the shaft. As shown in Figure 1B, the weight 106 is mounted off-center on the electric-motor shaft 104. Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B. As shown in Figures 2A-B, the asymmetrically-mounted weight creates an elliptical oscillation of the end of the shaft, normal to the shaft axis, when the shaft is rotated at relatively high speed by the electric motor. Figure 2A shows displacement of the weight and

shaft from the stationary shaft axis as the shaft is rotated, looking down on the weight and shaft along the shaft axis, as in Figure 1B. In Figure 2A, a small mark 202 is provided at the periphery of the disk-shaped end the of electric-motor shaft to illustrate rotation of the shaft. When the shaft rotates at high speed, a point 204 on the edge of the weight traces an ellipsoid 206 and the center of the shaft 208 traces a narrower and smaller ellipsoid 210. Were the shaft balanced, the center of the shaft would remain at a position 212 in the center of the diagram during rotation, but the presence of the asymmetrically-mounted weight attached to the shaft, as well as other geometric and weight-distribution characteristics of the electric motor, shaft, and unbalanced weight together create forces that move the end of the shaft along the elliptical path 210 when the shaft is rotated at relatively high speed. The movement can be characterized, as shown in Figure 2B, by a major axis 220 and minor axis 222 of vibration, with the direction of the major axis of vibration equal to the direction of the major axis of the ellipsoids, shown in Figure 2A, and the length of the major axis corresponding to the amplitude of vibration in this direction. In many applications, in which oscillation back and forth along a defined path is desired, designers seek to force the major-axis-amplitude/minor-axis-amplitude ratio to be as large as possible, to approach a linear path, but, because the vibration is produced by a rotational force, it is generally not possible to achieve oscillation back and forth along a defined path. In many cases, the path traced by the shaft center may be close to circular. The frequency of vibration of the unbalanced electric motor is equal to the rotational frequency of the electric-motor shaft, and is therefore constrained by the rate at which the motor can rotate the shaft. At low rotational speeds, little vibration is produced.

While effective in producing vibrations, there are many problems associated with the unbalanced-electric-motor vibration-generating units, such as that shown in Figure 1A, commonly used in the various devices, systems, and applications discussed above. Unbalancing the shaft of an electric motor not only produces useful vibrations that can be harnessed for various applications, but also produces destructive, unbalanced forces within the motor that contribute to rapid deterioration of motor parts. Enormous care and effort is undertaken to precisely balance rotating parts of motors, vehicles, and other types of machinery, and the consequences of unbalanced rotating

parts are well known to anyone familiar with automobiles, machine tools, and other such devices and systems. The useful lifetimes of many devices and appliances, particularly hand-held devices and appliances, that employ unbalanced electric motors for generating vibrations may range from a few tens of hours to a few thousands of hours of use, after which the vibrational amplitude produced by the devices declines precipitously as the electric motor and other parts deteriorate. Unbalanced electric motors are relatively inefficient at producing vibrational motion. A far greater amount of power is consumed by an unbalanced electrical motor to produce a given vibrational force than the theoretical minimum power required to produce the given vibrational force. As a result, many hand-held devices that employ unbalanced electric motors for generating vibrations quickly consume batteries during use. Unbalanced electric motors, as discussed above, oscillating motion back and forth along a predefined path, or space curve, cannot generally be produced by unbalanced electric motors. Unbalanced electric motors generate vibrations in only a very limited portion of the total vibrational-force/frequency space. Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors. The graph is shown as a continuous hypothetical curve, although, of course, actual data would be discrete. As shown in Figure 3, for relatively low-power electric motors used in hand-held appliances, only a fairly narrow range of frequencies centered about 80 Hz (302 in Figure 3) generate a significant vibrational force. Moreover, the vibrational force is relatively modest. The bulk of energy consumed by an unbalanced electric motor is used to spin the shaft and unbalanced weight and to overcome frictional and inertial forces within the motor. Only a relatively small portion of the consumed energy is translated into desired vibrational forces.

Because of the above-discussed disadvantages with the commonly employed unbalanced-electric-motor vibration-generation units, designers, manufacturers, and, ultimately, users of a wide variety of different vibration-based devices, appliances, and systems continue to seek more efficient and capable vibration-generating units for incorporation into many consumer appliances, devices, and systems.

SUMMARY

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices.

Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B.

Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors.

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document.

Figures 5A-G illustrate one particular type of ORM.

Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs.

Figure 10 shows a plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by ORMs.

Figures 11-18 show a variety of different alternative implementations of ORMs.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17.

Figure 20 illustrates a first coil layer.

Figure 21 illustrates a second coil layer.

Figure 22A illustrates a cross-section of a stator having two coil layers.

Figure 22B illustrates a cross-section of a stator having four coil layers.

Figure 22C illustrates a cross-section of a stator having two coil layers.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate.

Figure 23B illustrates the motor with a magnetic armature in an upward position.

Figure 23C illustrates the motor with a magnetic armature in a downward position.

Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation.

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration.

Figures 26A-B illustrate multiple resonant frequencies within a device or system.

Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response.

Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device.

Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figures 37A-D illustrate pulse-width modulation control of an ORM.

Figure 38A illustrates a control pattern that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806.

Figure 38B illustrates the actual vibration response of the ORM.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f.

Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs.

Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM.

Figures 46A-B illustrate several possible direct-sensing approaches.

DETAILED DESCRIPTION

The current document is directed to various oscillating resonant modules ("ORMs"), including various types of linear oscillating resonant modules ("linear ORMs"), that can be used within a wide variety of different types of appliances, devices, and systems, to generate vibrational forces. ORMs produce vibrational forces by oscillation of a weight or component within the ORM along a segment of a space curve, rather than as a by-product of an unbalanced rotation, as in the case of unbalanced electric motors. The oscillatory nature of the ORM vibration-inducing motion effectively addresses many problems associated with unbalanced electric motors. Combining an ORM with feedback control, so that the driving frequency produced by the ORM falls close to the resonant frequency of a device in which the ORM is included, results in optimal power consumption with respect to the amplitude and frequency of vibration produced by the ORM as well as maximal vibration energy of the device. Oscillation within a ORM may translate into highly directional driving forces produced by the ORM to drive a vibration response in an appliance or device that incorporates the ORM. The current document includes a first subsection, in which various types of ORMs are described, a second subsection on which an ORM controller is discussed, and a third subsection in which accurate methods for ORM control, to which the current document is directed, are described in detail.

ORMs

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document. In contrast to the above-discussed unbalanced electric motors often used to generate vibrations in vibration-driven appliances, an oscillating resonant module contains a weight, or mass, that oscillates back and forth along a path. The path may be a linear path, or line segment, but, in the general case, can be potentially any particular segment of a space curve. Figure 4A illustrates operation of a linear oscillating resonant module. In a first diagram 402, labeled with the time "0," the linear ORM is depicted at time 0 (404 in Figure 4A), with the mass or weight 406 centered within a linear path 408 bounded by two stops 410 and 412. When the linear ORM is activated, the weight begins moving to the left, as shown in diagram 414. The small arrow 415 within the disk-like mass 406 indicates

the direction of movement. The mass continues to move, as shown in diagram 416, until the mass strikes the left-hand stop 410, at which point the direction of travel of the mass reverses and the mass begins moving back in the opposite direction, as shown in diagram 418. In diagrams 419 and 420, the mass continues in its rightward direction of travel during time intervals 4 and 5. At time 6, as shown in diagram 421, the mass strikes the right-hand stop 404 and reverses direction, traveling back in the leftward direction, as shown in diagram 422. Ellipses 424 indicate that this process continues indefinitely during operation of the linear ORM. The mass oscillates back and forward along the linear path. The period of oscillation and the maximum amplitude of oscillation can generally be controlled by control signals input to an ORM.

Figure 4B illustrates a mapping of a continuous logical movement of the weight along a circle to the actual linear motion of the weight within a linear ORM, as discussed above with reference to Figure 4A. In Figure 4B, the position of the weight is plotted along a circle 430. At time 0, represented by point 432, the weight position is vertically mapped, as indicated by dotted line 434 as well as by the solid line 436 within the circle 430, to a central point 438 on the linear path 440 shown below the circle. The position of the weight travels along the circle, in a counter-clockwise direction, as long as the linear ORM operates, as indicated by the dashed circular arrow 442. At time 1, indicated by point 444 on circle 430, the position of the mass is mapped, by vertical dashed line 446, to point 448 on linear path 440. At time 2, represented by point 450, the position of the mass on the linear path 440 is point 452. At time 3, represented by point 454 along the circle, the position of the mass is again point 448. Thus, as the position of the mass plotted along the circle has moved from point 444 to point 454, the direction of movement of the mass has reversed and the mass is now continuing in the opposite direction from the direction in which it originally moved. Small horizontal arrows, such as arrow 456, shown below the linear path 440, illustrate the linear motion of the mass of the linear ORM between each pair of adjacent time points. Thus, the back-and-forth oscillation of the mass in a linear ORM can be described by a logical revolution of a mass about a circle. If the circle has a radius of 1, then the position x at time t of the mass along the actual path of travel can be expressed as:

$$x(t) = \cos\left(\omega t - \frac{\pi}{2}\right),$$

where ω is the angular velocity at which the point representing the mass moves around the circle.

Figure 4C illustrates a general space-curve segment path. In Figure 4C, a short space-curve segment 460 is shown plotted in a three-dimensional Cartesian coordinate system 462. The weight or mass of an oscillating resonant module ("ORM") may oscillate back and forth along such a space-curve-segment path. In the first plot in Figure 4C 458, the weight or mass moves from left to right along the path, as indicated by the small curved arrows, such as curved arrow 460. As shown in the second plot 462 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it reverses directions and move to the left. As shown in the third plot 464 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it again reverses direction and moves to the right. Ellipses 466 indicate that this back-and-forth oscillation continues while the ORM operates. The space-curve-segment path of the weight in an ORM is defined by the physical implementation and operation of the ORM.

Figure 4D illustrates two additional example paths along which the weight or mass of an ORM may oscillate. The first path is a circular arc 470 and the second path is a partially elliptical arc-like path 472. As mentioned above, many additional different types of space-curve-segment paths for ORMs are possible.

Figures 5A-G illustrate one particular type of ORM. Figures 5A-G all use the same illustration conventions, next discussed with reference to Figure 5A. The ORM includes a cylindrical housing 502 within which a solid, cylindrical mass 504, or weight, can move linearly along the inner, hollow, cylindrically shaped chamber 506 within the cylindrical housing or tube 502. The weight is a magnet, in the described an implementation, with polarity indicated by the "+" sign 510 on the right-hand end and the "-" sign 512 on the left-hand end of the weight 504. The cylindrical chamber 506 is capped by two magnetic disks 514 and 516 with polarities indicated by the "+" sign 518 and the "-" sign 519. The disk-like magnets 514 and 518 are magnetically oriented opposite from the magnetic orientation of the weight 504, so that when the

weight moves to either the extreme left or extreme right sides of the cylindrical chamber, the weight is repelled by one of the disk-like magnets at the left or right ends of the cylindrical chamber. In other words, the disk-like magnets act much like springs, to facilitate deceleration and reversal of direction of motion of the weight and to minimize or prevent mechanical-impact forces of the weight and the end caps that close off the cylindrical chamber. Finally, a coil of conductive wire 520 girdles the cylindrical housing, or tube 502 at approximately the mid-point of the cylindrical housing.

Figures 5B-G illustrate operation of the ORM shown in Figure 5A. When an electric current is applied to the coil 520 in a first direction 522, a corresponding magnetic force 524 is generated in a direction parallel to the axis of the cylindrical chamber, which accelerates the weight 504 in the direction of the magnetic force 524. When the weight reaches a point at or close to the corresponding disk-like magnet 514, as shown in Figure 5C, a magnetic force due to the repulsion of the disk-like magnet 514 and the weight 504, 526, is generated in the opposite direction, decelerating the weight and reversing its direction. As the weight reverses direction, as shown in Figure 5D, current is applied in an opposite direction 530 to the coil 520, producing a magnetic force 532 in an opposite direction from the direction of the magnetic force shown in Figure 5B, which accelerates the weight 504 in a direction opposite to the direction in which the weight is accelerated in Figure 5B. As shown in Figure 5E, the weight then moves rightward until, as shown in Figure 5F, the weight is decelerated, stopped, and then accelerated in the opposite direction by repulsion of the disk-like magnet 516. An electrical current is then applied to the coil 520 in the same direction 534 as in Figure 5B, again accelerating the solid cylindrical mass in the same direction as in Figure 5B. Thus, by a combination of a magnetic field with rapidly reversing polarity, generated by alternating the direction of current applied to the coil, and by the repulsive forces between the weight magnet and the disk-like magnets at each end of the hollow, cylindrical chamber, the weight linearly oscillates back and forth within the cylindrical housing 502, imparting a directional force at the ends of the cylindrical chamber with each reversal in direction.

Clearly, the amplitude of the vibration and other characteristics of the vibrational forces produced within the ORM are related to the length of the hollow chamber in which the weight oscillates, the current applied to the coil, the mass of the weight, the acceleration of the weight produced by the coil, and the mass of the entire ORM. All of these parameters are essentially design parameters for the ORM, and thus the ORM can be designed to produce a wide variety of different amplitudes.

The frequency of the oscillation of the solid, cylindrical mass is determined by the frequency at which the direction of the current applied to the coil is changed. Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM. Figures 6A-B both use the same illustration conventions, described next with respect to Figure 6A. The H-bridge switch receives, as input, a directional signal *d* 602 and direct-current ("DC") power 604. The direction-control signal *d* 602 controls four switches 606-609, shown as transistors in Figure 6A. When the input control signal *d* 602 is high, or "1," as shown in Figure 6A, switches 608 and 609 are closed and switches 606 and 607 are open, and therefore current flows, as indicated by curved arrows, such as curved arrow 610, from the power-source input 604 to ground 612 in a leftward direction through the coil 614. When the input-control signal *d* is low, or "0," as shown in Figure 6B, the direction of the current through the coil is reversed. The H-bridge switch, shown in Figures 6A-B, is but one example of various different types of electrical and electromechanical switches that can be used to rapidly alternate the direction of current within the coil of an ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G. The ORM, in addition to the cylindrical housing, coil, and internal components shown in Figure 5A, includes a power supply, a user interface, generally comprising electromechanical buttons or switches, the H-bridge switch, discussed above with reference to Figures 7A-B, a central processing unit ("CPU"), generally a small, low-powered microprocessor, and one or more electromechanical sensors. All of these components are packaged together as an ORM within a vibration-based appliance, device, or system.

As shown in Figure 7, the ORM 700 is controlled by a control program executed by the CPU microprocessor 702. The microprocessor may contain sufficient on-board memory to store the control program and other values needed during execution of the control program, or, alternatively, may be coupled to a low-powered memory chip 704 or flash memory for storing the control program. The CPU receives inputs from the user controls 706 that together comprise a user interface. These controls may include any of various dials, pushbuttons, switches, or other electromechanical-control devices. As one example, the user controls may include a dial to select a strength of vibration, which corresponds to the current applied to the coil, a switch to select one of various different operational modes, and a power button. The user controls generate signals input to the CPU 708-710. A power supply 712 provides power, as needed, to user controls 714, to the CPU 716 and optional, associated memory, to the H-bridge switch 718, and, when needed, to one or more sensors 732. The voltage and current supplied by the power supply to the various components may vary, depending on the operational characteristics and requirements of the components. The H-bridge switch 720 receives a control-signal input *d* 722 from the CPU. The power supply 712 receives a control input 724 from the CPU to control the current supplied to the H-bridge switch 718 for transfer to the coil 726. The CPU receives input 730 from one or more electromechanical sensors 732 that generate a signal corresponding to the strength of vibration currently being produced by the linearly oscillating mass 734. Sensors may include one or more of accelerometers, piezoelectric devices, pressure-sensing devices, or other types of sensors that can generate signals corresponding to the strength of desired vibrational forces.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM. Figure 8A provides a control-flow diagram for the high-level control program. The program begins execution, in step 802, upon a power-on event invoked by a user through a power button or other user control. In step 802, various local variables are set to default values, including the variables: (1) *mode*, which indicates the current operational mode of the device; (2) *strength*, a numerical value corresponding to the current user-selected strength of operation, corresponding to the electrical current applied to the coil; (3)

lvl0, a previously sensed vibrational strength; (4) *lvl1*, a currently sensed vibrational strength; (6) *freq*, the current frequency at which the direction of current is alternated in the coil; (6) *d*, the control output to the H-bridge switch; and (7) *inc*, a Boolean value that indicates that the frequency is currently being increased. Next, in step 804, the control program waits for a next event. The remaining steps represent a continuously executing loop, or event handler, in which each event that occurs is appropriately handled by the control program. In certain implementations of the control program, events may be initiated by interrupt-like mechanisms and stacked for execution while, in more primitive implementations, certain events that overlap in time may be ignored or dropped. In the implementation illustrated in Figures 8A-C, two timers are used, one for controlling the change in direction of the current applied to the coil, at a currently established frequency, and the other for controlling a monitoring interval at which the control program monitors the vibrational force currently produced. Rather than using a formal timer mechanism, certain implementations may simply employ counted loops or other simple programming techniques for periodically carrying out tasks. When an event occurs, the control program begins a series of tasks, the first of which is represented by the conditional step 806, to determine what event has occurred and appropriately handle that event. When the frequency timer has expired, as determined in step 806, the value of the output signal *d* is flipped, in step 808, and output to the H-bridge switch, with the frequency timer being reset to trigger a next frequency-related event. The frequency-timer interval is determined by the current value of the variable *freq*. Otherwise, when the event is a monitor timer expiration event, as determined in step 810, then a routine "monitor" is called in step 812. Otherwise, when the event corresponds to a change in the user input through the user interface, as determined in step 814, the routine "control" is called in step 816. Otherwise, when the event is a power-down event, as determined in step 818, resulting from deactivation of a power button by the user, then the control program appropriately powers down the device, in step 820, and the control program terminates in step 822. Any other of various types of events that may occur are handled by a default event handler 824. These events may include various error conditions that arise during operation of the device.

Figure 8B provides a control-flow diagram for the routine "monitor," called in step 812 of Figure 8A. In step 830, the routine "monitor" converts the sensor input to an integer representing the current vibrational force produced by the ORM and stores the integer value in the variable *lvl1*. Next, in step 832, the routine "monitor" determines whether or not the ORM is currently operating in the default mode. In the default mode, the ORM uses continuous feedback control to optimize the vibrational force produced by the ORM by continuously seeking to operate the ORM at a frequency as close as possible to the resonant frequency for the ORM. Other, more complex operational modes may be handled by various more complex routines, represented by step 834 in Figure 8B. More complex vibrational modes may systematically and/or periodically alter the frequency or produce various complex, multi-component vibrational modes useful in certain applications, appliances, devices, and systems. These more complex modes are application dependent, and are not further described in the control-flow diagrams. In the case that the operational mode is the default mode, in which the control program seeks to optimize the vibrational force generated by the device, in step 836, the routine "monitor" determines whether the local variable *inc* is set to TRUE. If so, then the control program is currently increasing the frequency at which the device operates in order to obtain the resonance frequency. When *lvl1* is greater than *lvl0*, as determined in step 838, then the vibrational force has been recently increased by increasing the frequency, and so the routine "monitor" increases the frequency again, in step 840, and correspondingly resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 842, then the control program has increased the frequency past the resonance frequency, and therefore, in step 844, the control program decreases the frequency, sets the variable *inc* to FALSE, and correspondingly resets the frequency timer. In similar fashion, when the variable *inc* is initially FALSE, as determined in step 836, and when *lvl1* is greater than *lvl0*, as determined in step 846, the routine "monitor" decreases the value stored in the variable *freq*, in step 848 and resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 860, then the routine "monitor" increases the value stored in the variable *freq*, sets the variable *inc* to TRUE, and resets

the frequency timer in step 862. Finally, the value in *lvl1* is transferred to *lvl0* and the monitor timer is reset, in step 864.

Figure 8C provides a control-flow diagram for the routine "control," called in step 816 in Figure 8A. This routine is invoked when a change in the user controls has occurred. In step 860, the variables *mode* and *strength* are set to the currently selected mode and vibrational strength, represented by the current states of control features in the user interface. Next, in step 862, the routine "control" computes an output value *p* corresponding to the currently selected strength, stored in the variable *strength*, and outputs the value *p* to the power supply so that the power supply outputs an appropriate current to the coil. Finally, in step 864, the routine "control" computes a new monitor timer interval and resets the monitor timer accordingly.

The control program described with reference to Figures 8A-C is one example of many different implementations of the control program that can be carried out, depending on requirements of the ORM, the parameters and characteristics inherent in a particular ORM, the types of control inputs received from a particular user interface, the nature of the power supply, and the types of operational modes that are implemented for the ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs. Figure 9 has the same axes as the graph shown in Figure 3. However, unlike Figure 3, Figure 9 includes many different curves, such as curve 902, each representing the vibrational forces and frequencies that can be obtained from a particular ORM implementation. Again, an ORMs generally has at least one resonant frequency that is characteristic of the geometry and weights of various components of the ORM, and each ORM is naturally operated at a frequency close to this resonant frequency in order to achieve maximum vibrational force. Thus, rather than being restricted, over all possible implementations, to a relatively narrow range of frequencies and vibrational forces, as in the case of unbalanced electrical motors, ORMs can be designed and implemented to produce desired vibrational forces over a wide range of vibrational frequencies, and desired vibrational frequencies over a wide range of desired vibrational forces. The contrast is perhaps best seen in Figure 10. Figure 10 shows a

plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by linear ORMs. Unbalanced electric motors can be implemented to produce amplitude/frequency combinations roughly within the cross-hatched square region 1002 within amplitude/frequency space. By contrast, linear ORMs can be designed and implemented to produce amplitude/frequency combinations underlying curve 1004. Thus, linear ORMs can achieve much higher operational frequencies and much lower operational frequencies than can be practically obtained by unbalanced electric motors, and can produce much higher amplitudes and vibrational forces than can be achieved by relatively low-powered unbalanced electrical motors used in hand-held appliances and other commonly encountered devices and systems. Furthermore, when larger vibrational forces are needed, balanced electrical motors are generally impractical or infeasible, due to the destructive forces produced within the electrical motors. In general, a single implemented linear ORM can access a much larger region of amplitude/frequency space than currently available vibration modules, which generally operate at fixed amplitudes and/or fixed frequencies, as further discussed below.

Figures 11-18 show a variety of different alternative implementations of ORMs. Figure 11 provides a schematic illustration of an ORM similar to that discussed above with reference to Figure 4A. Note that, in place of the end magnets 1102 and 1104, mechanical springs may alternatively be used. These may be traditional helical springs made from metal or springs made from a compressible and durable material or mechanical device that seeks to restore its initial shape when depressed or compressed. Note that the weight and chamber may be cylindrical, in cross section, as discussed above with reference to Figure 5A, or may have other shapes, including rectangular or hexagonal cross-sections.

Figure 12 shows a similar implementation in which the control unit and power supply are incorporated into the moving mass 1202. In this implementation, the relative masses of the moving mass 1202 and remaining components of the ORM is maximized, thus maximizing the vibrational forces produced at a given level of power consumption.

Figure 13 shows yet an alternative ORM. In this alternative implementation, additional coils 1302 and 1304 are incorporated in the moving mass, and a centering magnet or coil 1306 is positioned in a fixed location on the housing so that, when the direction of the current applied to the coils 1302 and 1304 is alternated, an oscillating rotational force is generated to cause the movable weight to oscillate both in a plane perpendicular to the axis of the chamber as well as linearly oscillating the direction of the chamber.

Figure 14 illustrates an ORM in which multiple electromagnetic coils are employed. In Figure 14, two coils 1402 and 1404 are placed in two different positions on the housing. The first coil 1402 may be used to drive linear oscillation of the moving mass 1406, while the second coil may be activated in order to shorten the length of the chamber within which the moving mass linearly oscillates, essentially serving as a second repelling magnet. In this implementation of the ORM, the moving mass may linearly oscillate with at least two different amplitudes, depending on whether or not the second coil 1404 is activated to repel the moving mass. Additionally more complex patterns of current reversal in the two coils can be employed to produce complex multi-component vibrational modes of the moving mass.

When the housing is fully enclosed, air within the chamber serves to dampen oscillation of the moving mass. This dampening may be minimized by providing channels, on the sides of the moving mass, to allow air to pass from one side of the moving mass to the other, by channels through the moving mass, or by providing openings in the housing to allow air to be forced from the housing and drawn into the housing. Additionally, different fluids or liquids may be employed within the chamber to change the dampening effect produced by displacement of the fluids and gasses as the moving mass linearly oscillates.

Figure 15 illustrates an alternative ORM an implementation of the linear-resonant vibration module to which current document is directed in which a plunger linearly oscillates to produce a vibration. The plunger 1502 is slideably contained within a moveable-component track orthogonal to a long axis of the main housing 1504 of the ORM that includes the power supply, microcontroller, and other control components. The plunger is girdled by, or includes, a driving magnet 1506 that

is attracted to, and seeks to be positioned in alignment with, a centering magnet 1508 mounted within the housing. Applying current to one of two driving coils 1512 and 1514 forces the driving magnet away from the equilibrium position shown in Figure 15. By rapidly switching the direction of current applied to the driving coils, the microcontroller can control the plunger to linearly oscillate in an up-and-down fashion, as indicated by arrow 1520.

Figure 16 shows yet another ORM an implementation of the linear-resonant vibration module to which current document is directed. In this an implementation of the linear-resonant vibration module to which current document is directed, a spring-like member 1602 is clamped at one end 1604 to the housing. Driving magnets 1606 and 1608 are fixed to the spring-like member 1602, and when current is rapidly reversed in a coil 1610, the spring-like member 1602 is induced to vibrate at a relatively high frequency.

Figure 17 shows another ORM similar to the ORM shown in Figure 16. In this ORM, the spring member 1702 is extended to provide an external massage arm 1704 that extends out from the housing to provide a linearly oscillating massage-foot member 1706 for massaging human skin or some other substrate, depending on the application.

Figure 18 shows a mechanical vibration adjustment feature that can be added to either of the ORMs shown in Figures 16 and 17. An adjustment screw 1802 can be manipulated to alter the position of a movable spring clamp 1804 that acts as a movable clamping point for the spring-like member 1806. Moving the movable spring clamp 1804 leftward, in Figure 18, shortens the length of the spring-like member and thus tends to increase the resonant frequency at a particular power-consumption level. Conversely, moving the movable spring clamp rightward, in Figure 18, lengthens the spring-like member and decreases the vibrational frequency.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17. In this implementation, the massage foot is enhanced to include elastomer bristles 1902-1906 to transfer the linear oscillation of the massage foot to human skin or another substrate. The elastomeric bristles, or pad or brush comprising numerous elastomeric bristles, allow transmission of vibration to a surface even at low

operational powers, when a rigid or even semi-compliant massage foot would instead simply stop moving for inability to overcome frictional forces.

Figure 20-23C illustrate a different type of ORM. This ORM comprises a motor incorporated within a printed circuit board ("PCB"). The motor includes moving and non-moving components that interact via electromagnetic forces to produce motion. The non-moving components include a stator that generates a magnetic field. A stator can be created by using one or more coils. In certain implementations, a stator adapted to integration with a planar substrate is produced using combinations of one or more spiral-shaped conductive traces.

Figure 20 illustrates a first coil layer. The first coil layer 2000 includes a substrate 2002 and a spiral-shaped trace 2004 that is wound in a clockwise direction from the outside of the spiral to the inside of the spiral. The spiral-shaped trace 2004 surrounds a central core and overlays the substrate 2002. In some implementations, the substrate 2002 is a printed circuit board. The width and thickness of the trace influence the conductivity of the resulting coil. In general, thicker and wider traces have lower electrical resistance and result in coils with lower resistance and higher current carrying capacity. Spirals with a larger core diameter and spirals having a larger number of turns produce coils with correspondingly higher inductance. The inductance of the spiral-shaped trace 2004 with an air core at the center of the spiral is expressed as:

$$L(uH) = \frac{r^2 N^2}{8r + 11W}$$

where:

r is the core radius in inches;

N is the number of turns; and

W is the total width of the windings in inches.

The inductance of the resulting coil can be adjusted by altering the above parameters, as well as through the selection of core materials.

A first connection pad 2006 and a second connection pad 2008 terminate the ends of the spiral-shaped trace 2004. In certain implementations, the first

connection pad 2006 and/or the second connection pad 2008 are incorporated into one or more conductive vias connecting the first coil layer to other coil layers or to electrical circuits constructed on the substrate. Additional connection pads 2010, 2012, 2014, and 2016 can provide connection points or can be incorporated into vias that connect multiple layers of traces.

Figure 20 additionally illustrates the placement of a number of motor elements in a particular motor implementation. At the center of the spiral-shaped trace 2004 is a circular opening 2018. The circular opening provides a space for an armature 2020. The armature 2020 can be made from a ferrous metal or a magnetic material and moves in a direction substantially perpendicular to the surface of the substrate 2002 in response to a drive current applied to the coil layer. A centering spring 2022 retains the armature 2020 in the circular opening 2018 in the substrate 2002, and allows limited movement perpendicular to the substrate.

In certain implementations, the traces and connection pads are made from conductive material, such as metal, copper, aluminum, or conductive alloys. The traces and connection pads on the first coil layer 2000 can be fabricated using printed-circuit-board manufacturing techniques. In some implementations, foil decals are created and laminated onto the substrate 2002. The construction of multi-layer coils is achieved using a number of techniques, including: multi-layer PCB construction; laminated foil decals separated by insulating layers; and 2-sided PCB construction. In some implementations, the traces and connection pads are embedded into the substrate 2002.

Figure 21 illustrates a second coil layer. The second coil layer 2100 is constructed using techniques already described for the construction of the first coil layer 2000. A spiral-shaped trace 2102 winds in a clockwise direction from the starting connection pad 2104 to the ending connection pad 2106. The coil layer of Figure 20 is positioned over the coil layer of Figure 21 and the two layers are aligned with one another so that the second connection pad 2008 in Figure 20 overlays the starting connection pad 2104 in Figure 21, and the connection pad 2010 in Figure 20 aligns with the ending connection pad 2106 in Figure 21. PCB vias form electrical connections between the second connection pad 2008 in Figure 1 and the starting

connection pad 2104. When the first coil layer 2000 in Figure 20 and the second coil layer 2100 in Figure 21 are connected in this way and energized, the inductance of the layers is additive. In one mode of operation, current flows into the coil layer of Figure 20 starting at the first connection pad 2006, clockwise around the coil to the second connection pad 2008, through a via to the starting connection pad 2104, and clockwise to the ending connection pad 2106. Adding additional coil layers increases the total inductance of the resulting coil. Additional connection pads 2108, 2110, 2112, and 2114 provide connection points and support for vias that connect to additional coil layers. In certain implementations, additional coil layers can be added to the coil using similar methods to those described above. The additional coil layers are separated by insulating layers or placed on opposite sides of an insulating substrate. In certain implementations, the multi-layer coil is used as a stator in a motor.

Figure 22A illustrates a cross-section of a stator having two coil layers. A first coil layer 2202 and a second coil layer 2204 are laminated onto an insulating planar substrate 2206, such as a PCB. The first and second coil layers 2202 and 2204 are separated by an insulating layer and electrically connected to each other with a via 2208. The stator is driven by a first connection pad 2210 and a second connection pad 2212. In certain implementations, the second connection pad 2212 is routed to the front surface of the PCB using a via. An opening 2214 is provided for an armature that moves perpendicularly to the surface of the substrate in response to energizing the stator. The first and second coil layers can be constructed using the coil layers illustrated in Figures 20 and 21, or with similar trace patters arranged so that the coil layers produce a single direction of rotation around the opening 2214. The implementations illustrated in Figure 22A can be extended to include additional coil layers laminated to both sides of a planar substrate.

Figure 22B illustrates a cross-section of a stator having four coil layers. A first-front coil layer 2250 and a second-front coil layer 2252 are laminated onto a front surface of an insulating planar substrate 2254, such as a PCB. A first-back coil layer 2256 and a second-back coil layer 2258 are laminated onto a back surface of the insulating planar substrate 2254. A first via 2260 electrically connects the end of the first-front coil layer 2250 to the beginning of second-front coil layer 2252. A second

via 2262 electrically connects the end of the first-back coil layer 2256 to the beginning of second-back coil layer 2258. Cross-substrate via 2264 connects the end of first-front coil layer 2250 to the end of first-back coil layer 2256. When current enters at an entry connection pad 2266 and passes through the four coil layers, the current travels with a single direction of rotation until the current exits at an exit connection pad 2268. The inductance of the stator in Figure 22B is approximately double that of the stator shown in Figure 22A.

Figure 22C illustrates a cross-section of a stator having two coil layers. A front coil layer 2280 and a back coil layer 2282 are laminated onto opposing sides of an insulating planar substrate 2284, such as a PCB. A via 2288 electrically connects the front coil layer 2280 to the back coil layer 2282 forming a coil wound in a single direction around the opening 2290. Connection pads 2292 and 2294 provide electrical contacts for connecting the coil to a drive current.

In some implementations, the coil layers that make up the stator are not interconnected to form a single coil. For example, cross-substrate via 2264 may be omitted, and the two front coil layers 2250 and 2252 are electrically driven independently from the two back coil layers 2256 and 2258. In other implementations, the two front coil layers 2250 and 2252 are counter-wound with respect to the two back coil layers 2256 and 2258. In this configuration, the magnetic fields generated in the opening 2270 by the two front coil layers oppose the magnetic field generated by the two back coil layers.

PCBs are suitable substrates for making the coils and motors described in the current document. A PCB can be constructed using a PCB process where layers of printed copper are separated by a hard laminate core, for example, using FR-4 glass-reinforced epoxy. A PCB made from polyimide can support a greater density of coils and increased mechanical flexibility. A PCB made from a ceramic, such as aluminum oxide, provides increased heat resistance. The stators described above can be constructed with any of these PCB materials.

In certain implementations, the coil layers described above are arranged to form one or more coils that overlay the front and/or back surfaces of a PCB. The coils form a stator that drives the armature of a motor.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate. The motor 2300 is constructed on a substrate 2302 , such as a PCB. A first front coil layer 2304 and a second front coil layer 2306 overlay the front surface of the substrate 2302. A first back coil layer 2308 and a second back coil layer 2310 overlay the back surface of the substrate. A first via 2312 electrically connects the first front coil layer 2304 to the second front coil layer 2306 to form a front coil, and a second via 2314 electrically connects the first back coil layer 2308 to the second back coil layer 2310 to form a back coil. Front coil connections 2316 and 2318 provide electrical connectivity for driving the front coil, and back coil connections 2320 and 2322 provide electrical connectivity for driving the back coil.

A magnetic armature 2324 having a north pole 2326 and a south pole 2328 is positioned in an opening in the substrate 2302 through the center of the front and back coils. In order to drive the magnetic armature 2324 into vibration, a first oscillating current is applied to the front coil connections 2316 and 2318, and a second oscillating current is applied to the back coil connections 2320 and 2322. When the motor is operated, the current that flows through the front coil and the current that flows through the back coil flow with opposite directions of rotation. In certain implementations, this is accomplished by applying the same oscillating current to both front and back coils provided the coils are counter-wound. In an alternative implementation, where the coils are not counter-wound, the second oscillating current is 180 degrees out of phase with the first oscillating current. The resulting oscillating magnetic field provides a magneto-motive force to the north pole 2326 and the south pole 2328 in synchrony, driving the magnetic armature 2324 into vibration at a frequency proportional to the frequency at which the oscillating current is applied. In an alternative implementation, the second front coil layer 2306 is connected to the first back coil layer 2308 with a third conductive via to form a single-drive counter-wound stator that is driven with a single oscillating current to produce vibratory motion of the armature.

The magnetic armature is constructed from an axially polarized magnet. In one implementation, the magnet is a neodymium grade N-42 disk magnet. The size

and shape of the magnet is adapted based, in part, on the desired vibration profile of the motor.

Figure 23B illustrates the motor with the magnetic armature in an upward position. When a first driving current is applied to a front coil 2330, the front coil 2330 generates a downward magnetic flux 2332. In response to the downward magnetic flux 2332, an upward vertical force is exerted on the north pole 2336. As the first driving current is applied, a second driving current is applied to a back coil 2338 and an upward magnetic flux 2340 is generated. In response to the upward magnetic flux 2340, an upward vertical force is exerted on the south pole 2342 of the magnet. In response to the upward forces, the magnetic armature 2334 moves upwards as illustrated in Figure 23B.

Figure 23C illustrates the motor with the magnetic armature in a downward position. When the direction of the first and second driving currents is reversed, the forces on the north pole 2360 and south pole 2362 are reversed. When the first reversed current is applied to a front coil 2364, the front coil 2364 generates an upward magnetic flux 2366, and a downward vertical force is exerted on the north pole 2360. When the second reversed current is applied to a back coil 2368 a downward magnetic flux 2370 is generated. A downward vertical force is exerted on the south pole 2362 of the magnetic armature 2372. In response to these two forces, the magnetic armature 2372 moves downwards as illustrated in Figure 23C.

The drive currents are alternated to cause the magnetic armature to vibrate perpendicularly to the surface of the substrate at a chosen frequency. In one implementation, the front coil and back coil are counter-wound with respect to each other. The front and back coils are connected with a conductive via or wire and driven with one drive current. This arrangement causes the front and back coils to generate simultaneous magnetic flux signals in opposing directions, which, in turn, acts on the north and south poles of the magnetic armature to drive the magnetic armature into vibration.

In alternative implementations, additional coil layers are employed. For example, an 8-layer PCB can have four front coil layers and four back coil layers. The four front coil layers are connected to form a front coil, and the four back coil layers

are connected to form a back coil. In certain implementations, the front coil and back coil are counter wound, and driven with a single drive current as explained above.

Next, a slightly more mathematically descriptive explanation of oscillation, resonance, and the Q factor is provided. Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation. Great insight into harmonic oscillators can be provided by considering a simple, one-dimensional spring. Figure 24A illustrates a spring that can be extended in the x direction. In a first diagram 2402, the spring is shown in an equilibrium, resting state with a point or mass 2404 at the end of the spring located at the position $x = 0$. In a second diagram 2406, the spring has been pulled rightward, along the x direction, with the mass 2404 now located at a position x. As is well known, the extended spring has potential energy that results in a force F_x 2408 that points in the opposite direction. In other words, were the spring released, the mass would travel leftward, oscillate back and forth, and eventually settle back to the 0 position shown in diagram 2402. Were the spring frictionless, however, the mass would continue to oscillate back and forth, in a manner similar to the linear ORM described in Figures 4A-B, indefinitely.

The frictionless spring can be mathematically modeled as follows:

$$F_x(x) = -kx,$$

where $F_x(x)$ is the force exerted by the spring;
x is the position of the spring end; and
k is the force constant.

The force constant k is a property of the spring, including all of the parameters that contribute to its elasticity, compressibility, and other physical characteristics of the spring. In more complex, realistic situations, many different factors may contribute to the force constants associated with harmonic oscillators, including interaction with other harmonic-oscillation modes within a physical device or module.

The potential energy of the spring system illustrated in Figure 24A can be modeled as:

$$U(x) = \frac{1}{2}kx^2,$$

where $U(x)$ is the potential energy of the spring system.

Using Newton's second law, the equation that models the force exerted by the spring when it is extended or compressed can be modeled as a simple, second-order differential equation:

$$m\ddot{x} = Fx = -kx,$$

where m = mass of oscillator; and

$$\ddot{x} = \frac{d^2x}{dt^2}.$$

This differential equation can be simplified as:

$$\ddot{x} = \frac{-k}{m} \qquad x = -\omega^2 x,$$

where $\omega = \sqrt{\frac{k}{m}}$.

The general solution for this simple, second-order differential equation is, in one form:

$$x(t) = C_1 e^{i\omega t} + C_2 e^{-i\omega t}.$$

In this equation, C_1 and C_2 are arbitrary constants that are determined by the initial conditions of a particular spring system. This solution can be recast as:

$$x(t) = B_1 \cos(\omega t) + B_2 \sin(\omega t),$$

where $B_1 = C_1 + C_2$; and

$$B_2 = i(C_1 - C_2).$$

A final, perhaps most elegant form of the solution is:

$$x(t) = \mathrm{Re}[Ae^{i(\omega t - \delta)}],$$

where $Ae^{-i\delta} = B_1 - iB_2 = C$.

In this equation, A is the amplitude of the oscillation, ω is an angular velocity of the oscillation, as discussed above with reference to Figure 24B, and δ is an initial phase offset. This final expression describes the mapping of a rotation to linear harmonic oscillation, as discussed above with reference to Figure 4B, shown again, in Figure

24B, with annotations taken from final expression for the solution to the differential equation.

As mentioned above, a frictionless spring would continue to oscillate indefinitely after being released from an extended position. However, in actual systems, there are always resistive forces, such as friction, that dampen the oscillation so that, over time, the amplitude of the oscillation decreases and the oscillation finally stops. This more complex and more realistic scenario can be modeled by including a resistive-force term in the second-order differential equation:

$$m\ddot{x} + b\dot{x} + kx = 0,$$

where $-b\dot{x}$ is a resistive force; and

$$\dot{x} = \frac{dx}{dt}.$$

Defining several new constants as follows:

$$\beta = \frac{b}{2m} = \text{ damping constant, and}$$

$$\omega_0 = \sqrt{\frac{k}{m}} = \text{ natural frequency}$$

and solving the above modified second-order ordinary differential equation, the following result is obtained:

$$x(t) = Ae^{-\beta t}\cos(\omega_1 t - \delta)$$

where $\omega_1 = \sqrt{\omega_0^2 - \beta^2}$; and

$\beta < \omega_0$.

when, as indicated above, the damping constant β has a value less than the value of the natural frequency ω_0, the system in under-damped and the amplitude of the oscillations decrease non-linearly, as shown in Figure 24C. When β is greater than ω_0, the system is over-damped, in which case only a single oscillation may occur, as shown in Figure 24D.

Most physical systems have one or more natural frequencies at which they oscillate, when mechanically perturbed from their equilibrium states. In ORMs,

a motor is used to continuously perturb the system in order to drive the ORM to oscillate and generate vibration. A device in which an ORM is incorporated vibrates in response to a driving vibration generated by the ORM. In this case, an external driving force $F(t)$ is applied by the ORM to drive continuous oscillation of the device in which it is included. An external-force-driven linear oscillator can be modeled by the following expression:

$$m\ddot{x} + b\dot{x} + kx = F(t),$$

where $F(t)$ is an external driving force.

With the definition:

$$f(t) = \frac{F(t)}{m},$$

the mathematical model becomes:

$$\ddot{x} + 2\beta\dot{x} + \omega_0^2 x = f(t).$$

A solution for this expression is:

$$x(t) = A\cos(\omega t - \delta)$$

where $f(t) = f_0\cos(\omega t)$:

$$A^2 = \frac{f_0^2}{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2} \text{ ;and}$$

$$\delta = \arctan\left(\frac{2\beta\omega}{\omega_0^2 - \omega^2}\right).$$

In this expression, the constant ω is the driving frequency of the driving force, which is somewhat less than the natural frequency ω_0. As can be seen in the expression for the square of the amplitude, which is proportional to the energy of the vibration, the amplitude is maximized when the denominator of this expression is a value approaching 0. Maximizing the expression can be carried out either by varying the physical device in order to vary the natural frequency ω_0, while the external-driving-force frequency remains fixed ω, or by varying the driving frequency ω when the natural frequency ω_0 is fixed. When ω_0 varies and ω is fixed, A is maximum when ω_0

$= \omega$; and when ω varies and ω_0, A is maximum when $\omega = \sqrt{\omega_0^2 - 2\beta^2}$. This is where the term "resonance" arises. The resonant frequency is the frequency at which the amplitude A is maximized. As can be seen, this occurs, in general, when the driving frequency of the motor or other mechanical-force-input mechanism has a frequency close to or equal to the natural frequency ω_0 of the physical system. A quality factor Q can be expressed, in terms of the natural frequency and damping factor, as:

$$Q = \frac{\omega_0}{2\beta}.$$

This is the reciprocal of the ratio of the width of the amplitude peak at half its maximum value to the natural frequency ω_0.

An ORM Controller

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration. The vibration may be generated for application to people, animals, or objects for various purposes, including therapeutic purposes, or may instead be generated to provide haptic feedback, such as vibration in mobile phones, vibration-based notification, or vibration-based communications. Thus, the current document is directed to particular features of a generic ORM-containing device or system that may be used in a wide variety of different types of applications or included in larger devices and systems. In Figure 25, the device, appliance, or system is represented by an outer rectangle 2502. The device includes four ORMs 2504-2507. The ORMs may be of any of many different types, including the types of ORM discussed above. In general, the ORMs convert input energy, such as an electrical current, to mechanical vibration. The device also includes several vibration sensor 2510-2511. There are a variety of different types of vibration sensors, including piezoelectric accelerometers that measure acceleration in one, two, or three different orthogonal directions. Other types of sensors may include membranes attached to moving coils that generate electronic signals when the membrane vibrates, similar to a reverse audio speaker. In addition, the device or system contains a controller 2516. The controller includes ORM control logic 2418 that transmits control signals, in certain cases electrical signals that also serve to power the ORMs. The ORM

control logic may be implemented as a sequence of processor instructions, when the controller 2516 is a processor or processor-controlled controller subsystem. In many of the ORM devices and systems, the controller accesses some type of electronic memory 2520, which stores processor instructions and other types of data for implementing ORM control logic 2518. Not shown in Figure 25 are various standard components and signal lines, including a power supply and power-transmitting circuitry, display screens, push buttons, other user-interface-related components, and other types of logic and logic-controlled subcomponents particular to particular types of devices, such as transceivers and communications subsystems within mobile phones. A set of double-headed arrows, such as double-headed arrow 2522, represent the fact that the controller may control many other subcomponents and features of the device or system in addition to the ORMs.

In the previous discussion of oscillation, vibration, and resonance, simple mathematical models for one-dimensional harmonic oscillation were developed. However, in the generic ORM-containing device or system, there may be multiple ORMs, activation of which produce very complex three-dimensional spatial vibration. Vibration modes of individual ORMs may couple to produce a large number of complex spatial-vibration modes. The physical characteristics of these vibration modes may be highly dependent on the exact geometry, weight and balance, and the material type of the housing and internal components of a particular device or system. As a result, there may be numerous different natural resonant frequencies for the device or system.

Figures 26A-B illustrate multiple resonant frequencies within a device or system. In Figure 26A, the vibrational energy, or square of the amplitude of the vibration, is plotted with respect to frequency. The vertical axis represents the energy and vibration 2602 and the horizontal axis represents the frequency of vibration 2604. The plotted curve 2606 shows numerous different vibration-energy peaks 2610-2615. The heights and positions of these peaks along the frequency axis 2604 may vary considerably with slight changes to the physical characteristics of a device or system that is vibrated by ORM components.

Figure 26B shows a more complex type of vibration-response plot. The vibration response is represented by a surface 2620 in the plot shown in Figure 26B. Measured amplitudes or vibration energies produce a surface 2620 in a three-dimensional Cartesian coordinate system that includes an *x*-direction vibration frequency axis 2522, a *y*-direction frequency axis 2624, and a vibration-energy axis 2626. The device or system for which the vibration-response surface 2620 is obtained includes two ORMs, one of which generates vibrations in the *x* direction and one of which generates vibrations in the *y* direction. The two ORMs can be independently controlled to generate vibrations in their respective directions at different frequencies. The *x*, *y* plane 2628 below the plotted vibration-energy surface 2620 represents all possible *x*-direction vibration frequencies and *y*-direction vibration frequencies that can be generated by the two ORMs within the device or system. As shown in Figure 26B, the surface includes three local vibration-energy maxima 2630-2632. These three local maxima are each associated with *x*-direction frequency and *y*-direction frequency components 2634. Thus, in the case shown in Figure 26B, two ORMs which generate vibrations in two different directions within the device or system may generate a complex vibration-response surface with respect to the frequencies at which the two ORMs are operated. Depending on the types and numbers of ORMs, the vibration response may be a hyper-dimensional surface in a much higher dimensional frequency space. In all cases, however, the device or system generally has some number of characteristic resonant frequencies that represent maximal vibration energy or amplitude with respect to the frequencies at which individual ORMs are driven with the device or system. In general, the number of resonant frequencies is equal to the number of vibrational degrees of freedom in the device, appliance, or system.

A vibration-response obtained for a device or system by measuring sensor output can be used to identify and tabulate the natural resonant frequencies for the device or system. Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25. Each row in the resonant-frequency table 2702, such as row 2704, represents a local maxima, or peak, in the vibration response for the generic device. In the example table shown in Figure 27, each peak is characterized by an amplitude in the *x* 2706, *y* 2707, and *z*

2708 directions as well as by the frequency of vibration represented by the peak ω 2710 and by the frequency at which each of the four ORMs are driven by the ORM control logic 2712-2715. Thus, to achieve maximum vibration energy of the vibration of the generic device at any of the resonant frequencies for the device, the ORMs are driven at the control frequencies for that resonant frequency.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response. Figure 28A shows the vibration-response for a simple device, vibration of which is stimulated by a single ORM. There is a single natural frequency ω_1 2802 corresponding to the vibration-energy peak 2804 in the vibration-response plot of vibration energy with response to frequency. Figure 28B shows a plot of the frequency of vibration generated by an ORM with respect to time over a time interval that represents an ORM control scheme. In Figure 28B, the vertical axis 2810 represents the frequency at which the ORM is driven by ORM-control input and the horizontal axis 2812 represents time. The control curve 2814 indicates that the ORM is non-linearly driven over an initial time period 2816 to the natural frequency ω_1 2818 for the device in which the ORM is included. At a final point in time t_f 2820, input to the ORM is discontinued. Figure 28C shows a vibration-response curve for the device containing the ORM when the ORM is operated according to the control curve 2814 discussed above with reference to Figure 28B. As shown in the vibration-response curve 2822, there is an initial lag time 2824 following initiation of the control scheme before a perceptible device vibration occurs, at time t_i 2826. The vibrational energy, or amplitude of vibration, very steeply increases from this point on as the ORM is controlled to approach and equal the natural frequency ω_1 for the device. At time t_f 2820, the vibrational energy of the device relatively steeply falls, since the ORM is no longer being driven. However, the vibrational energy does not immediately fall to 0, as in the control curve, but over a short period of time 2828 after the ORM ceases to be driven.

The generic device, as discussed above, contains a memory that may store various types of control schemes, or control patterns, for the ORMs that are controlled by the ORM control logic. Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device.

The example patterns include a linear ramp-up and ramp-down pattern 2802, a constant control over a specified duration of time 2904, and an oscillating control 2906. The patterns may be parameterized by the duration of the pattern 2908 and the maximum input to the ORM 2910. The input may be specified as the current or voltage, for certain types of ORMs. Other ORMs may be controlled by digital control signals in which numerically encoded commands are transmitted to the ORM. The control patterns can be scaled in both time and frequency in order to generate a variety of equivalent vibration responses for the ORM with similar forms, but different maximum amplitudes and over different periods of time.

A set of scalable control patterns, such as those shown in Figure 29, and a table of resonant frequencies, such as that shown in Figure 27, can be used to generate a table of different types of vibration that can be generated in the generic device by controlling the ORMs within the device according to scaled control patterns. Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25. Each row in the table, such as row 3004, represents a different vibration type that can be produced in the generic device by controlling the ORMs within the device. For example, a cell phone may use a variety of different haptic vibration signals to alert the cell phone user of many different types of events. Each different vibration signal corresponds to a different vibration- type. Each vibration type is characterized by a vibration-type identifier 3006, an amplitude range for the vibration 3008, a reference duration for the vibration 3010, and the control pattern and scaling parameters for the pattern for each of the ORMs 3012-3015. Each vibration type can be scaled within the amplitude range and may also be scaled for a desired duration.

By using either external or internal sensors to characterize the natural resonant frequencies for a physical device or system that contains ORMs, a large number of different vibration responses for the physical device or system can be compiled based on the resonant frequencies as well as a set of ORM control patterns. In alternative vibration-control approaches, the different types of vibration responses may be computed, on the fly, rather than tabulated based on a set of control patterns. However, in all cases, characterization of the resonant frequencies of the device or

system that is vibrated by the ORMs contained within the device or system is a necessary step in producing predictable vibration responses via ORM control.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system. Figure 31 illustrates the inner control loop of the control logic within the physical device shown in Figure 25. The inner control loop waits, in step 3102, for a next event and then handles the event that occurs. When the event is a characterize-vibration event, as determined in step 3104, the routine *characterize vibration* is called to handle the event in step 3106. When the event is a generate-vibration event, as determined in step 3108, a generate-vibration routine is called in step 3110 to generate a vibration in response to the generate-vibration event. When the next event is a user-input event, as determined in step 3112, a process-input routine is called, in step 3114, to handle the input from the user. Ellipses 3116 are used in Figure 31 to indicate that many other types of events are handled by the inner event loop of the control logic. When, after handling the most recently occurring event, there are other events that are queued for handling which arose while handling the most recently handled event, as determined in step 3118, then a next event is dequeued in step 3120 with control flowing back to step 3104. Otherwise, control flows back to step 3102 where the inner event loop waits for a next event to occur.

The characterize-vibration event 3104 is an event that is raised by control-logic routines, timer-expiration handlers, and by other control logic in order to control the ORMs and sensors within the generic device to carry out a re-characterization of the vibration-response for the physical device, as discussed above with reference to Figures 26A-B, in order to update the resonant-frequency table, such as the resonant-frequency table discussed above with reference to Figure 27. In devices that employ a vibration-type table, such as the vibration-type table discussed with reference to Figure 30, the vibration-type table is also updated following update of the resonant-frequency table.

A generate-vibration event is raised by control logic in order to vibrate the generic device for a variety of different reasons. As one example, the device may

be vibrated in response to user input. As another example, the device may be vibrated when the control logic determines that any of various alert conditions have arisen. As yet another example, generate-vibration events may be raised in order to communicate information to a device user.

Figure 32 provides a control-flow diagram for the characterize-vibration event handler, called in step 3106 of Figurer 31. In step 3202, the routine calls a subroutine *sweep* in order to generate a sampling of a vibration-response curve, surface, or hyper-dimensional surface. In step 3204, the routine calls a store-vibration-maxima subroutine in order to identify the resonant frequencies from the curve or surface sampled in step 3202. Finally, in step 3206, the routine calls a compute-and-store-vibration-type-controls subroutine in order to update the vibration-type table based on the new resonant-frequency determination made in steps 3202 and 3204.

Figure 33 provides a control-flow diagram for the subroutine *sweep*, called in step 3202 of Figurer 32. In step 3302, the subroutine *sweep* initializes a data structure for storing a vibration response. As discussed above, the vibration response may be a sampled curve, sampled surface, or sampled hyper-dimensional surface. In the *for*-loop of steps 3304-3306, a frequency sweep of each ORM is initiated. A frequency sweep is a control pattern that continuously sweeps each ORM over a wide range of driving frequencies. Each ORM repeats a single frequency sweep over a different time interval, so that following a number of iterations, the multi-dimensional ORM-driving-frequency space can be sampled. Then, in the *for*-loop of steps 3308-3312, the *sweep* routine continuously samples the vibration amplitude or vibrational energy produced in the device, using sensor output, while the driving-frequency sweeps take place. There are, of course, many alternative methods for sampling the multi-dimensional driving-frequency space in order to generate a sampled vibration-response curve, surface, or hyper-surface.

Figure 34 provides a control-flow diagram for the store-variation-maxima subroutine called in step 3204 of Figure 32. In step 3402, the routine identifies local maxima in the vibration-response curve or surface produced by the *sweep* routine. There are many well-known mathematical techniques for identifying local maxima within a curve, surface, or hyper-surface. Then, in the *for*-loop of steps 3404-3406,

data that characterizes each of the local maxima are tabulated in the resonant-frequency table.

Figure 35 provides a control-flow diagram for the compute-and-store-vibration-type-control subroutine called in step 3206 of Figure 32. In a *for*-loop of steps 3503-3509, each possible set of ORM/control-pattern/resonant-frequency triples is considered. The currently considered triple is used to estimate the vibration mode and intensity of the resulting device vibration, in step 3504. In step 3505, the nearest vibration-type to the estimated vibration mode is identified, if there is one. If a nearest vibration type is found, as determined in step 3506, and when the current ORM/control-pattern/resonant-frequency triple provides a device response closer to the vibration type than the control parameters currently associated with the vibration-type, as determined in step 3507, then, in step 3508, the vibration-type table entry for the found vibration type is updated with the current control parameters represented by the currently considered ORM/control-pattern/resonant-frequency triple. Of course, in certain cases, there may be too many possible ORM/control-pattern/resonant-frequency triples to consider in a reasonable amount of time, in which case the resonant-frequency data may be used in other ways to find the best control parameters for the vibration types in the vibration-type table.

Figure 36 provides a control-flow diagram for the generate-vibration handler called in step 3110 of Figure 31. In step 3602, the handler receives a vibration type, duration, and amplitude associated with the generate-vibration event that is being handled. In step 3604, the appropriate ORM control parameters and patterns are selected from the vibration-type table. In step 3606, the ORM control parameters are scaled according to the received duration and amplitude. In step 3608, a stop time at which the vibration will finish is determined from the received duration. Then, in the *for*-loop of steps 3610-3613, the generate-vibration handler continuously adjusts inputs to each ORM according to the scaled ORM control parameters produced in step 3606.

Precise and Accurate Control of ORMs

The current document is directed to various approaches used within the control logic of an ORM-containing device, appliance, or system, to accurately and precisely control the ORMs to produce time-dependent driving oscillations in conformance with desired control patterns. As discussed above, the combination of controlling ORMs in accordance with control patterns and the accurate characterization of the resonant frequencies of the device, appliance, or system together allow for reproducible generation of many different types of vibration responses of the device, appliance, or system to the driving oscillations of control-pattern-controlled ORMs.

As further discussed below, many current control regimes fail to accurately reproduce the desired driving time-dependent oscillations in each ORM within a device, appliance, or system. As a result, the vibration response of the device, appliance, or system may vary significantly from a desired vibration response and, perhaps more importantly, may not be accurately reproduced at different points in time, due to the inability to accurately and deterministically control the ORMs to produce driving oscillations in conformance with desired control patterns.

A first approach to more accurately controlling ORMs is to use pulse-width modulation control signals rather than conventional constant-duration control pulses. Figures 37A-D illustrate pulse-width modulation control of an ORM. Figure 37A shows a desired vibration response for an ORM that represents a desired time-dependent driving oscillation for inducing at least a portion of the vibration response of a device, appliance, or system in which the ORM is included. The desired vibration response of the ORM is a sine-wave-like 3702 oscillation that is plotted, in Figure 37A, on an amplitude versus time coordinate system 3704. Figure 37B illustrate a hypothetical control regime that attempts to produce the desired driving oscillation discussed above with reference to Figure 37A in a hypothetical ORM. Constant-width voltage pulses, such as voltage pulse 3706, are input to the ORM to drive the weight or mass in forward and backward directions along the oscillation path. These pulses are plotted in Figure 37B in a voltage versus time coordinate system 3708. Because the constant-width pulses are a rather crude approximation of the desired sine-wave-like vibration response, the control regime shown in Figure 37B comprises a series of positive-voltage, 0-voltage, and negative-voltage constant-width pulses 3706 and

3710-3713 that produce a vibration response, superimposed in Figure 37B over the control pulses, as curve 3716. In general, the pulse widths are controlled by an oscillating clock or clock-based timing signal. The vibration-response curve 3716 differs significantly from the desired driving oscillation shown in Figure 37A. Figure 37C shows the desired vibration response 3702 plotted together with the vibration response produced by the constant-width voltage-pulse control 3716. In fact, this is actually a relatively favorable case, because the sequence of positive, 0-voltage, and negative voltage pulses shown in Figure 37B has a period close to the period of the desired sine-wave-like vibration response. Otherwise, the actual vibration response would differ even more greatly from the desired vibration response, often having irregularly shaped wave forms.

Figure 37D illustrates pulse-width-modulation control of the ORM. In pulse-width-modulation control, rather than using constant-width voltage pulses to control the ORM, the controller instead uses variable-width pulses. Moreover, much shorter pulses can be used to more precisely control the vibration response of the ORM. In essence, pulse-width modulation allows a variable-frequency control signal to be used, rather than a constant-frequency control signal. Because a variable-frequency control signal can contain a much greater amount of information than a constant-frequency control signal, the pulse-width-modulation control signals can be used to much more precisely steer the vibration response of the ORM towards a desired wave form. As shown in Figure 37D, many more voltage pulses are used in order to achieve the sine-wave-like vibration response of the ORM. For example, in the constant-width-pulse control shown in Figure 37B, a positive-voltage pulse 3706, a 0-voltage pulse, and a negative-voltage pulse 3710 are used to attempt to approximate the first period of the desired vibration response. By contrast, as shown in Figure 37D, four positive-voltage pulses 3720-3722 and 3726 and three negative-voltage pulses 3723-3725 are employed to produce the first period of the desired vibration response. Moreover, these seven pulses have varying pulse widths and are irregularly spaced along the time axis.

Another problem associated with conventional control of ORMs is that the vibration response produced by a control pattern is often very different from the vibration response that might be predicted from the control pattern or desired. For

example, in Figure 38A, a control pattern is shown that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806. Of course, this control pattern may correspond to a large number of positive-voltage pulses in the time interval t_i to t_f. The vibration response of the ORM is shown in Figure 38B. In this figure, the horizontal time axis 3808 has been rescaled to show more detail. The control pattern 3802 shown in Figure 38A might be initially assumed to produce a pulse of constant-amplitude vibrations over the time interval t_i to t_f. However, as shown in Figure 38B, the actual vibration response of the ORM, shown as curve 3810, includes an initial ramp-up interval 3812 in which the amplitude of the vibration response steadily increases to the desired amplitude, a middle period 3814 in which the ORM is oscillating at the desired amplitude, a short period 3816 at the end of the time interval t_i to t_f during which, in anticipation of the sharp control-pattern edge at time t_f, the control voltage is dropped to 0 so that the vibration will fall to a low level at time t_f, and a fourth undesired ramp-down interval 3818, extending well past the time t_f, during which vibration of the ORM continues at increasingly smaller amplitudes.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f. In a first plot 3902, the naïve control pattern is shown. In a second plot 3904, the naïve control pattern is modified in order to produce the constant-amplitude oscillation that is desired. First, a large-voltage input 3906 occurs prior to time t_i in order to quickly force the ORM to begin vibrating. From time t_i to a time prior to time t_f, a lower-voltage input 3908 is provided in order to control the ORM to oscillate at the desired amplitude. Prior to time t_f, a negative-voltage control signal 3910 is input to the ORM in order to sharply drive the ORM towards oscillation out of phase with the desired driving oscillation during the time interval t_i to t_f. This negative-voltage control signal is then relaxed linearly 3912 in order to stop ORM vibration in a relatively short period of time. As shown in plot 3914 in Figure 39, the vibration response of the ORM much more closely approximates a desired constant-amplitude vibration between time intervals t_i and t_f.

Many different types of control inputs can be used to shape the vibration response of an ORM. For example, short control pulses can push the vibration to a

different phase, resulting in cancellation of the previously established oscillation. The various types of inputs depend on the type and form of control signals that can be transmitted to the ORM, which, in turn, depends on the type of ROM, the driving force used to induce oscillation of the moving mass within the ORM, and the type of logic circuitry that receives input signals and translates them into oscillations.

Thus, in addition to pulse-width modulation, a wide variety of different types of complex control signals may be devised in order to achieve the vibration response desired from the simple control patterns discussed above, including control pattern 3802 shown in Figure 38A. Many different control-signal parameters may be varied in order to control an ORM to provide a desired vibration response, including varying the voltage of the control signal, using pulse-width modulation to finely tailor the control signal to produce a desired vibration response, and adjusting the control signal to include pre-response and post-response signals to remove undesired ramp-up and ramp-down periods in the vibration response.

In addition to varying the input control to an ORM, an ORM may be designed to include a variety of different mechanical controls to further increase the range of vibration responses of the ORM. Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs. Equivalent electromagnetic features may be included in other types of ORMs. Figure 40A illustrates a first type of ORM. In a first diagram 4002, the ORM is shown in an equilibrium, non-vibrating position. The ORM includes a moveable weight or mass 4002 that is connected to two ends of the ORM 4004 and 4006 by springs 4008 and 4010. Diagram 4012 shows the ORM when the movable mass 4002 has been moved, by application of a translational force, such as an electromagnetic force, to the furthest position in the leftward direction along the oscillation path. In this position, spring 4010 is compressed and spring 4008 is extended. In both cases, the springs have potential energy that produces forces that force the movable mass 4002 back in the rightward direction towards stop 4012. Diagram 4014 shows the ORM with the movable mass in the furthest rightward direction.

Figure 40B shows the equilibrium and largest-amplitude positions of a movable mass in a different type of ORM. In a first diagram 4016, the ORM is shown in an equilibrium position. The ORM features an arc-like oscillation path 4018 along which the moving mass 4020, attached to a rotor 4022, oscillates. The moving mass 4020 is attached to the rotor 4022 by a flexible support 4024. Diagram 4026 shows the ORM with the movable mass in the furthest leftward position and diagram 4028 shows the ORM with the movable mass in the furthest rightward direction, similar to the positions shown for the ORM of Figure 40A in diagrams 4012 and 4014.

Figure 40C illustrates movable mechanical stops included in the ORM discussed above with reference to Figure 40A. The movable stops are depicted by features 4030 and 4032 in a first diagram 4034. Of course, the depictions do not necessarily reflect the shape, size, and structure of mechanical stops needed to stop motion of the moveable mass in the various different types of ORMs, but are instead used to illustrate positioning of the moveable stops and their deployment. In a second diagram 4036, the movable stops have been repositioned 4038 and 4040 in order to limit the length of travel of the moving mass 4002. The second diagram 4036 shows the leftward extent of motion of the moving mass 4002 with the movable stops deployed and diagram 4042 shows the rightward extent of travel of the moving mass when the movable stops are deployed. Similar illustration conventions are used, in Figure 40D, to illustrate deployment of movable stops in the ORM discussed above with reference to Figure 40B. Use of movable stops can significantly alter the vibration response of the ORM to a given control input. This may include changing the amplitude of the vibration response, the frequency of the vibration response, and changing the force imparted by the moving mass to the ORM when the moving mass strikes the stops versus the original end stops 4002 and 4004. In general, the vibration-response alterations are complex functions of the geometry, material composition, and driving forces used in the ORM.

Figures 40E-F illustrate use of the movable stops, discussed above with reference to Figures 40C and 40D, as latches. As shown in a first diagram 4048 in Figure 40E, the movable stops have been repositioned 4050 and 4052 closer to the center of the oscillation path. As shown in diagram 4054, the left-hand movable stop

4056 has been deployed when the moving mass 4002 has just reached its leftward, stopped position. As a result, motion of the moving mass is stopped, resulting in an immediate cessation of the driving oscillation produced by the ORM and a higher force exerted in the last oscillation on the left-end stop 4004 of the ORM. Diagram 4058 shows the right-hand movable stop 4052 deployed to latch the moving mass 4002 at its furthest right-hand position. Figure 40F shows similar deployment of the movable stops, in the ORM discussed above with reference to Figure 40B, to latch the moving mass at its leftward and rightward extents. Latching of the moveable mass may trap the moveable mass in a high-potential-energy state, so that immediate, rapid oscillation may ensue when the latch is released. Latching may also significantly alter the relaxation of the oscillation at the end of control-pattern execution.

The current document is directed to employing the various different types of alternative control of ORMs to more accurately generate desired vibration responses. This involves use of a much greater amount of information about the ORM than used in the vibration response table discussed above. Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document. The information is stored in five different tables. An ORM table 4102 stores control information for each different ORM in a device, appliance, or system. This information includes an identifier for the ORM 4104, an indication of the ORM type 4105, an indication of the minimum pulse width that can be input in a control signal 4106, an indication of the minimum amplitude 4107 and maximum amplitude 4108 of an input control signal, indications of whether or not mechanical or electromagnetic latches are available in the ORM 4110 and 4112, the oscillation path length within the ORM 4114, the number of movable stops, or path blocks included in the ORM 4115, and the positioning range for each moveable stop 4116-4117. An event-types table 4120 includes various different types of control events. These may include deployment of latches, movement of movable stops, and output of control pulses of various different widths and amplitudes. An events table 4122 includes ordered pairs of event types and relative times that each represents one of the many different types of control events that can be input to ORMs. Each control event includes an event ID 4123, an event type

4124, and a relative time that specifies a time point within a control pattern 4126 at which the event occurs. Table 4128 includes the actual control actions that a logic controller employs to initiate each type of event in each type of ORM. For each type of control, the table includes an indication of the event type 4130, the ORM type 4131, a control ID 4132, a signal type 4133, a signal strength 4134, and any of many different other characterizations of the type of control 4135 executed by the control logic in order to control an ORM to produce a particular type of event. Finally, table 4140 lists all of the different types of control patterns that can be used to control ORMs. These are equivalent to the previously discussed control patterns. Each control pattern includes a control-pattern identifier 4142, an indication of the number of events in the control pattern 4144, and the event identifiers for those events 4146-4149.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36. The alternative information incorporates more accurate control of ORMs using the information and techniques discussed above with reference to Figures 37A-41. In step 4202, the routine receives a vibration type, duration, amplitude, and start time for a desired device, appliance, or system vibration response. Then, in the *for*-loop of steps 4204-4212, the routine prepares for controlling each of the ORMs in the device, appliance, or system. In step 4205, a control-pattern ID is selected from the vibration-type table for the ORM, modified with respect to the previously described vibration-type table to include the identifiers of control patterns that are tabulated in the control-patterns table 4149. In step 4206, the identified control pattern is selected from the control-patterns table. In the inner *for*-loop of steps 4207-4212, each event is selected from the control pattern selected in step 4206. For each event, a corresponding event control entry is selected from the event-control table, in step 4208. The controls are scaled, in step 4209, according to the desired duration and amplitude for the vibration response. In step 4210, the time associated with the event, selected from the events table, is also scaled. In step 4211, the scaled controls and times are added to a list of time-ordered events, the controls for which are issued to the ORM during generation of the desired vibration response. In step 4214, the routine waits until the desired start time for the vibration response. Note that the desired start time takes into consideration any pre-vibration-

response controls needed to produce the desired vibration response. Then, in the *while*-loop of steps 4216-4222, the routine carries out ORM control over a set of time points spanning the desired vibration-response duration. In the inner *for*-loop of steps 4217-4220, the routine initiates a control sequence for each of the time-ordered events for each of the ORMs at the points in time in which the control sequence is specified for issuance. Then, in step 4221, the routine waits for a next update-control time point.

The above-discussed methods for more accurate and reliable control of ORMs provide increased opportunities for generating increasingly complex vibration responses in devices, appliances, and systems that contain ORMs. However, with increasing complexity, attention is needed to simplifying and increasing the efficiency of driving-oscillation sensing in order to provide feedback-based control to ORMs. In addition, with more accurate control, it is possible to increase the complexity of ORM time-dependent driving oscillations, significantly increasing the types of time-dependent driving oscillations that can be encoded in control patterns and thus increasing the device, appliance, and system vibration responses to controlled ORM driving oscillations.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control. Figure 43 provides a simplified ORM-containing device architecture similar to that provided by Figure 25, discussed above. However, as shown in Figure 43, each of the ORMs, such as ORM 2504, is coupled to an additional passive oscillator, such as passive oscillator 4302. In various different implementations, a given ORM may be coupled to one, two, or more passive oscillators. When an ORM is mechanically coupled to one or more additional passive oscillators, the passive oscillators greatly increase the number of degrees of freedom for vibration of the combined ORM and one or more passive oscillators. The mathematical models for the vibration modes and resonant frequencies become far more complex, involving eigenvalue problems arising from coupled differential equations. As discussed above, the number of resonant frequencies for a system is generally proportional to the number of vibrational degrees of freedom. Furthermore, coupling passive oscillators to ORMs may provide new, complex vibrational modes with different frequencies and

amplitudes. Thus, vibration components comprising an ORM and one or more passive oscillators can significantly increase the complexity of the time-dependent driving oscillations produced by these vibration components, and therefore greatly expand the types, frequencies, and modes of vibration responses produced in a device, appliance, or system containing the complex vibration components.

In the simpler system shown in Figure 25, two vibration sensors 2510 and 2511 were included. These vibration sensors detected vibration in one, two, or three orthogonal directions of the device, appliance, or system 2502 in which multiple ORMs are included. However, as shown in Figure 43, sensors that provide information regarding the driving oscillations produced by ORMs and passive oscillators, such as sensors 4304 and 4305 in ORM 2504 and passive oscillator 4302, respectively, may also provide information to local control logic, such as control logic 4306, within ORMs as well as the controller 2516 that controls one or more ORMs within the device, appliance, or system 2502. The sensors local to ORMs and passive oscillators may be designed to sense driving-oscillation characteristics while vibration sensors 2510 and 2511 are designed to sense the vibration response of the entire device, appliance, or system 2502.

By including a variety of different types of sensors within different positions and components of an ORM-containing device, appliance, or system, an opportunity is provided for hierarchical sensing and corresponding feedback control within a device, appliance, or system. In many cases, the output from a vibration sensor may be difficult to translate into accurate feedback information and corresponding control signals. For example, the vibration sensed by the vibration sensors 2510-2511 may be rather indirectly related to the individual driving oscillations produced by the ORM-based vibration components, such as the vibration component comprising ORM 2504 and mechanically coupled passive oscillator 4302. In such cases, a significant amount of inference may be necessary to logically infer the driving oscillations of the vibration components producing the vibration-sensor signals and to compute corresponding adjustments to ORM control. Furthermore, there may be significant temporal lags between sensor vibration and the driving oscillations that produce the sensor vibration. Many of the common techniques for sensing ORM driving

oscillations in order to provide local feedback to ORMs may suffer similar problems. Furthermore, there may be many different types of interferences and couplings between electromechanical driving forces, electromagnetic sensors, and other device components that mask or entirely prevent accurate inference of the real-time characteristics of ORMs and the vibration-response of the entire device, appliance, or system. For this reason, simpler and more direct types of sensing and control can provide enormous benefits in achieving desired vibration responses of the entire device, appliance, or system, particularly in devices, appliances, and systems that include multiple vibration components, each consisting of an ORM and one or more passive oscillators as well as various types of vibration sensors external to ORMs and passive oscillators as well as sensors within, or coupled to, ORMs and passive oscillators.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control. In Figure 44, a linear ORM 4402, used in previous examples, is again shown as an example ORM. The linear ORM includes a mass or weight 4404 that is driven electromagnetically by a drive coil 4406 to oscillate along a linear tube 4408. In this ORM, two sensor coils 4410 and 4412 are additionally included in order to detect motion of the weight or mass 4404 within the ORM as it is driven to oscillate. The sensor information may be provided to an internal ORM control logic 4414 or to the controller 2516 within the device, appliance, or system that includes the ORM. In certain cases, both the internal ORM control logic as well as the device controller may receive sensor information, for various different types of feedback-based control purposes. In the lower portion 4420 of Figure 44, a small control-flow diagram is provided to indicate how the sensor information is used. When a controller receives a target frequency ω_t at which the ORM is to oscillate, in step 4422, the control logic or controller initiates oscillation of the weight or mass, in step 4424, and then, in the *while*-loop of steps 4426-4430, continues to monitor the sensor output and modify control input to the ORM in order that the ORM oscillates at the target frequency ω_t. This involves reading the sensor data to determine the actual frequency of oscillation ω_a, in step 4427, then determining a difference between the target and actual frequencies in step 4428, using the

determined difference to compute modifications to the current control of the ORM and modify the control in a way estimated to result in the ORM achieving the target frequency ω_t, in step 4429, and executing the modified control in step 4430. In many cases, the computations are sufficiently complex that the feedback-based control needs to be implemented by control routines running on a processor. Furthermore, because the sensors 4410 and 4412 are essentially external to the actual oscillating mass or weight and oscillation path, the data that they output does not directly correspond to position and velocity data for the moving mass or weight, but is instead a signal proportional to the current induced in the sensor coils by the moving mass. A fair amount of interpretation is required to convert the sensor information into velocity and position information, or even into information related to the actual frequency ω_a of oscillation. Moreover, there may be significant electromagnetic interference between the drive coil 4406 and the sensor coils 4410 and 4412, limiting the accuracy at which the actual frequency ω_a or mass position and velocity can be determined. Sensor-coil-based inferences may also suffer from significant lag times between passing of the moving weight through the sensor coil and generation of a corresponding signal. In a complex system in which many different sensors are being monitored for many different ORMs, as well as sensors that detect the vibration response for a device, appliance, or system containing the ORMs, use of inferential feedback information, such as that provided by the sensor coils shown in Figure 44, may be problematic, at best.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the direct sensor data. When a target frequency ω_t is received in step 4512, the control initiates oscillation of the mass in step 4514. In

addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the sensor and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the difference and position with time over several readings, but because of the direct nature of the position sensing, is generally far less inferential and computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position

of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

Although the present invention has been described in terms of particular embodiments, it is not intended that the invention be limited to these embodiments. Modifications will be apparent to those skilled in the art. For example, any of many different design and implementation parameters may be varied in order to provide different implementations of the ORM control logic discussed above, including choice of type of logic control, programming language, in the case of a processor-controlled controller, modular organization, data structures, control structures, logic circuitry, processor type, and many other such design and implementation parameters. Many different types of direct sensors that relatively directly determine the velocity and position of the oscillating mass within an ORM can be used in different types of ORMs. Various types of electromagnetic sensors that sense position, precious-metal brush-contact sensors, and Reed switches are examples of the many types of sensors that can be used to directly determine oscillating-mass position and velocity and induce direct, corresponding control of the ORM.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. The foregoing descriptions of specific embodiments of the present invention are presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments are shown and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents:

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First Named Inventor/Applicant Name:	Robin Elenga
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1		35099-008C1-E-CORRAPP-1.pdf	5789059 843f6755588ac652d70725026e4e51abecc b881b	yes	103

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008CT	7971

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NOTIFICATION DATE	DELIVERY MODE
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The time period for reply, if any, is set in the attached communication.

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Application No. : 16806925
Applicant : Elenga
Filing Date : 03/02/2020
Date Mailed : 06/23/2021

NOTICE TO FILE CORRECTED APPLICATION PAPERS

Notice of Allowance Mailed

This application has been accorded an Allowance Date and is being prepared for issuance. The application, however, is incomplete for the reasons below.

Applicant is given two (2) months from the mail date of this Notice within which to respond. This time period for reply is extendable under 37 CFR 1.136(a) for only TWO additional MONTHS.

The informalities requiring correction are indicated in the attachment(s). If the informality pertains to the abstract, specification (including claims) or drawings, the informality must be corrected with an amendment in compliance with 37 CFR 1.121 (or, if the application is a reissue application, 37 CFR 1.173). Such an amendment may be filed after payment of the issue fee if limited to correction of informalities noted herein. See Waiver of 37 CFR 1.312 for Documents Required by the Office of Patent Publication, 1280 Off. Gaz. Patent Office 918 (March 23, 2004). In addition, if the informality is not corrected until after payment of the issue fee, for purposes of 35 U.S.C. 154(b)(1)(iv), "all outstanding requirements" will be considered to have been satisfied when the informality has been corrected. A failure to respond within the above-identified time period will result in the application being ABANDONED.

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Application No. 16806925

IDENTIFICATION OF APPLICATION DEFICIENCIES IN APPLICATION FILED ON OR AFTER SEPTEMBER 16, 2012

[X] Applicant must provide legible text for the following item(s).

- [X] Specification filed 05/18/2020, page(s) 26, 27, 28.
- [ ] Claims filed , claim(s) .
- [ ] Other: .

[ ] Applicant must provide missing information on the following page(s) of the specification by amending the specification to add the missing text. No new matter may be added.
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[ ] The specification refers to one or more applications by attorney docket number and does not show the U.S. application number(s). Applicant must supply the U.S. application number in place of each attorney docket number.
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[ ] Applicant must provide an Abstract of the Disclosure.

[ ] The Application Data Sheet (ADS dated) does not supply the inventor's city and/or does not supply the inventor's U.S. state and/or does not supply the inventor's country. Applicant must submit a signed, in accordance with 37 CFR 1.76(e) and 1.33(b), application data sheet that corrects this deficiency. To be in compliance with 37 CFR 1.76, the corrected application data sheet must identify the information being changed by using underlining for additions and strikethroughs or brackets for deletions.

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Courtesy Reminder for
Application Serial No: 16/806,925

Attorney Docket No: 35099.008C1
Customer Number: 34395
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TITLE OF INVENTION: OSCILLATING-RESONANT-MODULE CONTROLLER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$600	$0.00	$0.00	$600	09/14/2021

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED. THIS NOTICE OF ALLOWANCE IS NOT A GRANT OF PATENT RIGHTS. THIS APPLICATION IS SUBJECT TO WITHDRAWAL FROM ISSUE AT THE INITIATIVE OF THE OFFICE OR UPON PETITION BY THE APPLICANT. SEE 37 CFR 1.313 AND MPEP 1308.

THE ISSUE FEE AND PUBLICATION FEE (IF REQUIRED) MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED. SEE 35 U.S.C. 151. THE ISSUE FEE DUE INDICATED ABOVE DOES NOT REFLECT A CREDIT FOR ANY PREVIOUSLY PAID ISSUE FEE IN THIS APPLICATION. IF AN ISSUE FEE HAS PREVIOUSLY BEEN PAID IN THIS APPLICATION (AS SHOWN ABOVE), THE RETURN OF PART B OF THIS FORM WILL BE CONSIDERED A REQUEST TO REAPPLY THE PREVIOUSLY PAID ISSUE FEE TOWARD THE ISSUE FEE NOW DUE.

HOW TO REPLY TO THIS NOTICE:

I. Review the ENTITY STATUS shown above. If the ENTITY STATUS is shown as SMALL or MICRO, verify whether entitlement to that entity status still applies.

If the ENTITY STATUS is the same as shown above, pay the TOTAL FEE(S) DUE shown above.

If the ENTITY STATUS is changed from that shown above, on PART B - FEE(S) TRANSMITTAL, complete section number 5 titled "Change in Entity Status (from status indicated above)".

For purposes of this notice, small entity fees are 1/2 the amount of undiscounted fees, and micro entity fees are 1/2 the amount of small entity fees.

II. PART B - FEE(S) TRANSMITTAL, or its equivalent, must be completed and returned to the United States Patent and Trademark Office (USPTO) with your ISSUE FEE and PUBLICATION FEE (if required). If you are charging the fee(s) to your deposit account, section "4b" of Part B - Fee(s) Transmittal should be completed and an extra copy of the form should be submitted. If an equivalent of Part B is filed, a request to reapply a previously paid issue fee must be clearly made, and delays in processing may occur due to the difficulty in recognizing the paper as an equivalent of Part B.

III. All communications regarding this application must give the application number. Please direct all communications prior to issuance to Mail Stop ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Maintenance fees are due in utility patents issuing on applications filed on or after Dec. 12, 1980. It is patentee's responsibility to ensure timely payment of maintenance fees when due. More information is available at www.uspto.gov/PatentMaintenanceFees.

PART B - FEE(S) TRANSMITTAL

Complete and send this form, together with applicable fee(s), by mail or fax, or via EFS-Web.

By mail, send to: Mail Stop ISSUE FEE
Commissioner for Patents
P.O. Box 1450
Alexandria, Virginia 22313-1450

By fax, send to: (571)-273-2885

INSTRUCTIONS: This form should be used for transmitting the ISSUE FEE and PUBLICATION FEE (if required). Blocks 1 through 5 should be completed where appropriate. All further correspondence including the Patent, advance orders and notification of maintenance fees will be mailed to the current correspondence address as indicated unless corrected below or directed otherwise in Block 1, by (a) specifying a new correspondence address; and/or (b) indicating a separate "FEE ADDRESS" for maintenance fee notifications.

CURRENT CORRESPONDENCE ADDRESS (Note: Use Block 1 for any change of address)

34395 7590 06/14/2021
OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
Gig Harbor, WA 98332

Note: A certificate of mailing can only be used for domestic mailings of the Fee(s) Transmittal. This certificate cannot be used for any other accompanying papers. Each additional paper, such as an assignment or formal drawing, must have its own certificate of mailing or transmission.

Certificate of Mailing or Transmission

I hereby certify that this Fee(s) Transmittal is being deposited with the United States Postal Service with sufficient postage for first class mail in an envelope addressed to the Mail Stop ISSUE FEE address above, or being transmitted to the USPTO via EFS-Web or by facsimile to (571) 273-2885, on the date below.

(Typed or printed name)
(Signature)
(Date)

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008C1	7971

TITLE OF INVENTION: OSCILLATING-RESONANT-MODULE CONTROLLER

APPLN. TYPE	ENTITY STATUS	ISSUE FEE DUE	PUBLICATION FEE DUE	PREV. PAID ISSUE FEE	TOTAL FEE(S) DUE	DATE DUE
nonprovisional	SMALL	$600	$0.00	$0.00	$600	09/14/2021

EXAMINER	ART UNIT	CLASS-SUBCLASS
IMTIAZ, ZOHEB S	2846	318-119000

1. Change of correspondence address or indication of "Fee Address" (37 CFR 1.363).

❑ Change of correspondence address (or Change of Correspondence Address form PTO/SB/122) attached.

❑ "Fee Address" indication (or "Fee Address" Indication form PTO/SB/47; Rev 03-09 or more recent) attached. **Use of a Customer Number is required.**

2. For printing on the patent front page, list
(1) The names of up to 3 registered patent attorneys or agents OR, alternatively,
(2) The name of a single firm (having as a member a registered attorney or agent) and the names of up to 2 registered patent attorneys or agents. If no name is listed, no name will be printed.

1 _____
2 _____
3 _____

3. ASSIGNEE NAME AND RESIDENCE DATA TO BE PRINTED ON THE PATENT (print or type)

PLEASE NOTE: Unless an assignee is identified below, no assignee data will appear on the patent. If an assignee is identified below, the document must have been previously recorded, or filed for recordation, as set forth in 37 CFR 3.11 and 37 CFR 3.81(a). Completion of this form is NOT a substitute for filing an assignment.

(A) NAME OF ASSIGNEE (B) RESIDENCE: (CITY and STATE OR COUNTRY)

Please check the appropriate assignee category or categories (will not be printed on the patent) : ❑ Individual ❑ Corporation or other private group entity ❑ Government

4a. Fees submitted: ❑Issue Fee ❑Publication Fee (if required) ❑Advance Order - # of Copies _____

4b. Method of Payment: *(Please first reapply any previously paid fee shown above)*

❑ Electronic Payment via EFS-Web ❑ Enclosed check ❑ Non-electronic payment by credit card (Attach form PTO-2038)

❑ The Director is hereby authorized to charge the required fee(s), any deficiency, or credit any overpayment to Deposit Account No. _____

5. **Change in Entity Status** (from status indicated above)

❑ Applicant certifying micro entity status. See 37 CFR 1.29

❑ Applicant asserting small entity status. See 37 CFR 1.27

❑ Applicant changing to regular undiscounted fee status.

NOTE: Absent a valid certification of Micro Entity Status (see forms PTO/SB/15A and 15B), issue fee payment in the micro entity amount will not be accepted at the risk of application abandonment.
NOTE: If the application was previously under micro entity status, checking this box will be taken to be a notification of loss of entitlement to micro entity status.
NOTE: Checking this box will be taken to be a notification of loss of entitlement to small or micro entity status, as applicable.

NOTE: This form must be signed in accordance with 37 CFR 1.31 and 1.33. See 37 CFR 1.4 for signature requirements and certifications.

Authorized Signature _____ Date _____

Typed or printed name _____ Registration No. _____

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008C1	7971

34395 7590 06/14/2021

OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
Gig Harbor, WA 98332

EXAMINER	
IMTIAZ, ZOHEB S	

ART UNIT	PAPER NUMBER
2846	

DATE MAILED: 06/14/2021

Determination of Patent Term Adjustment under 35 U.S.C. 154 (b)
(Applications filed on or after May 29, 2000)

The Office has discontinued providing a Patent Term Adjustment (PTA) calculation with the Notice of Allowance.

Section 1(h)(2) of the AIA Technical Corrections Act amended 35 U.S.C. 154(b)(3)(B)(i) to eliminate the requirement that the Office provide a patent term adjustment determination with the notice of allowance. See Revisions to Patent Term Adjustment, 78 Fed. Reg. 19416, 19417 (Apr. 1, 2013). Therefore, the Office is no longer providing an initial patent term adjustment determination with the notice of allowance. The Office will continue to provide a patent term adjustment determination with the Issue Notification Letter that is mailed to applicant approximately three weeks prior to the issue date of the patent, and will include the patent term adjustment on the patent. Any request for reconsideration of the patent term adjustment determination (or reinstatement of patent term adjustment) should follow the process outlined in 37 CFR 1.705.

Any questions regarding the Patent Term Extension or Adjustment determination should be directed to the Office of Patent Legal Administration at (571)-272-7702. Questions relating to issue and publication fee payments should be directed to the Customer Service Center of the Office of Patent Publication at 1-(888)-786-0101 or (571)-272-4200.

OMB Clearance and PRA Burden Statement for PTOL-85 Part B

The Paperwork Reduction Act (PRA) of 1995 requires Federal agencies to obtain Office of Management and Budget approval before requesting most types of information from the public. When OMB approves an agency request to collect information from the public, OMB (i) provides a valid OMB Control Number and expiration date for the agency to display on the instrument that will be used to collect the information and (ii) requires the agency to inform the public about the OMB Control Number's legal significance in accordance with 5 CFR 1320.5(b).

The information collected by PTOL-85 Part B is required by 37 CFR 1.311. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 30 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, Virginia 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, Virginia 22313-1450. Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether disclosure of these records is required by the Freedom of Information Act.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspection or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Notice of Allowability	Application No. 16/806,925	Applicant(s) Elenga et al.	
	Examiner ZOHEB S IMTIAZ	Art Unit 2846	AIA (FITF) Status Yes

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address--

All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance (PTOL-85) or other appropriate communication will be mailed in due course. **THIS NOTICE OF ALLOWABILITY IS NOT A GRANT OF PATENT RIGHTS.** This application is subject to withdrawal from issue at the initiative of the Office or upon petition by the applicant. See 37 CFR 1.313 and MPEP 1308.

1. ☑ This communication is responsive to 29 April 2021.
   ☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2. ☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

3. ☑ The allowed claim(s) is/are 1-16 and 21-24 . As a result of the allowed claim(s), you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information , please see **http://www.uspto.gov/patents/init_events/pph/index.jsp** or send an inquiry to **PPHfeedback@uspto.gov.**

4. ☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

   Certified copies:

   a) ☐ All b) ☐ Some *c) ☐ None of the:

   1. ☐ Certified copies of the priority documents have been received.
   2. ☐ Certified copies of the priority documents have been received in Application No. _____ .
   3. ☐ Copies of the certified copies of the priority documents have been received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

   * Certified copies not received: _____ .

Applicant has THREE MONTHS FROM THE "MAILING DATE" of this communication to file a reply complying with the requirements noted below. Failure to timely comply will result in ABANDONMENT of this application.
THIS THREE-MONTH PERIOD IS NOT EXTENDABLE.

5. ☐ CORRECTED DRAWINGS (as "replacement sheets") must be submitted.
   ☐ including changes required by the attached Examiner's Amendment / Comment or in the Office action of Paper No./Mail Date _____ .

   Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the drawings in the front (not the back) of each sheet. Replacement sheet(s) should be labeled as such in the header according to 37 CFR 1.121(d).

6. ☐ DEPOSIT OF and/or INFORMATION about the deposit of BIOLOGICAL MATERIAL must be submitted. Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Attachment(s)

1. ☑ Notice of References Cited (PTO-892)
2. ☐ Information Disclosure Statements (PTO/SB/08), Paper No./Mail Date _____.
3. ☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material _____.
4. ☐ Interview Summary (PTO-413), Paper No./Mail Date. _____.
5. ☐ Examiner's Amendment/Comment
6. ☑ Examiner's Statement of Reasons for Allowance
7. ☐ Other _____.

/ZOHEB S IMTIAZ/
Examiner, Art Unit 2846

Notice of Pre-AIA or AIA Status

The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

Allowable Subject Matter

Claim 1-16 and 21-24 are allowed.

The following is an examiner's statement of reasons for allowance:

Upon further consideration and in a view of the limitation, the prior art does not explicitly teach or fairly suggest alone or in combination the following:

Claims 1-16 and 21-24 are allowable among other elements and details, but for at least the reason "an oscillation path, which represents a segment of a space curve, along which a point within a mass moves; a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along an the oscillation path that represents a segment of a space curve" in combination with the remaining of the claimed subject matter.

Elenga et al. is the closest prior art of record.

Elenga et al. teach a motor control apparatus that utilizes a oscillation resonant module. However, prior art does not tech or fairly suggest alone or in combination teach an oscillation path, which represents a segment of a space curve, along which a point within a mass moves; a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along an the oscillation path that represents a segment of a space curveas seen in claims 1-16 and 21-24 **which is neither inherent nor obvious.**

Any comments considered necessary by applicant must be submitted no later than the payment of the issue fee and, to avoid processing delays, should preferably accompany the issue fee. Such submissions should be clearly labeled "Comments on Statement of Reasons for Allowance."

Response to Arguments

Applicant's arguments filed 4/29/2021 with respect to claims 1-16 and 21-24 have been fully considered and are persuasive. The rejection mailed on 10/29/2020 has been withdrawn.

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to ZOHEB S IMTIAZ whose telephone number is (571)272-4308. The examiner can normally be reached on 11am-730pm.

Examiner interviews are available via telephone, in-person, and video conferencing using a USPTO supplied web-based collaboration tool. To schedule an interview, applicant is encouraged to use the USPTO Automated Interview Request (AIR) at http://www.uspto.gov/interviewpractice.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Eduardo Colon Santana can be reached on 571-272-2060. The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

Information regarding the status of an application may be obtained from the Patent Application Information Retrieval (PAIR) system. Status information for published applications may be obtained from either Private PAIR or Public PAIR. Status information for unpublished applications is available through Private PAIR only. For more information about the PAIR system, see https://ppair-my.uspto.gov/pair/PrivatePair. Should you have questions on access to the Private PAIR system, contact the Electronic Business Center (EBC) at 866-217-9197 (toll-free). If you would like assistance from a

USPTO Customer Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/ZOHEB S IMTIAZ/
Examiner, Art Unit 2846

Notice of References Cited	Application/Control No. 16/806,925	Applicant(s)/Patent Under Reexamination Elenga et al.	
	Examiner ZOHEB S IMTIAZ	Art Unit 2846	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	CPC Classification	US Classification
*	A	US-20120232780-A1	09-2012	Delson; Nathan	A63F13/06	701/400
*	B	US-20130237751-A1	09-2013	Alexander; Taylor Lawrence	A61H19/44	600/38
*	C	US-20120133308-A1	05-2012	Elenga; Robin	H02P25/032	318/128
*	D	US-20070256428-A1	11-2007	Unger; Reuven Z-M	H02K11/33	62/6
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					

FOREIGN PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
	T					

NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
	V	
	W	
	X	

*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	**Art Unit**
	ZOHEB S IMTIAZ	2846

CPC							
Symbol						**Type**	**Version**
H02P	/	25	/	032		F	2016-02-01

CPC Combination Sets								
Symbol						**Type**	**Set**	**Ranking**	**Version**
	/		/						

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	20	
/ZOHEB S IMTIAZ/ Examiner, Art Unit 2846	07 June 2021	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	5

U.S. Patent and Trademark Office — Part of Paper No.: 20210607

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	**Art Unit**
	ZOHEB S IMTIAZ	2846

INTERNATIONAL CLASSIFICATION					
CLAIMED					
H02P25/032	/	25	/	032	

NON-CLAIMED					
	/		/		

US ORIGINAL CLASSIFICATION	
CLASS	**SUBCLASS**

CROSS REFERENCES(S)						
CLASS	**SUBCLASS (ONE SUBCLASS PER BLOCK)**					

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	20	
/ZOHEB S IMTIAZ/ Examiner, Art Unit 2846	07 June 2021	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	5

U.S. Patent and Trademark Office — Part of Paper No.: 20210607

Issue Classification	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	Art Unit
	ZOHEB S IMTIAZ	2846

☐ Claims renumbered in the same order as presented by applicant ☐ CPA ☐ T.D. ☐ R.1.47

CLAIMS															
Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original	Final	Original
1	1	10	10	-	19										
2	2	11	11	-	20										
3	3	12	12	17	21										
4	4	13	13	18	22										
5	5	14	14	19	23										
6	6	15	15	20	24										
7	7	16	16												
8	8	-	17												
9	9	-	18												

NONE		Total Claims Allowed:	
(Assistant Examiner)	(Date)	20	
/ZOHEB S IMTIAZ/ Examiner, Art Unit 2846	07 June 2021	O.G. Print Claim(s)	O.G. Print Figure
(Primary Examiner)	(Date)	1	5

U.S. Patent and Trademark Office — Part of Paper No.: 20210607

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	Art Unit
	ZOHEB S IMTIAZ	2846

CPC - Searched*		
Symbol	Date	Examiner
H02P25/032 or A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004	10/24/2020	ZI

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner
318		10/24/2020	ZI
310		10/24/2020	ZI

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
East search history attached	10/24/2020	ZI
Updated search history attached	06/07/2021	ZI

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	Art Unit
	ZOHEB S IMTIAZ	2846

Interference Search			
US Class/CPC Symbol	**US Subclass/CPC Group**	**Date**	**Examiner**
H02P25/032 or A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004		06/07/2021	ZI
318		06/07/2021	ZI
310		06/07/2021	ZI

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	50	(space near3 curve) same (oscillat$3)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:32
L2	873	(space near3 curve) same (weight or mass or object)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:32
L3	22,754	(oscillat$3) near3 (resonant)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:32
L4	6	2 and 3	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:32
L5	0	(urve) same (weight or mass or object)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:35
L6	178,967	(curve) same (weight or mass or object)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:35
L7	646	3 and 6	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:35
L8	3,719,628	(sens$3 or detect$3) same control$3	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:35
L9	434	7 and 8	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:36
L10	169,728	"318".clas. or "310".clas.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:36
L11	18	9 and 10	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:36
S1	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/11/15 19:13
S2	1	"15043584"	US-PGPUB; USPAT	OR	OFF	2018/11/15 19:28
S3	1,808	"ORM"	US-PGPUB; USPAT	OR	OFF	2018/11/16 17:58
S4	63,684	(sens$3) same control$3 same vibrat$3	US-PGPUB; USPAT	OR	OFF	2018/11/16 17:59
S6	3,012	"ORM" or (oscillating near resonant)	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:00
S7	64	S4 and S6	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:00
S8	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:10
S9	2	"20120133308"	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:31

S10	1	"20130237751"	US-PGPUB; USPAT	OR	OFF	2018/11/17 16:06
S11	1	"20070256428"	US-PGPUB; USPAT	OR	OFF	2018/11/17 16:44
S12	1	"20130237751"	US-PGPUB; USPAT	OR	OFF	2018/12/09 23:40
S13	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/12/10 00:53
S14	1	"20070256428"	US-PGPUB; USPAT	OR	OFF	2018/12/10 02:37
S15	4	"15350314" "15350322" "15350322"	US-PGPUB; USPAT	OR	OFF	2018/12/10 12:40
S16	2	"20060145547"	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:03
S17	80	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2018/12/10 13:26
S18	5	((("RESONANT") near3 ("SYSTEMS") near3 ("INC"))).AS,AANM.	USPAT	OR	OFF	2018/12/10 13:26
S19	1,815	"ORM"	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S20	64,032	(sens$3) same control$3 same vibrat$3	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S21	5	S19 and S20	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S22	2,519	(A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004).cpc.	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S23	3	S21 and S22	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S24	169,654	"318".clas. or "310".clas.	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S25	0	S23 and S24	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:32
S26	1	"15043584"	US-PGPUB; USPAT	OR	OFF	2018/12/12 16:35
S27	1	"15043575"	US-PGPUB; USPAT	OR	OFF	2018/12/12 16:36
S28	17,492	mechanical near3 generator	US-PGPUB; USPAT	OR	OFF	2018/12/17 12:49

S29	141	H02P25/03	US-PGPUB; USPAT	OR	OFF	2020/10/24 14:37
S30	497	H02P25/032.cpc.	US-PGPUB; USPAT	OR	OFF	2020/10/24 14:37
S31	6	((("RESONANT") near3 ("SYSTEMS") near3 ("INC"))).AS,AANM.	USPAT	OR	OFF	2020/10/24 14:37
S32	97	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2020/10/24 14:37
S33	97	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2020/10/24 14:38
S34	3	(space near3 curve) same (mass or load) same (sens$3) same (oscillat$3)	US-PGPUB; USPAT	OR	OFF	2021/06/05 15:18
S35	11,953	(oscillat$3) same (mass or load) same (control$3) same (sens$3 or detect$3)	US-PGPUB; USPAT	OR	OFF	2021/06/05 15:23
S36	84	(space near3 curve) and S35	US-PGPUB; USPAT	OR	OFF	2021/06/05 15:24
S37	2	"20140361714"	US-PGPUB; USPAT	OR	OFF	2021/06/05 15:42
S38	136	OSCILLAT$3 SAME (PROFILE OR GRAPH) SAME (MASS OR OBJECT OR WEIGHT OR LOAD) SAME (ACTUATOR OR MOTOR) SAME (SENS$3 OR DETECT$3)	US-PGPUB; USPAT	OR	OFF	2021/06/07 14:25
S39	113	OSCILLAT$3 SAME (curve) SAME (MASS OR OBJECT OR WEIGHT OR LOAD) SAME (ACTUATOR OR MOTOR) SAME (SENS$3 OR DETECT$3)	US-PGPUB; USPAT	OR	OFF	2021/06/07 14:28
S40	50	(space near3 curve) same (oscillat$3)	US-PGPUB; USPAT	OR	OFF	2021/06/07 17:12
S41	1	"20160248310"	US-PGPUB; USPAT	OR	OFF	2021/06/07 17:22
S42	22,754	(oscillat$3 near3 resonant)	US-PGPUB; USPAT	OR	OFF	2021/06/07 17:33
S43	25	(oscillat$3 near3 resonant) same mass same curve	US-PGPUB; USPAT	OR	OFF	2021/06/07 17:33

S44	51	(oscillat$3 near3 resonant) same (weight or load mass) same curve	US-PGPUB; USPAT	OR	OFF	2021/06/07 19:16
S45	241	(oscillat$3 near3 resonant) same (mass or load or weight or object) same (path or curve)	US-PGPUB; USPAT	OR	OFF	2021/06/07 20:52
S46	194	(sens$3 or detect$3) and S45	US-PGPUB; USPAT	OR	OFF	2021/06/07 20:52

EAST Search History (Interference)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L12	16	((("RESONANT") near3 ("SYSTEMS") near3 ("INC"))).AS,AANM.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:42
L13	98	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:42
L14	169,728	"318".clas. or "310".clas.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:42
L15	3,530	(A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004).cpc.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L16	241	(oscillat$3 near3 resonant) same (mass or load or weight or object) same (path or curve)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L17	873	(space near3 curve) same (weight or mass or object)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L18	22,754	(oscillat$3) near3 (resonant)	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L19	6	17 and 18	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L20	0	14 and 19	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:43
L21	3	15 and 19	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:44
L22	4	((space near3 curve) same (oscillat$3) same (sens$3 or detect$3) same (control$3)).clm.	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:44

L23	2	14 and 17	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:44
L24	3	15 and 17	US-PGPUB; USPAT	OR	OFF	2021/06/07 23:45

6/7/2021 11:45:21 PM
C:\Users\zimtiaz\Documents\EAST\Workspaces\15043584.wsp

PTO/SB/06 (09-11)
Approved for use through 1/31/2014. OMB 0651-0032
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PATENT APPLICATION FEE DETERMINATION RECORD Substitute for Form PTO-875	Application or Docket Number 16/806,925	Filing Date 03/02/2020	☐ To be Mailed

ENTITY: ☐ LARGE ☑ SMALL ☐ MICRO

APPLICATION AS FILED - PART I

	(Column 1)	(Column 2)			
FOR	NUMBER FILED	NUMBER EXTRA		RATE ($)	FEE ($)
☐ BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A		N/A	
☐ SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A		N/A	
☐ EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	minus 20 =	*		x $50 =	
INDEPENDENT CLAIMS (37 CFR 1.16(h))	minus 3 =	*		x $230 =	
☐ APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).				
☐ MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))					
* If the difference in column 1 is less than zero, enter "0" in column 2.				TOTAL	

APPLICATION AS AMENDED - PART II

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT	04/29/2021	CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	* 20	Minus	** 20	= 0		x $50 =	0
	Independent (37 CFR 1.16(h))	* 2	Minus	*** 3	= 0		x $240 =	0
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	0

		(Column 1)		(Column 2)	(Column 3)			
AMENDMENT		CLAIMS REMAINING AFTER AMENDMENT		HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA		RATE ($)	ADDITIONAL FEE ($)
	Total (37 CFR 1.16(i))	*	Minus	**	=		x $0 =	
	Independent (37 CFR 1.16(h))	*	Minus	***	=		x $0 =	
	☐ Application Size Fee (37 CFR 1.16(s))							
	☐ FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							
							TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.	LIE
** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".	/TRACEY T BELL/
*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".	
The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.	

This collection of information is required by 37 CFR 1.16. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Robin Elenga et l.
Application No.:	16/806,925
Filed:	March 2, 2020
Title:	OSCILLATING-RESONANT-MODULE CONTROLLER
	Conf. No.: 7971
	Examiner: Zoheb S. Imtiaz
	Art Unit: 2846
	Docket No.: 35099.008C1

MAIL STOP AMENDMENT
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

AMENDMENT

INTRODUCTORY COMMENTS

Sir:

In response to the Office Action dated October 29, 2020, please extend the period of time for response three months, to expire on April 29, 2021. Please amend the application as follows:

AMENDMENTS TO THE CLAIMS

1. (currently amended) An oscillating resonant module comprising:

an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

a mass that is driven by energy supplied to the oscillating resonant module to ~~travel~~ oscillate back and forth along ~~an~~ the oscillation path that represents a segment of a space curve;

one or more sensors that output indications ~~directly correlated with~~ of the ~~position~~ positions of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives ~~output~~ outputs from the one or more sensors, and

controls oscillation of the mass to produce a ~~predetermined~~ vibration response according to the received control ~~signal~~ signals by ~~repeatedly generating a control output to an actuator that drives the mass to oscillate, corresponding to one or more most recently~~ generating, using one or more of the received sensor ~~outputs.~~ outputs, control outputs to an actuator that drives the mass to oscillate.

2. (original) The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more:

mechanical sensors;

electromagnetic sensors; and

optical sensors.

3. (current amended) The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor ~~output~~ outputs, the velocity of the mass from the positions of the mass at two or more points in time.

4. (current amended) The oscillating resonant module of claim 3 wherein the control ~~output~~ outputs, output by the control component to the actuator, ~~is~~ are computed as the output value of a function that takes, as input, the current position of the mass.

5. (currently amendment) The oscillating resonant module of claim 3 wherein the control ~~output~~ outputs, output by the control component to the actuator, ~~is~~ are computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

6. (currently amendment) The oscillating resonant module of claim 3 wherein the control ~~output~~ outputs, output by the control component to the actuator, ~~is~~ are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

7. (currently amendment) The oscillating resonant module of claim 3 wherein the control ~~output~~ outputs, output by the control component to the actuator, ~~is~~ are computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

8. (original) The oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

9. (original) The oscillating resonant module of claim 8 wherein ~~the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.~~ wherein at least one of the one or more sensors is a Hall-effect sensor.

10. (currently amended) A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

~~the one or more oscillating resonant modules, each of which responds to control inputs to produce driving oscillations and includes a sensor that provides sensor data to a control component within the oscillating resonant module;~~

~~one or more vibration sensors;~~

~~a stored characterization of the natural vibration frequencies of the physical device; and~~

~~a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.~~

a controller; and

the one or more oscillating resonant modules, each oscillating resonant including

an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;

a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path that represents a segment of a space curve;

one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module by the controller,

receives outputs from the one or more sensors, and

controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

11. (currently amended) The physical device of claim 10 ~~wherein each of the one or more oscillating resonant modules comprises:~~ further comprising:

~~a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;~~

~~one or more sensors that output indications directly correlated with the position of the mass within the oscillation path at specific points in time; and~~

~~a control component that~~

~~receives control signals input to the oscillating resonant module,~~

~~receives output from the one or more sensors, and~~

~~controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.~~

one or more vibration sensors;

a stored characterization of the natural vibration frequencies of the physical device; and

a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.

12. (original) The physical device of claim 10 wherein the characterization of the natural vibration frequencies of the physical device is determined by simultaneously sweeping the driving oscillations of the one or more oscillating resonant modules over driving-oscillation ranges and monitoring the physical device vibration response using output from the one or more vibration sensors to identify the maximum-amplitude frequencies.

13. (original) The physical device of claim 12 wherein the characterization of the natural vibration frequencies of the physical device is determined periodically by the controller.

14. (original) The physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device.

15. (original) The physical device of claim 10 wherein at least one of the each of the one or more oscillating resonant modules is mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

16. (original) The physical device of claim 15 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

Cancel 17-20.

21. (new) The physical device of claim 1 further comprising:

a controller, within the physical device, that

receives control signals input to the physical device, and

outputs control signals to one or more of the one or more oscillating resonant modules to controls the vibration response produced by the one or more oscillating resonant modules.

22. (new) The physical device of claim 21 wherein, when the controller outputs control signals to a selected oscillating resonant module, other of the oscillating resonant modules passively respond to the vibration response produced by the selected oscillating resonant module.

23. (new) The physical device of claim 21 wherein the controller passes at least a portion of the received control signals input to the physical device to one or more of the one or more oscillating resonant module.

24. (new) The physical device of claim 21 wherein the controller controls the one or more oscillating resonant modules to each produce a vibration response, the vibration responses produced by the oscillating resonant modules together producing a resonant-frequency vibration mode in the physical device.

REMARKS

Claims 1-20 are pending in the current application. In an Office Action dated October 29, 2020, the Examiner rejected claims 1-2 under 35 U.S. C. §102 as being anticipated by Elenga et al., U.S. Patent Application Publication No. 2012/0133308 ("Elenga"), rejected claims 3-7 under 35 U.S.C. §103 as being unpatentable over Elenga in view of Alexander, U.S. Patent Application Publication No. 2013/0237751 ("Alexander"), rejected claims 8-9 and 15-17, and 20 under 35 U.S.C. §103 as being unpatentable over Elenga in view of Ziegler et al., EP2410641 ("Ziegler"), rejected claims 10-14 under 35 U.S.C. §103 as being unpatentable over Elenga in view of Unger et al., U.S. Patent Application Publication No. 2007/0256428 ("Unger"), rejected claim 18 under 35 U.S.C. §103 as being unpatentable over Elenga in view of Ziegler and Alexander, and rejected claim 19 under 35 U.S.C. §103 as being unpatentable over Elenga in view of Ziegler and in further view of Kraus, U.S. Patent Application Publication No. 2006/0145547 ("Kraus"). Applicants disagree with all of these claim rejections and do not believe that the Examiner has stated a *prima facie* rejection of any of the current claims. Specific traversals of certain of the claim rejections are provided below. Please note that claim 1 has been amended, above, to more particularly point out and specifically claim the invention which claim 1 is directed.

The current application provides, beginning in the middle of page 47, a discussion of direct sensing of the position of an oscillator within an oscillating resonant module by direct-position-sensing sensors within the oscillating resonant module:

> Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the direct sensor data. When a target frequency ω_t is received in step 4512, the control

initiates oscillation of the mass in step 4514. In addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the sensor and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the difference and position with time over several readings, but because of the direct nature of the position sensing, is generally far less inferential and computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

This passage clearly discusses the fact that, in the vibration-inducing motors and mechanisms known at the time of filing of the current application, no attempt was made to determine the positions of an oscillator with respect to an oscillation path within the

vibration-inducing motors and mechanisms. The current application discloses, in the above-quoted paragraphs, an oscillating resonant module that includes one or more sensors that provide direct indications of the positions of an oscillator along a path within the oscillating resonant module within which the oscillator moves back and forward. The Examiner appears not to have read and understood the above-quoted paragraphs, does not appear to understand certain terms and phrases used in the current claims and in the current application, and appears to fail to understand basic operation of various types of sensors.

Claim 1, as currently amended, is provided below:

> 1. An oscillating resonant module comprising:
> an oscillation path, which represents a segment of a space curve, along which a point within a mass moves;
> a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path;
> one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time; and
> a control component that
> receives control signals input to the oscillating resonant module,
> receives outputs from the one or more sensors, and
> controls oscillation of the mass to produce a vibration response according to the received control signals by generating, using one or more of the received sensor outputs, control outputs to an actuator that drives the mass to oscillate.

The first element of claim 1, "an oscillation path, which represents a segment of a space curve, along which a point within a mass moves," refers to a "space curve." The phrase "space curve" refers to the most general type of three-dimensional curve. Space curves represent the largest set of three-dimensional curves. Plane curves are a relatively small subset of the larger set of space curves. Most elementary discussions of curves, in secondary-education mathematics and even in initial undergraduate courses in mathematics, are generally directed to plane curves, because plane curves can be represented by relatively simple single-variable functions. Examples include the well-known plane curves, including lines, circles, ellipses, parabolas, and hyperbolas. By

contrast, the vast majority of space curves can only be represented parametrically, by a set of equations.

The third element of claim 1, "one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time," is discussed in the above-quoted paragraphs, beginning with a reference to "direct sensor 4504," that occurs in the second sentence of the first of the above-quoted paragraphs from the current application. The final paragraph of the above-quoted paragraphs discusses "many different approaches to direct sensing of the position and velocity of a moving mass within an ORM," where the acronym "ORM" is defined to mean oscillating resonant module. One described implementation uses a photodiode sensor. The final sentence in the final paragraph of the above-quoted paragraphs states that "[v]arious types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM."

Beginning on page 2 of the Office Action, the Examiner rejects claim 1 of the current application of follows:

> **Regarding claim 1, Elenga et al. teach,** An oscillating resonant module (**linear-resident vibration modules 400, figure 4A-4G**) comprising: a mass (**mass 404, figures 4a-4g**) that is driven by energy (**current application, paragraph 28**) supplied to the oscillating resonant module to travel back and forth (**"extreme left and extreme right", paragraph 28**) along an oscillation path that represents a segment of the space curve (**cylindrically shaped chamber 406, figure 4a-4g**); one or more sensors (**electromechanical sensors 632, figure 6; see paragraph 32-33, where there are one or more electromechanical sensors, such as accelerometers, which is directly correlated to the position of the mass**) that output indications directly correlated with position of the mass within the oscillation path at specific points in time; and a control component (**CPU 602, figure 6**) that receives control signals input (**user controls 606, figure 6**) to the oscillating resonant module, receives output from the one or more sensors (**see paragraph 33, where the CPU receives input 630 from one or more electromechanical sensors**), and controls oscillation of the mass (**as explained in paragraph 33, the CPU controls the amount of current applied to the coils depicted in figures 4a-4g, to move the mass back and forth**) to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator (**see driving component, claim 1**) that drives the

> mass to oscillate, corresponding to one or more most recently received sensor outputs (**see paragraphs 32-33, where the control is performed based on the output from the sensors**).

The use, by the Examiner, of the phrase "current application" in the statement of rejection is confusing. Normally, the phrase "current application" refers to the application that is currently under examination. It would make no sense to attempt to reject a patent application under 35 U.S.C. §102 based on statements contained in the application itself, so Applicants' representative assumes that, by the phrase "current application," the Examiner is referring to the cited reference Elenga.

The Examiner's assertions with respect to the second element of claim 1, "a mass that is driven by energy supplied to the oscillating resonant module to oscillate back and forth along the oscillation path," reveal that the Examiner has not properly interpreted the language of claim 1 of the current application. The Examiner attempts to read the "cylindrical chamber 406" mentioned in paragraph [0028] of Elenga onto the language "an oscillation path that represents a segment of a space curve" in the first element of claim 1 of the current application. This makes no sense. A space curve is an essentially one-dimensional mathematical object, in the sense that every point in a space curve can be represented by a single scalar distance, or coordinate, representing the distance along the curve from an arbitrary reference point. A cylindrical chamber is a fully three-dimensional mathematical object that requires three spatial coordinates to represent each point on and within the cylindrical chamber. The cylindrical chamber is not, and cannot possibly be, a segment of a space curve.

The Examiner asserts that paragraph [0028] of Elenga teaches the language of the second element of claim 1 of the current application "that is driven by energy." There is no mention of energy anywhere in paragraph [0028] of Elenga.

Thus, from a purely legal standpoint, the Examiner has failed to point to a teaching or suggestion of the first two elements of claim 1 in the cited reference Elenga. However, in fact, the cited reference Elenga does teach an oscillating resonant module that includes a mass, as claimed in the preamble and first two elements of claim 1. The fact that the Examiner does not understand the language of the first element of claim 1 and the fact that the Examiner and has apparently also misinterpreted the cited reference Elenga

are relevant to the current traversal because the Examiner also apparently fails to understand the language of the third element of claim 1 and has completely misinterpreted the cited reference Elenga with respect to the third element of claim 1 of the current application.

The third element of claim 1, as currently amended, recites "one or more sensors that output indications of the positions of the mass within the oscillation path at specific points in time." For this element, the Examiner cites electromechanical sensors 632 shown in Figure 6 and discussed in paragraphs [0032-0033] of the cited reference Elenga, asserting that this figure and these paragraphs show and discuss "one or more electromechanical sensors, such as accelerometers, which is directly correlated to the position of the mass." The cited paragraphs are provided below:

> Figure 6 provides a block diagram of the LRVM, illustrated in Figures 4A-G, that represents one implementation of the linear-resonant vibration module to which current application is directed. The LRVM, in addition to the cylindrical housing, coil, and internal components shown in Figure 4A, includes a power supply, a user interface, generally comprising electromechanical buttons or switches, the H-bridge switch, discussed above with reference to Figures 5A-B, a central processing unit ("CPU"), generally a small, low-powered microprocessor, and one or more electromechanical sensors. All of these components are packaged together as an LRVM within a vibration-based appliance, device, or system.
>
> As shown in Figure 6, the LRVM 600 is controlled by a control program executed by the CPU microprocessor 602. The microprocessor may contain sufficient on-board memory to store the control program and other values needed during execution of the control program, or, alternatively, may be coupled to a low-powered memory chip 604 or flash memory for storing the control program. The CPU receives inputs from the user controls 606 that together comprise a user interface. These controls may include any of various dials, pushbuttons, switches, or other electromechanical-control devices. As one example, the user controls may include a dial to select a strength of vibration, which corresponds to the current applied to the coil, a switch to select one of various different operational modes, and a power button. The user controls generate signals input to the CPU 608-610. A power supply 612 provides power, as needed, to user controls 614, to the CPU 616 and optional, associated memory, to the H-bridge switch 618, and, when needed, to one or more sensors 632. The voltage and current supplied by the power supply to the various components may vary, depending on the operational characteristics and requirements of the components. The H-bridge switch 620 receives a control-signal input *d* 622 from the CPU. The power supply 612 receives a

> control input 624 from the CPU to control the current supplied to the H-bridge switch 618 for transfer to the coil 626. **The CPU receives input 630 from one or more electromechanical sensors 632 that generate a signal corresponding to the strength of vibration currently being produced by the linearly oscillating mass 634. Sensors may include one or more of accelerometers, piezoelectric devices, pressure-sensing devices, or other types of sensors that can generate signals corresponding to the strength of desired vibrational forces.** (emphasis added)

As can be readily appreciated by perusing these paragraphs, there is nothing in the paragraphs that even remotely supports the Examiner's assertion that the "one or more electrical mechanical sensors, such as accelerometers," are "directly correlated to the position of the mass." The only mention in these paragraphs of the capabilities of the sensors occurs in the final two sentences in the second of the cited paragraphs, paragraph [0033], emphasized by bolding in the quotations above. The sensors generate a signal corresponding to the strength of vibration currently being produced by the linearly oscillating mass and signals corresponding to the strength of desired vibrational forces. Thus, the Examiner has failed to point to a teaching or suggestion of the second element of claim 1 of the current application in the cited reference Elenga. This is not surprising. As explained in the two paragraphs of the current application that discuss direct sensing of the position of an oscillator within an oscillating resonant module by direct-position-sensing sensors within the oscillating resonant module, quoted above, directed position sensing of an oscillator within an ORM was unknown at the time of filing of the current application.

The Examiner's attempt to read the second element of claim 1 onto an accelerometer makes no sense from a technical, scientific, and/or mathematical standpoint, just as the Examiner's attempt to read a segment of the space curve onto a three-dimensional cylindrical chamber makes no sense from a mathematical standpoint. Accelerometers measure acceleration, not position, as would be well known to anyone familiar with physics and electronics. Acceleration is described mathematically as the second differential of a function that returns the position of a point in space at a point in time supplied as an argument to the function. The first differential of the function is the velocity of the point in space. A point moving through space can have the same acceleration at different points in space. There is not, in general, a one-to-one mapping between acceleration and position.

It is possible, mathematically, to solve a second-order differential equation for acceleration by two integrations, the first integration producing an expression for the velocity and a first arbitrary constant and the second integration producing a final expression for position along with the first arbitrary constant and a second arbitrary constant. The final expression has no value in determining position with respect to time unless precise values can be assigned to the two arbitrary constants. This requires additional information. In general, to solve the second-order differential equation to produce a function of position with respect to time, it is necessary to know both the initial position of the point and the initial velocity of the point. Without that knowledge, it is mathematically and physically impossible to determine the position of an object using an accelerometer. In the case of an oscillating mass within an ORM, both the ORM and the oscillating mass are associated with positions in space. Were the accelerometer mounted on the oscillating mass, which is not the case in the cited reference Elenga, it might be theoretically possible to determine the position of the oscillating mass with respect to the ORM that contains the oscillating mass from the accelerometer data, but only in the case that the initial positions the ORM and the initial position of the oscillating mass were known and only in the case that the initial velocities of the oscillating mass and the ORM were known. No one familiar with electromechanical devices and basic physics would assert that this knowledge could be obtained from an accelerometer. However, if the accelerometer is not mounted on, or within, the oscillating mass, as in the case of the ORM disclosed in the cited reference Elenga, then it is impossible to determine the position of the oscillator within the ORM from the accelerometer data, since there is no direct correlation between accelerations experienced by the ORM, which would be detected by the accelerometer, and the accelerations experienced by the oscillating mass.

Thus, the Examiner's attempt to read the second element of claim 1 onto the cited reference Elenga is not supported by anything in the cited reference Elenga, is contradicted by clear statements in the current application, and makes no sense technically, scientifically, or mathematically. Claim 1 is not anticipated by the cited reference Elenga, and the Examiner has provided no support for the second element of claim 1 being taught by the cited reference Elenga other than a conclusory and incorrect assertion that the

accelerometers mentioned in the cited reference Elenga are capable of determining the position of an oscillating mass along an oscillation path within an ORM, which they are not.

The third control-component element of claim 1 of the current application is also not taught by the cited reference Elenga, because, in claim 1, the control component is explicitly claimed to receive output from the one or more sensors to which the second element of claim 1 is directed, and Elenga does not disclose such sensors. Claim 1 of the current application is not anticipated by Elenga and Elenga fails to suggest direct sensing of the positions of an oscillator within an ORM.

In the rejection of independent claim 3, the Examiner cites Alexander for teaching "the oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass in the positions of the message two or more points in time." However, Alexander does not provide an enabling description of anything related to determining either the positions or the velocities of an oscillating mass within an ORM. Alexander does mention, in paragraph [0036], that flux sensors might be mounted to an oscillating mass, in Alexander's device, to determine the position and velocity of the oscillating mass within the ORM. However, Alexander fails to disclose a workable or feasible implementation. For one thing, the flux sensors are stated to be mounted on the oscillating mass, but there no indication, in Alexander, of how the sensors could possibly communicate with a stationary control unit within the ORM. Furthermore, there is no indication of how sensors could be mounted to the oscillating mass without interfering with motion of the oscillating mass within the ORM. Sensors require electrical power, but, here again, not means for providing electrical power to sensors mounted on the oscillating mass are shown or discussed. The sensors are not described or illustrated in Alexander. The sensors are not even described to be magnetic-flux sensors. There is no discussion of how the sensors can discriminate between the magnetic field generated by the permanent magnets attached to the oscillating mass and the magnetic fields generated by the stater coils. Alexander appears to be a type of hypothetical discussion without even a threshold level of detail or explanation that would indicate any type of workable or feasible implementation. Perhaps it is for this reason that Alexander

did not issue as a patent.

Thus, the cited references do not teach, disclose, mention, or suggest either independent claim 1 of the current application or claims 2-9 that depend from claim 1 of the current application. Furthermore, as discussed above, it does not appear that the Examiner has properly interpreted the claim language and it does not appear that the Examiner understands space curves, accelerometers, and other subject matter recited in the current claims and discussed in the current application and/or the cited references.

Independent claim 10 has been amended to incorporate the limitations of independent claim 1 that are neither taught nor suggested by any of the cited references. Therefore, claim 10 is now unanticipated and nonobvious over cited references. Independent claim 17 independent claims 18-20 have been canceled to provide for four additional dependent claims depending from independent claim 10.

In Applicants' representative's opinion, all of the claims remaining in the current application are clearly allowable. Favorable consideration and a Notice of Allowance are earnestly solicited.

Respectfully submitted,
Robin Elenga et l.
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Electronic Patent Application Fee Transmittal					
Application Number:	16806925				
Filing Date:	02-Mar-2020				
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER				
First Named Inventor/Applicant Name:	Robin Elenga				
Filer:	Robert Walter Bergstrom/Joanne Bourguignon				
Attorney Docket Number:	35099.008C1				
Filed as Small Entity					
Filing Fees for Utility under 35 USC 111(a)					
Description		**Fee Code**	**Quantity**	**Amount**	**Sub-Total in USD($)**
Basic Filing:					
Pages:					
Claims:					
Miscellaneous-Filing:					
Petition:					
Patent-Appeals-and-Interference:					
Post-Allowance-and-Post-Issuance:					
Extension-of-Time:					

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Extension - 3 months with $0 paid	2253	1	740	740
Miscellaneous:				
			Total in USD ($)	**740**

Electronic Acknowledgement Receipt	
EFS ID:	42591665
Application Number:	16806925
International Application Number:	
Confirmation Number:	7971
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER
First Named Inventor/Applicant Name:	Robin Elenga
Customer Number:	34395
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
Filer Authorized By:	Robert Walter Bergstrom
Attorney Docket Number:	35099.008C1
Receipt Date:	29-APR-2021
Filing Date:	02-MAR-2020
Time Stamp:	14:20:57
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	yes
Payment Type	DA
Payment was successfully received in RAM	$740
RAM confirmation Number	E20214SE21570428
Deposit Account	502976
Authorized User	Joanne Bourguignon
The Director of the USPTO is hereby authorized to charge indicated fees and credit any overpayment as follows: 37 CFR 1.16 (National application filing, search, and examination fees) 37 CFR 1.17 (Patent application and reexamination processing fees)	

37 CFR 1.19 (Document supply fees)

37 CFR 1.20 (Post Issuance fees)

37 CFR 1.21 (Miscellaneous fees and charges)

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		35099-008C1-E-AMENDMENT-1.pdf	641565 2570ba29643f9abae19448 4166facfc3de798a47	yes	18

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	1
Amendment/Req. Reconsideration-After Non-Final Reject	2	2
Amendment Copy Claims/Response to Suggested Claims	3	8
Applicant Arguments/Remarks Made in an Amendment	9	18

Warnings:

Information:

2	Fee Worksheet (SB06)	fee-info.pdf	30990 7ae59acca89b9c7ec11be866b303e74f964b089e	no	2

Warnings:

Information:

Total Files Size (in bytes):	672555

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New Applications Under 35 U.S.C. 111

If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office

If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.

PTO/SB/92 (07-16)
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/Robert W. Bergstrom/	April 29, 2021
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This collection of information is required by 37 CFR 1.8. The information is required to obtain or retain a benefit by the public, which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1.8 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
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Courtesy Reminder for
Application Serial No: 16/806,925

Attorney Docket No: 35099.008C1
Customer Number: 34395
Date of Electronic Notification: 10/29/2020

This is a courtesy reminder that new correspondence is available for this application. If you have not done so already, please review the correspondence. The official date of notification of the outgoing correspondence will be indicated on the form PTOL-90 accompanying the correspondence.

An email notification regarding the correspondence was sent to the following email address(es) associated with your customer number:
joanne@olympicpatentworks.com

To view your correspondence online or update your email addresses, please visit us anytime at **https://ppair-my.uspto.gov/pair/PrivatePair.**
If you have any questions, please email the Electronic Business Center (EBC) at EBC@uspto.gov or call 1-866-217-9197.

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APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.	CONFIRMATION NO.
16/806,925	03/02/2020	Robin Elenga	35099.008C1	7971

34395 7590 10/29/2020

OLYMPIC PATENT WORKS PLLC
4979 Admiral Steet
Gig Harbor, WA 98332

EXAMINER	
IMTIAZ, ZOHEB S	

ART UNIT	PAPER NUMBER
2846	

NOTIFICATION DATE	DELIVERY MODE
10/29/2020	ELECTRONIC

Please find below and/or attached an Office communication concerning this application or proceeding.

The time period for reply, if any, is set in the attached communication.

Notice of the Office communication was sent electronically on above-indicated "Notification Date" to the following e-mail address(es):

joanne@olympicpatentworks.com

Office Action Summary	Application No. 16/806,925	Applicant(s) Elenga et al.	
	Examiner ZOHEB S IMTIAZ	Art Unit 2846	AIA (FITF) Status Yes

-- The MAILING DATE of this communication appears on the cover sheet with the correspondence address --

Period for Reply

A SHORTENED STATUTORY PERIOD FOR REPLY IS SET TO EXPIRE 3 MONTHS FROM THE MAILING DATE OF THIS COMMUNICATION.

- Extensions of time may be available under the provisions of 37 CFR 1.136(a). In no event, however, may a reply be timely filed after SIX (6) MONTHS from the mailing date of this communication.
- If NO period for reply is specified above, the maximum statutory period will apply and will expire SIX (6) MONTHS from the mailing date of this communication.
- Failure to reply within the set or extended period for reply will, by statute, cause the application to become ABANDONED (35 U.S.C. § 133). Any reply received by the Office later than three months after the mailing date of this communication, even if timely filed, may reduce any earned patent term adjustment. See 37 CFR 1.704(b).

Status

1)☑ Responsive to communication(s) filed on 2 March 2020.

☐ A declaration(s)/affidavit(s) under **37 CFR 1.130(b)** was/were filed on _____.

2a)☐ This action is **FINAL.** 2b) ☑ This action is non-final.

3)☐ An election was made by the applicant in response to a restriction requirement set forth during the interview on _____; the restriction requirement and election have been incorporated into this action.

4)☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11, 453 O.G. 213.

Disposition of Claims*

5) ☑ Claim(s) 1-20 is/are pending in the application.

5a) Of the above claim(s) _____ is/are withdrawn from consideration.

6) ☐ Claim(s) _____ is/are allowed.

7) ☑ Claim(s) 1-20 is/are rejected.

8) ☐ Claim(s) _____ is/are objected to.

9) ☐ Claim(s) _____ are subject to restriction and/or election requirement

* If any claims have been determined allowable, you may be eligible to benefit from the **Patent Prosecution Highway** program at a participating intellectual property office for the corresponding application. For more information, please see http://www.uspto.gov/patents/init_events/pph/index.jsp or send an inquiry to **PPHfeedback@uspto.gov.**

Application Papers

10)☐ The specification is objected to by the Examiner.

11)☑ The drawing(s) filed on 18 May 2020 is/are: a)☑ accepted or b)☐ objected to by the Examiner.

Applicant may not request that any objection to the drawing(s) be held in abeyance. See 37 CFR 1.85(a).

Replacement drawing sheet(s) including the correction is required if the drawing(s) is objected to. See 37 CFR 1.121(d).

Priority under 35 U.S.C. § 119

12)☐ Acknowledgment is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d) or (f).

Certified copies:

a)☐ All b)☐ Some** c)☐ None of the:

1.☐ Certified copies of the priority documents have been received.

2.☐ Certified copies of the priority documents have been received in Application No. _____.

3.☐ Copies of the certified copies of the priority documents have been received in this National Stage application from the International Bureau (PCT Rule 17.2(a)).

** See the attached detailed Office action for a list of the certified copies not received.

Attachment(s)

1) ☑ Notice of References Cited (PTO-892)

2) ☐ Information Disclosure Statement(s) (PTO/SB/08a and/or PTO/SB/08b) Paper No(s)/Mail Date _____.

3) ☐ Interview Summary (PTO-413) Paper No(s)/Mail Date _____.

4) ☐ Other: _____.

Notice of Pre-AIA or AIA Status

The present application, filed on or after March 16, 2013, is being examined under the first inventor to file provisions of the AIA.

Claim Rejections - 35 USC § 102

The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

> A person shall be entitled to a patent unless –
>
> (a)(2) the claimed invention was described in a patent issued under section 151, or in an application for patent published or deemed published under section 122(b), in which the patent or application, as the case may be, names another inventor and was effectively filed before the effective filing date of the claimed invention.

Claims 1-2 rejected under 35 U.S.C. 102(a)(2) as being anticipated by Elenga et al. US publication no.: 2012/0133308 A1.

Regarding claim 1, Elenga et al. teach, An oscillating resonant module (**linear-resonant vibration modules 400, figure 4A-4G**) comprising: a mass (**mass 404, figures 4a-4g**) that is driven by energy (**current application, paragraph 28**) supplied to the oscillating resonant module to travel back and forth (**"extreme left and extreme right", paragraph 28**) along an oscillation path that represents a segment of a space curve (**cylindrically shaped chamber 406, figure 4a-4g**); one or more sensors (**electromechanical sensors 632, figure 6; see paragraphs 32-33, where there are one or more electromechanical sensors, such as accelerometers, which is directly correlated to the position of the mass**) that output indications directly correlated with the position of the mass within the oscillation path at specific points in

time; and a control component (**CPU 602, figure 6**) that receives control signals input (**user controls 606, figure 6**) to the oscillating resonant module, receives output from the one or more sensors (**see paragraph 33, where the CPU receives input 630 from one or more electromechanical sensors**),and controls oscillation of the mass (**as explained in paragraph 33, the CPU controls the amount of current applied to the coils depicted in figures 4a-4g, to move the mass back and forth**) to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator (**see driving component, claim 1**) that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs (**see paragraphs 32-33, where the control is performed based on the output from the sensors**).

Regarding claim 2, Elenga et al. teach, the oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more: mechanical sensors (**see electromechanical sensors 632, paragraphs 32-33**); electromagnetic sensors; and optical sensors.

Claim Rejections - 35 USC § 103

The following is a quotation of 35 U.S.C. 103 which forms the basis for all obviousness rejections set forth in this Office action:

> A patent for a claimed invention may not be obtained, notwithstanding that the claimed invention is not identically disclosed as set forth in section 102, if the differences between the claimed invention and the prior art are such that the claimed invention as a whole would have been obvious before the effective filing date of the claimed invention to a person having ordinary skill in the art to which the claimed invention pertains. Patentability shall not be negated by the manner in which the invention was made.

Claims 3-5 and 6-7 are rejected under 35 U.S.C. 103 as being unpatentable over Elenga et al. US publication no.: 2012/0133308 A1 in view of Alexander US publication no.: 2013/0237751.

Regarding claim 3, Elenga et al. is silent on specifically teaching, the oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass from the positions of the mass at two or more points in time.

Alexander teaches: the oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output (**flux sensors in figure 3a, paragraph 36**), the velocity of the mass from the positions of the mass at two or more points in time (**see paragraph 37, where the speed is obtained from the sensor**).

In view of Alexander, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass from the positions of the mass at two or more points in time, for the purpose of improving the control of the apparatus by providing more relevant data.

Regarding claim 4, Elenga et al. is silent on specifically teaching, the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

Alexander teaches: the oscillating resonant module of claim 3 wherein the control output (**see paragraphs 36-39 where the control outputs are based on the position detected by the flux sensor**), output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

In view of Alexander, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass, for the purpose of improving the control of the apparatus by providing more relevant data.

Regarding claim 5, Elenga et al. is silent on specifically teaching: the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

Alexander teaches: the oscillating resonant module of claim 3 wherein the control output (**see paragraphs 36-39 where the control outputs are based on the position detected by the flux sensor and speed calculated and stored in a look-up table**), output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

In view of Alexander, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass, for the purpose of improving the control of the apparatus by providing an efficient method of accessing data.

Regarding claims 6-7, Elenga et al. is silent on specifically teaching, the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

Alexander teaches: the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass (**as explained in paragraph 39, there is a look-up table that includes parameters such as speed and speed**).

In view of Alexander, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current

velocity of the mass, for the purpose of improving the control of the apparatus by providing an efficient method of accessing data.

Claims 8-9 and 15-16, 17 and 20 are rejected under 35 U.S.C. 103 as being unpatentable over Elenga et al. US publication no.: 2012/0133308 A1 in view of Ziegler et al. EP2410641.

Regarding claims 8 and 15, Elenga et al. is silent on specifically teaching, the oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

Ziegler et al. teach: the oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules (**second armature 4, figure 1**) to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules (**as explained in paragraph 33 and figure 1 that the first armature and second armature are coupled to provide a wide range of vibration responses**).

In view of Ziegler et al.'s teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules, for the purpose providing vibration control for a larger module.

Regarding claims 9 and 16, Ziegler et al. teach, The oscillating resonant module of claim 8 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled (**as explained in paragraphs 35-36, current is applied to the coil 10 through which the second armature oscillates**).

Regarding claim 17, Elenga et al. teach, An oscillating resonant module comprising: a first mass (**mass 404, figures 4a-4g**) that is driven by energy supplied to the oscillating resonant module to travel back and forth (**extreme left and extreme right", paragraph 28**) along a first oscillation path that represents a segment of a space curve (**cylindrically shaped chamber 406, figure 4a-4g**); and a control component (**CPU 602, figure 6**) that receives control signals input (**user controls 606, figure 6**) to the oscillating resonant module, and controls oscillation of the first mass (**as explained in paragraph 33, the CPU controls the amount of current applied to the coils depicted in figures 4a-4g, to move the mass back and forth**) to produce a predetermined vibration response according to the received control signals by generating a control output to an actuator that drives the first mass to oscillate.

Elenga et al. is silent on specifically teaching: a second mass that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve.

Ziegler et al. teach: a second mass (second armature 4, figure 1) that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve (**as explained in paragraph 33 and figure 1**

that the first armature and second armature are coupled to provide a wide range of vibration responses).

In view of Ziegler et al.'s teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; a second mass that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve, for the purpose of reducing a transfer of vibrations.

Regarding claim 20, Elenga et al. teach, the oscillating resonant module of claim 17 included within a physical device to drive a vibration response in the physical device (**see paragraphs 3-4, where the invention disclosed in figures 4a-4g and 6 is applied in a physical device such as a toothbrush**).

Claims 10-14 are rejected under 35 U.S.C. 103 as being unpatentable over Elenga et al. US publication no.: 2012/0133308 A1 in view of Unger et al. US publication.: 2007/0256428 A1.

Regarding claim 10, Elenga et al. teach, a physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising: the one or more oscillating resonant modules (**linear-resonant vibration modules, figures 4a-4g; LRVM 600, figure 6**), each of which responds to control inputs to produce driving oscillations (**see paragraph 33, where the LRVM 600 is controlled by a CPU 602**)includes a sensor (**sensor 632, figure 6; paragraph 32**) that provides sensor data to a control component (**CPU processor 632, figure 6**) within the oscillating resonant

module; one or more vibration sensors (**see paragraph 33, where there are one or more sensors and include sensors that generate signals corresponding to the strength of desired "vibrational forces"**).

Elenga et al. is silent on specifically teaching: stored characterization of the natural vibration frequencies of the physical device; and a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.

Unger et al. teach: stored characterization (**see paragraph 46, where the frequency is stored**) of the natural vibration frequencies of the physical device; and a controller (**as explained in paragraphs 45-46, there is a controller that uses lookup table to access the stored frequency**) that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response

In view of Unger et al.'s teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; stored characterization of the natural vibration frequencies of the physical device; and a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to

exhibit a predetermined vibration response, for the purpose of improving the control of the system by providing easier and efficient methods of storing data.

Regarding claim 11, Elenga et al. teach, The physical device of claim 10 wherein each of the one or more oscillating resonant modules comprises: a mass (**mass 404, figures 4a-4g**) that is driven by energy ("**current application", paragraph 28**) supplied to the oscillating resonant module to travel back and forth (**"extreme left and extreme right", paragraph 28**) along an oscillation path that represents a segment of a space curve (**cylindrically shaped chamber 406, figure 4a-4g**); one or more sensors (**electromechanical sensors 632, figure 6; see paragraphs 32-33, where there are one or more electromechanical sensors, such as accelerometers, which is directly correlated to the position of the mass**) that output indications directly correlated with the position of the mass within the oscillation path at specific points in time; and a control component (**CPU 602, figure 6**) that receives control signals input (**user controls 606, figure 6**) to the oscillating resonant module, receives output from the one or more sensors (**see paragraph 33, where the CPU receives input 630 from one or more electromechanical sensors**), and controls oscillation of the mass (**as explained in paragraph 33, the CPU controls the amount of current applied to the coils depicted in figures 4a-4g, to move the mass back and forth**) to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator (**see driving component, claim 1**) that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs (**see paragraphs 32-33, where the control is performed based on the output from the sensors**).

Regarding claim 12, Unger et al. teach, The physical device of claim 10 wherein the characterization of the natural vibration frequencies of the physical device is determined by simultaneously sweeping the driving oscillations of the one or more oscillating resonant modules (**see paragraph 44, where "sweeping the frequency is disclosed which takes place continuously or in incremental steps, therefore implying that it sweeps simultaneously**) over driving-oscillation ranges and monitoring the physical device vibration response using output from the one or more vibration sensors to identify the maximum-amplitude frequencies.

Regarding claim 13, Unger et al. teach, the physical device of claim 12 wherein the characterization of the natural vibration frequencies (**see paragraph 45, where the "testing of frequency" is performed**) of the physical device is determined periodically by the controller.

Regarding claim 14, Elenga et al. is silent on specifically teaching: the physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device.

Unger et al. teach: the physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses (**see paragraphs 45-46, where the frequency is stored**) that is based on the stored characterization of the natural vibration frequencies of the physical device.

In view of Unger et al.'s teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga et al. to include; the physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device, for the purpose of improving the control of the system by providing easier and efficient methods of storing data.

Claim 18 is rejected under 35 U.S.C. 103 as being unpatentable over Elenga et al. US publication no.: 2012/0133308 A1 in view of Ziegler et al. EP2410641 and further in view of Alexander US publication no.: 2013/0237751.

Regarding claim 18, Elenga et al. as modified is silent on specifically teaching: the oscillating resonant module of claim 17 further comprising: one or more sensors that output indications directly correlated with the position of the first mass within the first oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

Alexander teaches: the oscillating resonant module of claim 17 further comprising: one or more sensors that output indications directly correlated with the position (**flux sensors in figure 3a, paragraph 36**) of the first mass within the first oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

In view of Alexander's teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by

Elenga et al. and Ziegler et al. to include; one or more sensors that output indications directly correlated with the position of the first mass within the first oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate, for the purpose of improving the control by providing essential data.

Claim 19 is rejected under 35 U.S.C. 103 as being unpatentable over Elenga et al. US publication no.: 2012/0133308 A1 in view of Ziegler et al. EP2410641 and further in view of Kraus US publication no.: US 2006/0145547.

Regarding claim 19, Elenga as modified is silent on specifically teaching: the oscillating resonant module of claim 17 further comprising: one or more sensors that output indications directly correlated with the position of the second mass within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

Kraus teaches: the oscillating resonant module of claim 17 further comprising: one or more sensors (**three sensors 12, figure 4; paragraph 33**) that output indications directly correlated with the position of the second mass (**as explained in paragraph 33, the sensors detect positions of multiple oscillation elements**) within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

In view of Kraus's teachings, it would've been obvious to one with the ordinary skills in the art, before the effective filing date of the application, with the apparatus as taught by Elenga

et al. and Ziegler et al. to include; the oscillating resonant module of claim 17 further comprising: one or more sensors that output indications directly correlated with the position of the second mass within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate, for the purpose of improving the control by providing essential data.

Conclusion

Any inquiry concerning this communication or earlier communications from the examiner should be directed to ZOHEB S IMTIAZ whose telephone number is (571)272-4308. The examiner can normally be reached on **Mon-Friday 11am-7pm.**

Examiner interviews are available via telephone, in-person, and video conferencing using a USPTO supplied web-based collaboration tool. To schedule an interview, applicant is encouraged to use the USPTO Automated Interview Request (AIR) at http://www.uspto.gov/interviewpractice.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, **Eduardo-Colon-Santana,** can be reached on **571-272-2060.** The fax phone number for the organization where this application or proceeding is assigned is 571-273-8300.

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Service Representative or access to the automated information system, call 800-786-9199 (IN USA OR CANADA) or 571-272-1000.

/ZOHEB S IMTIAZ/
Examiner, Art Unit 2846

Notice of References Cited	Application/Control No. 16/806,925	Applicant(s)/Patent Under Reexamination Elenga et al.	
	Examiner ZOHEB S IMTIAZ	Art Unit 2846	Page 1 of 1

U.S. PATENT DOCUMENTS

*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Name	CPC Classification	US Classification
*	A	US-20120232780-A1	09-2012	Delson; Nathan	A63F13/803	701/400
*	B	US-20130237751-A1	09-2013	Alexander; Taylor Lawrence	A61H19/44	600/38
*	C	US-20120133308-A1	05-2012	Elenga; Robin	H02P25/032	318/128
*	D	US-20070256428-A1	11-2007	Unger; Reuven Z-M	H02K11/33	62/6
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*		Document Number Country Code-Number-Kind Code	Date MM-YYYY	Country	Name	CPC Classification
	N					
	O					
	P					
	Q					
	R					
	S					
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NON-PATENT DOCUMENTS

*		Include as applicable: Author, Title Date, Publisher, Edition or Volume, Pertinent Pages)
	U	
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*A copy of this reference is not being furnished with this Office action. (See MPEP § 707.05(a).)
Dates in MM-YYYY format are publication dates. Classifications may be US or foreign.

Search Notes	Application/Control No.	Applicant(s)/Patent Under Reexamination
	16/806,925	Elenga et al.
	Examiner	Art Unit
	ZOHEB S IMTIAZ	2846

CPC - Searched*		
Symbol	Date	Examiner
H02P25/032 or A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004	10/24/2020	ZI

CPC Combination Sets - Searched*		
Symbol	Date	Examiner

US Classification - Searched*			
Class	Subclass	Date	Examiner
318		10/24/2020	ZI
310		10/24/2020	ZI

* See search history printout included with this form or the SEARCH NOTES box below to determine the scope of the search.

Search Notes		
Search Notes	Date	Examiner
East search history attached	10/24/2020	ZI

Interference Search			
US Class/CPC Symbol	US Subclass/CPC Group	Date	Examiner

EAST Search History

EAST Search History (Prior Art)

Ref #	Hits	Search Query	DBs	Default Operator	Plurals	Time Stamp
L1	141	H02P25/03	US-PGPUB; USPAT	OR	OFF	2020/10/24 14:37
L2	497	H02P25/032.cpc.	US-PGPUB; USPAT	OR	OFF	2020/10/24 14:37
L3	6	((("RESONANT") near3 ("SYSTEMS") near3 ("INC"))).AS,AANM.	USPAT	OR	OFF	2020/10/24 14:37
L4	97	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2020/10/24 14:37
L5	97	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2020/10/24 14:38
S1	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/11/15 19:13
S2	1	"15043584"	US-PGPUB; USPAT	OR	OFF	2018/11/15 19:28
S3	1,808	"ORM"	US-PGPUB; USPAT	OR	OFF	2018/11/16 17:58
S4	63,684	(sens$3) same control$3 same vibrat$3	US-PGPUB; USPAT	OR	OFF	2018/11/16 17:59
S6	3,012	"ORM" or (oscillating near resonant)	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:00
S7	64	S4 and S6	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:00
S8	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:10
S9	2	"20120133308"	US-PGPUB; USPAT	OR	OFF	2018/11/16 18:31
S10	1	"20130237751"	US-PGPUB; USPAT	OR	OFF	2018/11/17 16:06
S11	1	"20070256428"	US-PGPUB; USPAT	OR	OFF	2018/11/17 16:44
S12	1	"20130237751"	US-PGPUB; USPAT	OR	OFF	2018/12/09 23:40
S13	2	"20120232780"	US-PGPUB; USPAT	OR	OFF	2018/12/10 00:53

S14	1	"20070256428"	US-PGPUB; USPAT	OR	OFF	2018/12/10 02:37
S15	4	"15350314" "15350322" "15350322"	US-PGPUB; USPAT	OR	OFF	2018/12/10 12:40
S16	2	"20060145547"	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:03
S17	80	((("ELENGA") near3 ("Robin")) OR (("KNODLE") near3 ("Dan")) OR (("PEPIN") near3 ("Brian"))).INV.	US-PGPUB; USPAT; USOCR; EPO; JPO; DERWENT	OR	OFF	2018/12/10 13:26
S18	5	((("RESONANT") near3 ("SYSTEMS") near3 ("INC"))).AS,AANM.	USPAT	OR	OFF	2018/12/10 13:26
S19	1,815	"ORM"	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S20	64,032	(sens$3) same control$3 same vibrat$3	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S21	5	S19 and S20	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:29
S22	2,519	(A61H2201/5005 or A61H2201/5061 or A61H220/5084 or A61H23/0218 or A61H7/004).cpc.	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S23	3	S21 and S22	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S24	169,654	"318".clas. or "310".clas.	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:31
S25	0	S23 and S24	US-PGPUB; USPAT	OR	OFF	2018/12/10 13:32
S26	1	"15043584"	US-PGPUB; USPAT	OR	OFF	2018/12/12 16:35
S27	1	"15043575"	US-PGPUB; USPAT	OR	OFF	2018/12/12 16:36
S28	17,492	mechanical near3 generator	US-PGPUB; USPAT	OR	OFF	2018/12/17 12:49

EAST Search History (Interference)

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10/24/2020 2:38:24 PM
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Bibliographic Data

Application No: 16/806,925

Foreign Priority claimed: ○ Yes ◉ No

35 USC 119 (a-d) conditions met: ☐ Yes ☑ No ☐ Met After Allowance

Verified and Acknowledged: /ZOHEB S IMTIAZ/ Examiner's Signature | Initials

Title: OSCILLATING-RESONANT-MODULE CONTROLLER

FILING or 371(c) DATE	CLASS	GROUP ART UNIT	ATTORNEY DOCKET NO.
03/02/2020	318	2846	35099.008C1
RULE			

APPLICANTS

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Brian Pepin, Oakland, CA, UNITED STATES

CONTINUING DATA

This application is a CIP of 15043584 02/14/2016ABN

15043584 has PRO of 62116144 02/13/2015

FOREIGN APPLICATIONS

IF REQUIRED, FOREIGN LICENSE GRANTED**

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APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
16/806,925	03/02/2020	Robin Elenga	35099.008C1

CONFIRMATION NO. 7971

34395
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PUBLICATION NOTICE

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The above-identified application will be electronically published as a patent application publication pursuant to 37 CFR 1.211, et seq. The patent application publication number and publication date are set forth above.

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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
16/806,925	03/02/2020	2834	865	35099.008C1	20	3

CONFIRMATION NO. 7971

UPDATED FILING RECEIPT

34395
OLYMPIC PATENT WORKS PLLC
P.O. BOX 4277
SEATTLE, WA 98104

OC000000117133370

Date Mailed: 05/21/2020

Receipt is acknowledged of this non-provisional utility patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

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Assignment For Published Patent Application

Resonant Systems, Inc., Seattle, WA

Power of Attorney: None

Domestic Priority data as claimed by applicant

This application is a CIP of 15/043,584 02/14/2016 ABN
which claims benefit of 62/116,144 02/13/2015

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

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The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 16/806,925**

Projected Publication Date: 08/27/2020

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

OSCILLATING-RESONANT-MODULE CONTROLLER

Preliminary Class

310

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific

countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop

technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 16/806,925

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	75		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	330		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	380		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	20 minus 20 =	*	x 50 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 230 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	785		TOTAL	

APPLICATION AS AMENDED - PART II

AMENDMENT A

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)		RATE($)	ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Robin Elenga et al.
Application No.:	16/806.925
Filed:	March 2, 2020
Title:	OSCILLATING-RESONANT-MODULE CONTROLLER
	Conf. No.: 7971
	Docket No.: 35099.008C1

Box Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

RESPONSE TO NOTICE TO FILE MISSING PARTS OF APPLICATION

Sir:

In response to the Notice to File Missing Parts dated March 18, 2020, please find enclosed the following documents and fees to complete the filing requirements of the above-identified application.

_X_ Executed Declarations

_X_ Statutory basic filing; search and examination fee:
_X_ Utility – Small entity

_X_ General Authorization Under 37 C.F.R. § 1.136(a)(3)

_X_ Fifty-three sheets of Replacement Drawings: Figs. 1-46B

_X_ Substitute Specification

_X_ Marked up Specification

_X_ Missing Parts Surcharge – Small entity

Please charge to Deposit Account 50-2976 the sum of $ 865 At any time during the pendency of this application, please charge any fees required or credit any overpayment to Deposit Account No. 50-2976 pursuant to 37 CFR 1.25. Additionally, please charge any fees to Deposit Account No. 50-2976 under 37 CFR 1.16 through 1.21 inclusive, and any other sections in Title 37 of the Code of Federal Regulations that may regulate fees.

Respectfully submitted,
Robin Elenga et al.
OLYMPIC PATENT WORKS PLLC

/Robert W. Bergstrom/
Robert W. Bergstrom
Registration No. 39,906

Olympic Patent Works PLLC
P.O. Box 4277
Seattle, WA 98194-0277
206.621.1933 telephone
206.621.5302 fax

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	Robin Elenga et al.
Application No.:	16/806,925
Filed:	March 2, 2020
Title:	OSCILLATING-RESONANT-MODULE CONTROLLER
	Conf. No.: 7971
	Docket No.: 35099.008C1

MAIL STOP MISSING PARTS
Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

GENERAL AUTHORIZATION UNDER 37 C.F.R. § 1.136(a)(3)

Sir:

With respect to the above-identified application, the Commissioner is authorized to treat any concurrent or future reply requiring a petition for an extension of time under 37 C.F.R. § 1.136(a)(3) for its timely submission as incorporating a petition therefor for the appropriate length of time. The Commissioner is also authorized to charge any fees which may be required or credit any overpayment to Deposit Account No. 50-2976.

Respectfully submitted,
Robin Elenga et al.
Olympic Patent Works PLLC

/Robert W. Bergstrom/
Robert W. Bergstrom
Registration No. 39,906

Olympic Patent Works PLLC
P.O. Box 4277
Seattle, WA 98194-0277
206.621.1933 telephone
206.621.5302 fax

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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 15/043,584 filed on March 2, 2020.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

WARNING:

Petitioner/applicant is cautioned to avoid submitting personal information in documents filed in a patent application that may contribute to identity theft. Personal information such as social security numbers, bank account numbers, or credit card numbers (other than a check or credit card authorization form PTO-2038 submitted for payment purposes) is never required by the USPTO to support a petition or an application. If this type of personal information is included in documents submitted to the USPTO, petitioners/applicants should consider redacting such personal information from the documents before submitting them to the USPTO. Petitioner/applicant is advised that the record of a patent application is available to the public after publication of the application (unless a non-publication request in compliance with 37 CFR 1.213(a) is made in the application) or issuance of a patent. Furthermore, the record from an abandoned application may also be available to the public if the application is referenced in a published application or an issued patent (see 37 CFR 1.14). Checks and credit card authorization forms PTO-2038 submitted for payment purposes are not retained in the application file and therefore are not publicly available.

LEGAL NAME OF INVENTOR

Inventor: Robin Elenga Date (Optional): 3/6/2020

Signature:

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

☒ United States application or PCT international application number 15/043,584 filed on March 2, 2020.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

I hereby acknowledge that any willful false statement made in this declaration is punishable under 18 U.S.C. 1001 by fine or imprisonment of not more than five (5) years, or both.

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LEGAL NAME OF INVENTOR

Inventor: Brian Pepin (DocuSigned by:) Date (Optional): 3/9/2020

Signature: Brian Pepin (DocuSigned by:)

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

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DECLARATION (37 CFR 1.63) FOR UTILITY OR DESIGN APPLICATION USING AN APPLICATION DATA SHEET (37 CFR 1.76)

Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER

As the below named inventor, I hereby declare that:

This declaration is directed to:

☐ The attached application, or

▒ United States application or PCT international application number 15/043,584 filed on March 2, 2020.

The above-identified application was made or authorized to be made by me.

I believe that I am the original inventor or an original joint inventor of a claimed invention in the application.

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LEGAL NAME OF INVENTOR

Inventor: Dan Knodle Date (Optional): 3-6-2020

Signature: Dan W. Knodle

Note: An application data sheet (PTO/SB/14 or equivalent), including naming the entire inventive entity, must accompany this form or must have been previously filed. Use an additional PTO/AIA/01 form for each additional inventor.

This collection of information is required by 35 U.S.C. 115 and 37 CFR 1.63. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 1 minute to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Robin		Elenga	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Seattle	State/Province	WA	Country of Residence	US

Mailing Address of Inventor:

Address 1	3420 - 10th Avenue West
Address 2	

City	Seattle	State/Province	WA
Postal Code	98119	Country i	US

Inventor 2 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Dan		Knodle	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

City	Seattle	State/Province	WA	Country of Residence	US

Mailing Address of Inventor:

Address 1	3420 - 10th Avenue West
Address 2	

City	Seattle	State/Province	WA
Postal Code	98119	Country i	US

Inventor 3 Remove

Legal Name

Prefix	Given Name	Middle Name	Family Name	Suffix
	Brian		Pepin	

Residence Information (Select One) ◉ US Residency ○ Non US Residency ○ Active US Military Service

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

City	Oakland	State/Province	CA	Country of Residence	US

Mailing Address of Inventor:

Address 1	2355 Broadway		
Address 2			
City	Oakland	**State/Province**	WA
Postal Code	94612	**Country**	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	34395		
Email Address	joanne@olympicpatentworks.com	Add Email	Remove Email

Application Information:

Title of the Invention	OSCILLATING-RESONANT-MODULE CONTROLLER		
Attorney Docket Number	35099.008C1	**Small Entity Status Claimed**	☒
Application Type	Nonprovisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	53	**Suggested Figure for Publication (if any)**	45

Filing By Reference:

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)

☐ **Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	(●) Customer Number	( ) US Patent Practitioner	( ) Limited Recognition (37 CFR 11.9)
Customer Number	34395		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, 365(c), or 386(c) or indicate National Stage entry from a PCT application. Providing benefit claim information in the Application Data Sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the "Application Number" field blank.

Prior Application Status	Pending		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
	Continuation in part of	15/043584	2016-02-14
Prior Application Status	Expired		Remove
Application Number	Continuity Type	Prior Application Number	Filing or 371(c) Date (YYYY-MM-DD)
15/043584	Claims benefit of provisional	62/116144	2015-02-13

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button.

Foreign Priority Information:

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55. When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX)[i] the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

PTO/AIA/14 (11-15)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

Application Number	Country[i]	Filing Date (YYYY-MM-DD)	Access Code[i] (if applicable)

Remove

Additional Foreign Priority Data may be generated within this form by selecting the **Add** button.

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.

NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

PTO/AIA/14 (11-15)
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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

Authorization or Opt-Out of Authorization to Permit Access:

When this Application Data Sheet is properly signed and filed with the application, applicant has provided written authority to permit a participating foreign intellectual property (IP) office access to the instant application-as-filed (see paragraph A in subsection 1 below) and the European Patent Office (EPO) access to any search results from the instant application (see paragraph B in subsection 1 below).

Should applicant choose not to provide an authorization identified in subsection 1 below, applicant **must opt-out** of the authorization by checking the corresponding box A or B or both in subsection 2 below.

NOTE: This section of the Application Data Sheet is **ONLY** reviewed and processed with the **INITIAL** filing of an application. After the initial filing of an application, an Application Data Sheet cannot be used to provide or rescind authorization for access by a foreign IP office(s). Instead, Form PTO/SB/39 or PTO/SB/69 must be used as appropriate.

1. Authorization to Permit Access by a Foreign Intellectual Property Office(s)

A. Priority Document Exchange (PDX) - Unless box A in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (SIPO), the World Intellectual Property Organization (WIPO), and any other foreign intellectual property office participating with the USPTO in a bilateral or multilateral priority document exchange agreement in which a foreign application claiming priority to the instant patent application is filed, access to: (1) the instant patent application-as-filed and its related bibliographic data, (2) any foreign or domestic application to which priority or benefit is claimed by the instant application and its related bibliographic data, and (3) the date of filing of this Authorization. See 37 CFR 1.14(h)(1).

B. Search Results from U.S. Application to EPO - Unless box B in subsection 2 (opt-out of authorization) is checked, the undersigned hereby **grants the USPTO authority** to provide the EPO access to the bibliographic data and search results from the instant patent application when a European patent application claiming priority to the instant patent application is filed. See 37 CFR 1.14(h)(2).

The applicant is reminded that the EPO's Rule 141(1) EPC (European Patent Convention) requires applicants to submit a copy of search results from the instant application without delay in a European patent application that claims priority to the instant application.

2. Opt-Out of Authorizations to Permit Access by a Foreign Intellectual Property Office(s)

☒ A. Applicant **DOES NOT** authorize the USPTO to permit a participating foreign IP office access to the instant application-as-filed. If this box is checked, the USPTO will not be providing a participating foreign IP office with any documents and information identified in subsection 1A above.

☒ B. Applicant **DOES NOT** authorize the USPTO to transmit to the EPO any search results from the instant patent application. If this box is checked, the USPTO will not be providing the EPO with search results from the instant application.

NOTE: Once the application has published or is otherwise publicly available, the USPTO may provide access to the application in accordance with 37 CFR 1.14.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

(•) Assignee	( ) Legal Representative under 35 U.S.C. 117	( ) Joint Inventor
( ) Person to whom the inventor is obligated to assign.	( ) Person who shows sufficient proprietary interest	

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor:

If the Applicant is an Organization check here. ☒

Organization Name	RESONANT SYSTEMS, INC.		
Mailing Address Information For Applicant:			
Address 1	1406 NW 53rd		
Address 2	Suite 2a		
City	Seattle	**State/Province**	WA
Country	US	Postal Code	98107
Phone Number		Fax Number	
Email Address			

Additional Applicant Data may be generated within this form by selecting the Add button.

Assignee Information including Non-Applicant Assignee Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

Assignee 1

Complete this section if assignee information, including non-applicant assignee information, is desired to be included on the patent application publication. An assignee-applicant identified in the "Applicant Information" section will appear on the patent application publication as an applicant. For an assignee-applicant, complete this section only if identification as an assignee is also desired on the patent application publication.

If the Assignee or Non-Applicant Assignee is an Organization check here. ☑

Organization Name	RESONANT SYSTEMS, INC.

Mailing Address Information For Assignee including Non-Applicant Assignee:

Address 1	1406 NW 53rd		
Address 2	Suite 2a		
City	Seattle	**State/Province**	WA
Country i	US	Postal Code	98107
Phone Number		Fax Number	
Email Address			

Additional Assignee or Non-Applicant Assignee Data may be generated within this form by selecting the Add button.

Signature:

NOTE: This Application Data Sheet must be signed in accordance with 37 CFR 1.33(b). **However, if this Application Data Sheet is submitted with the INITIAL filing of the application and either box A or B is not checked in subsection 2 of the "Authorization or Opt-Out of Authorization to Permit Access" section, then this form must also be signed in accordance with 37 CFR 1.14(c).**

This Application Data Sheet **must** be signed by a patent practitioner if one or more of the applicants is a **juristic entity** (e.g., corporation or association). If the applicant is two or more joint inventors, this form must be signed by a patent practitioner, **all** joint inventors who are the applicant, or one or more joint inventor-applicants who have been given power of attorney (e.g., see USPTO Form PTO/AIA/81) on behalf of **all** joint inventor-applicants.

See 37 CFR 1.4(d) for the manner of making signatures and certifications.

Signature	/Robert W. Bergstrom/			Date (YYYY-MM-DD)	2020-03-02
First Name	Robert W.	Last Name	Bergstrom	Registration Number	39906

Additional Signature may be generated within this form by selecting the Add button.

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	35099.008C1
	Application Number	
Title of Invention	OSCILLATING-RESONANT-MODULE CONTROLLER	

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

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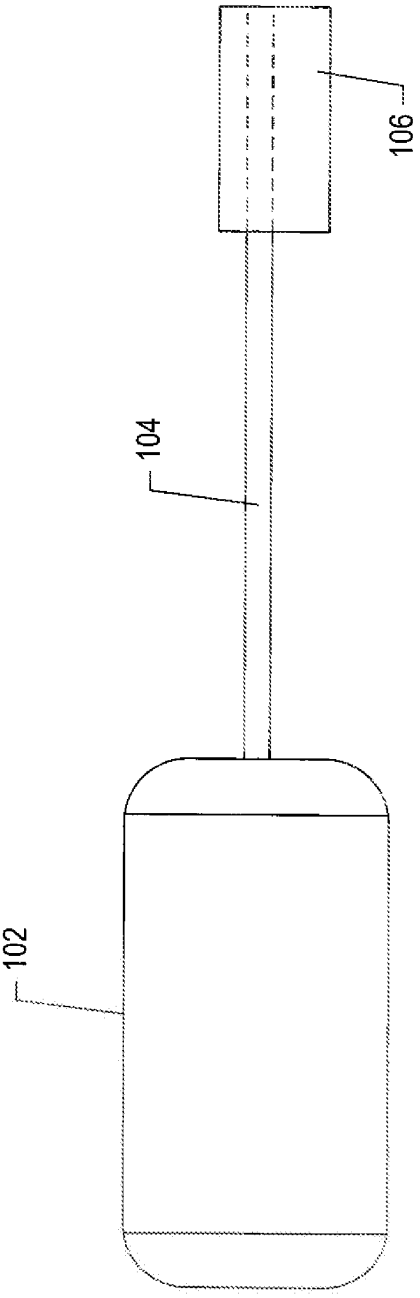


FIG. 1A
--Prior Art--

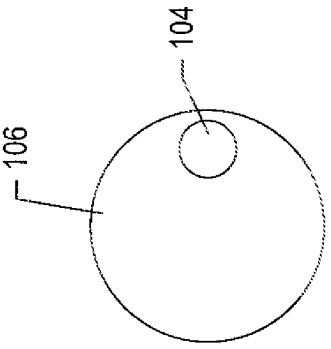


FIG. 1B
--Prior Art--

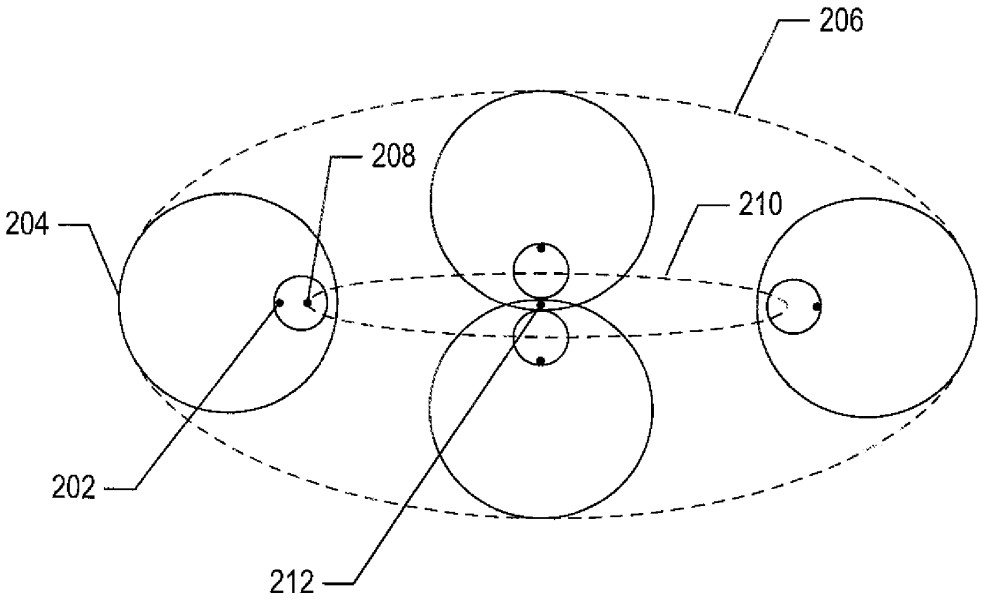


FIG. 2A

--Prior Art--

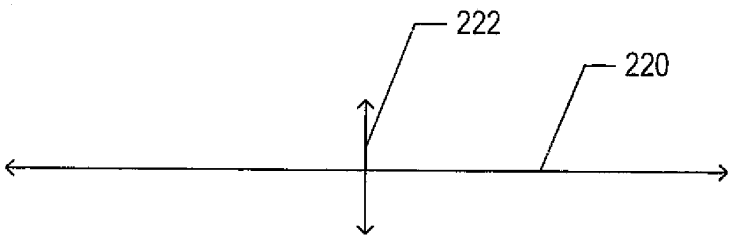


FIG. 2B

--Prior Art--

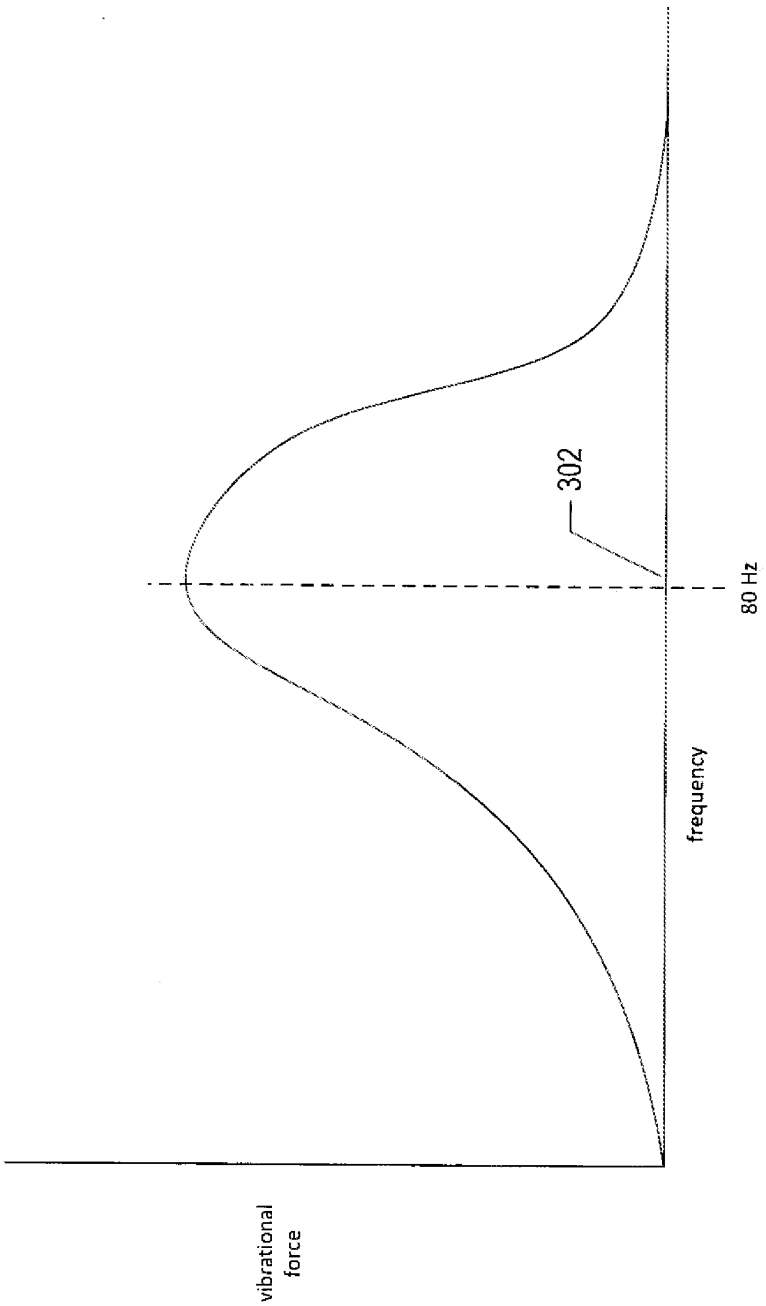


FIG. 3
--Prior Art--

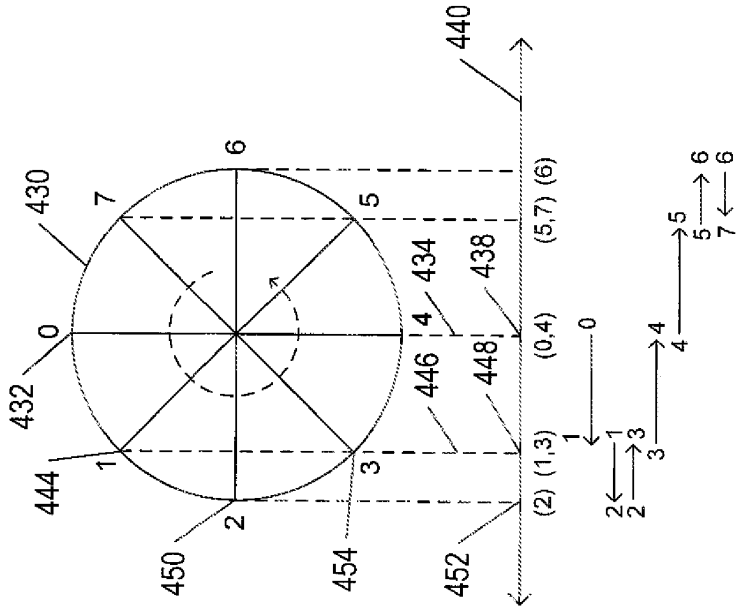

440
430
7
6
5
0
432
434
438
4
(5,7) (6)
(0,4)
446
448
444
1
3
(2) (1,3)
450
2
454
452
0
1
2
3
4
5
6
7

FIG. 4B

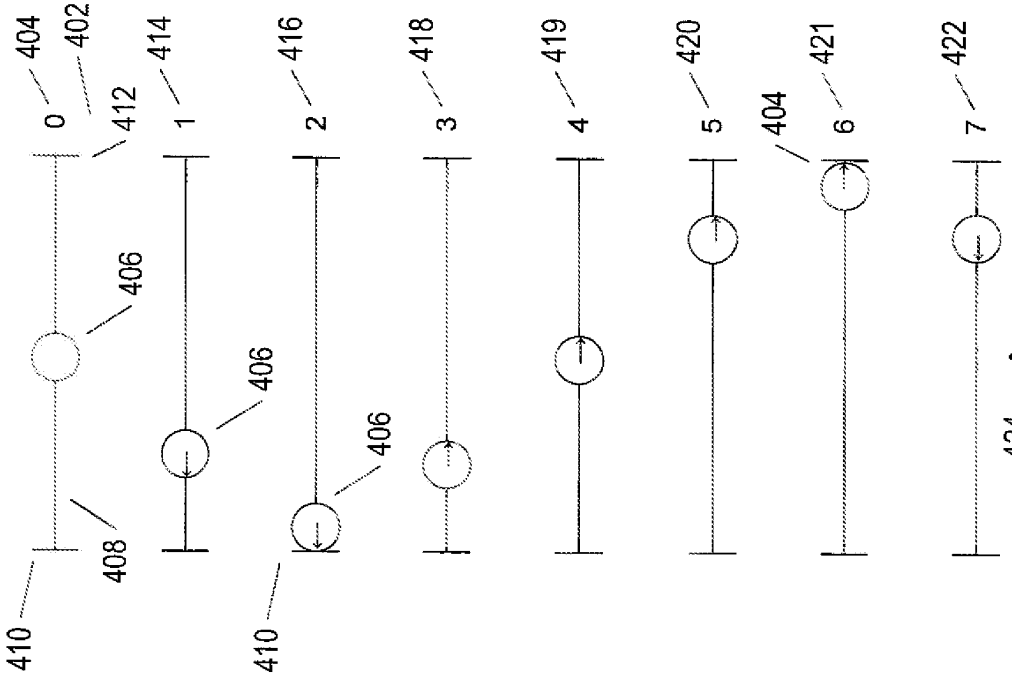

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410
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FIG. 4A

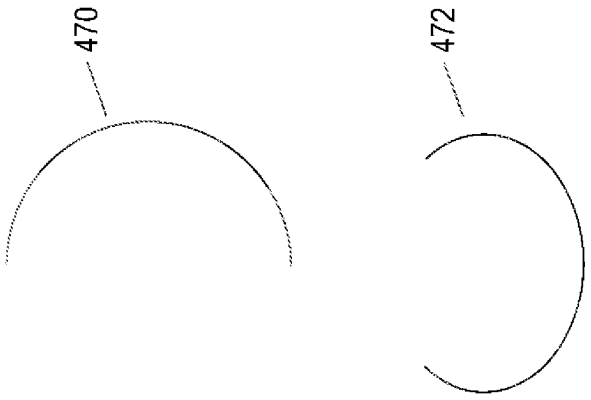


FIG. 4D

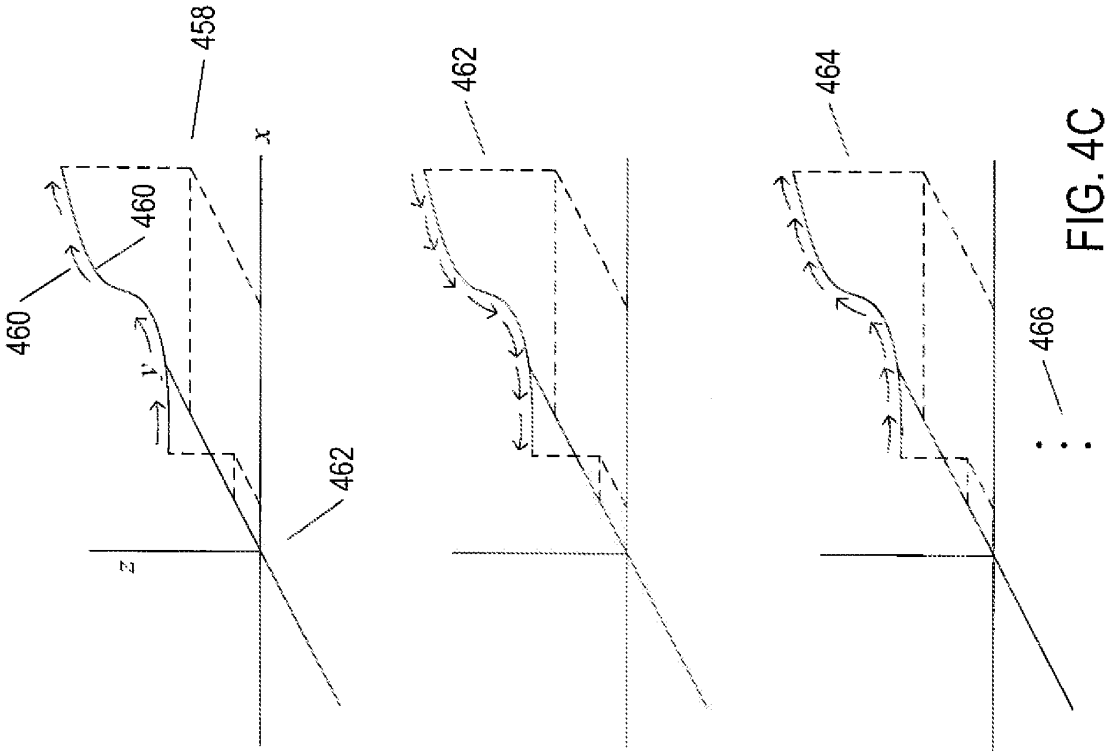


FIG. 4C

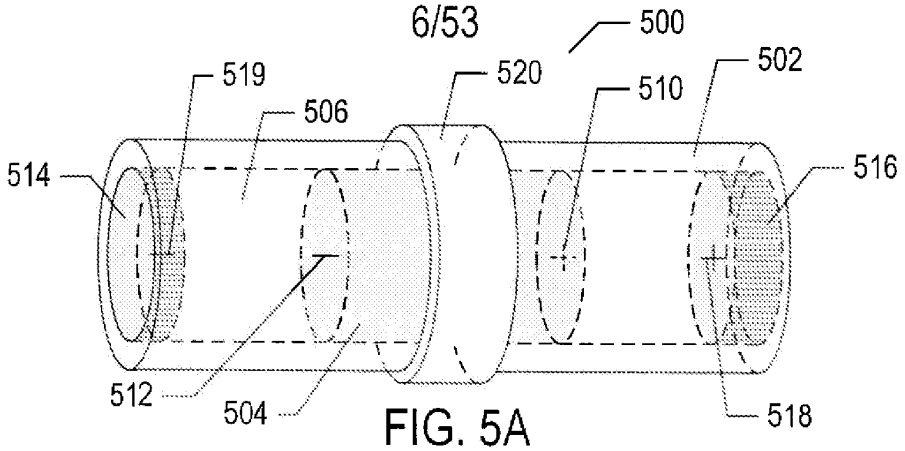


FIG. 5A

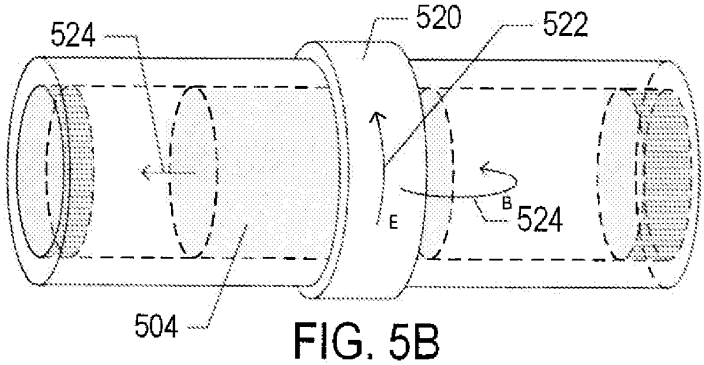


FIG. 5B

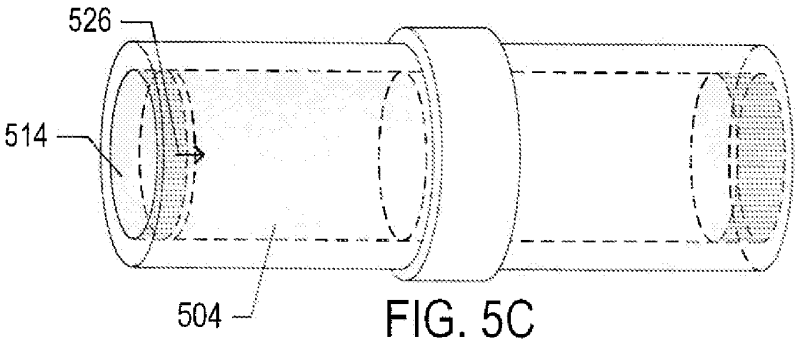


FIG. 5C

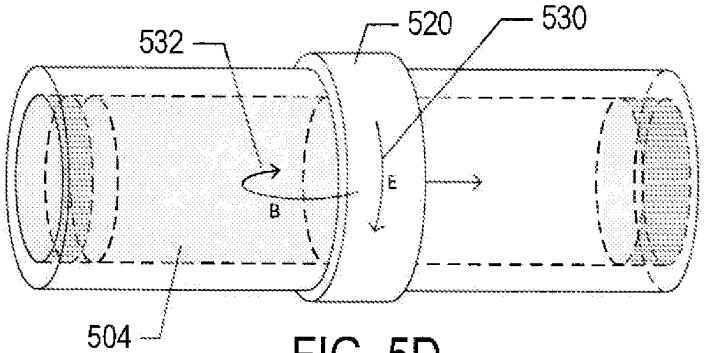


FIG. 5D

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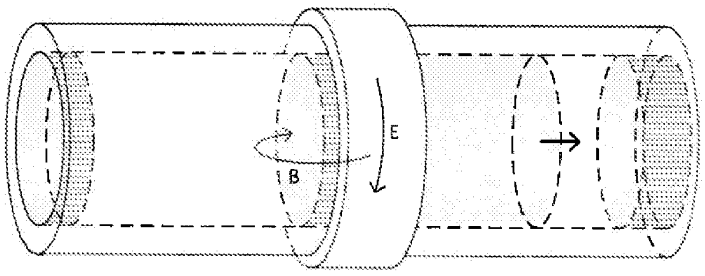


FIG. 5E

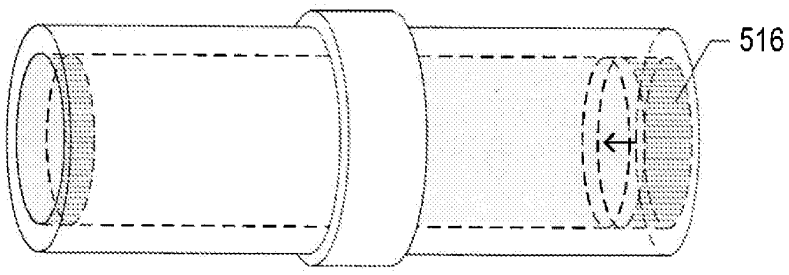


FIG. 5F

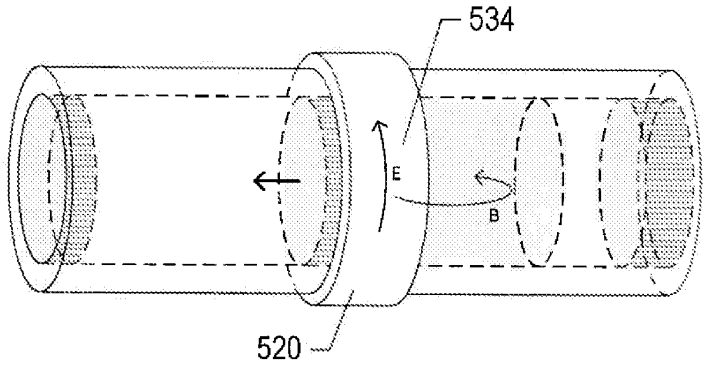


FIG. 5G

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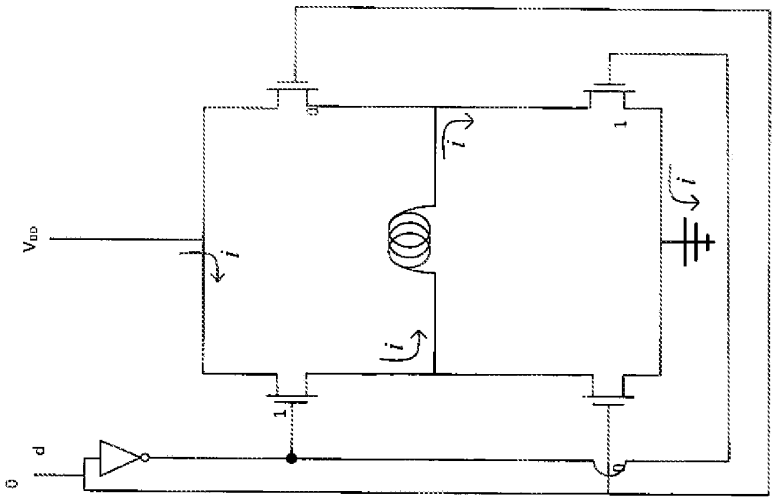


FIG. 6B

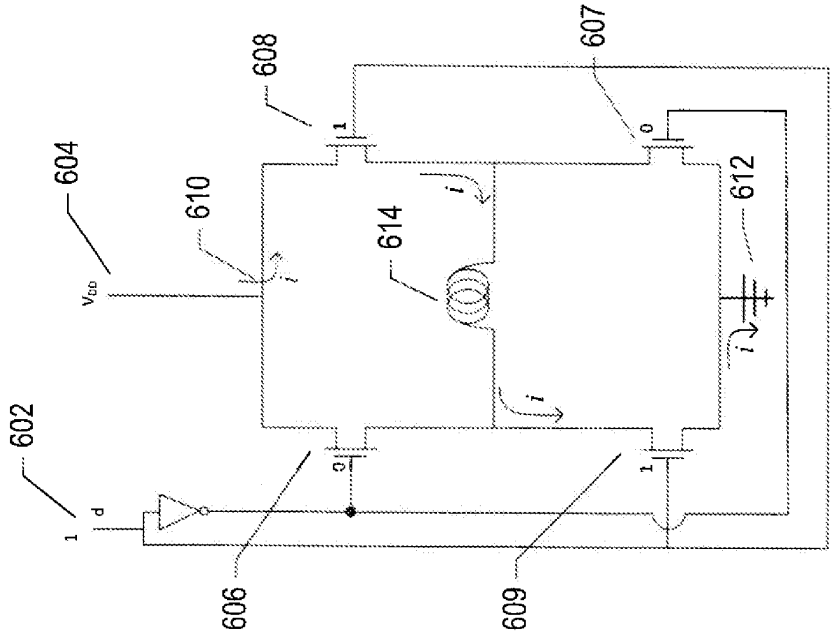


FIG. 6A

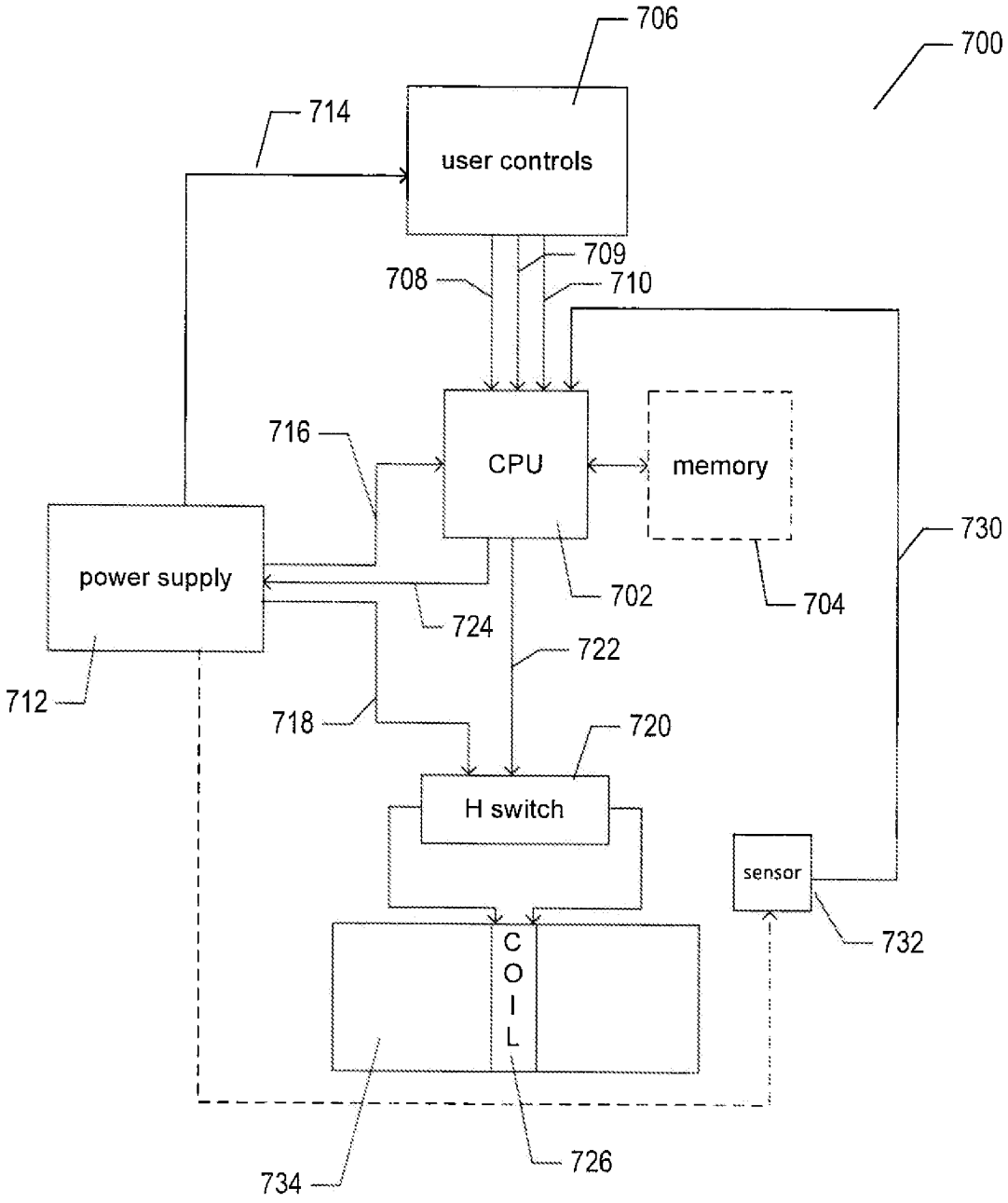

706
700
714
user controls
709
708
710
716
CPU
memory
730
power supply
702
704
724
722
712
718
720
H switch
sensor
732
C
O
I
L
734
726

FIG. 7

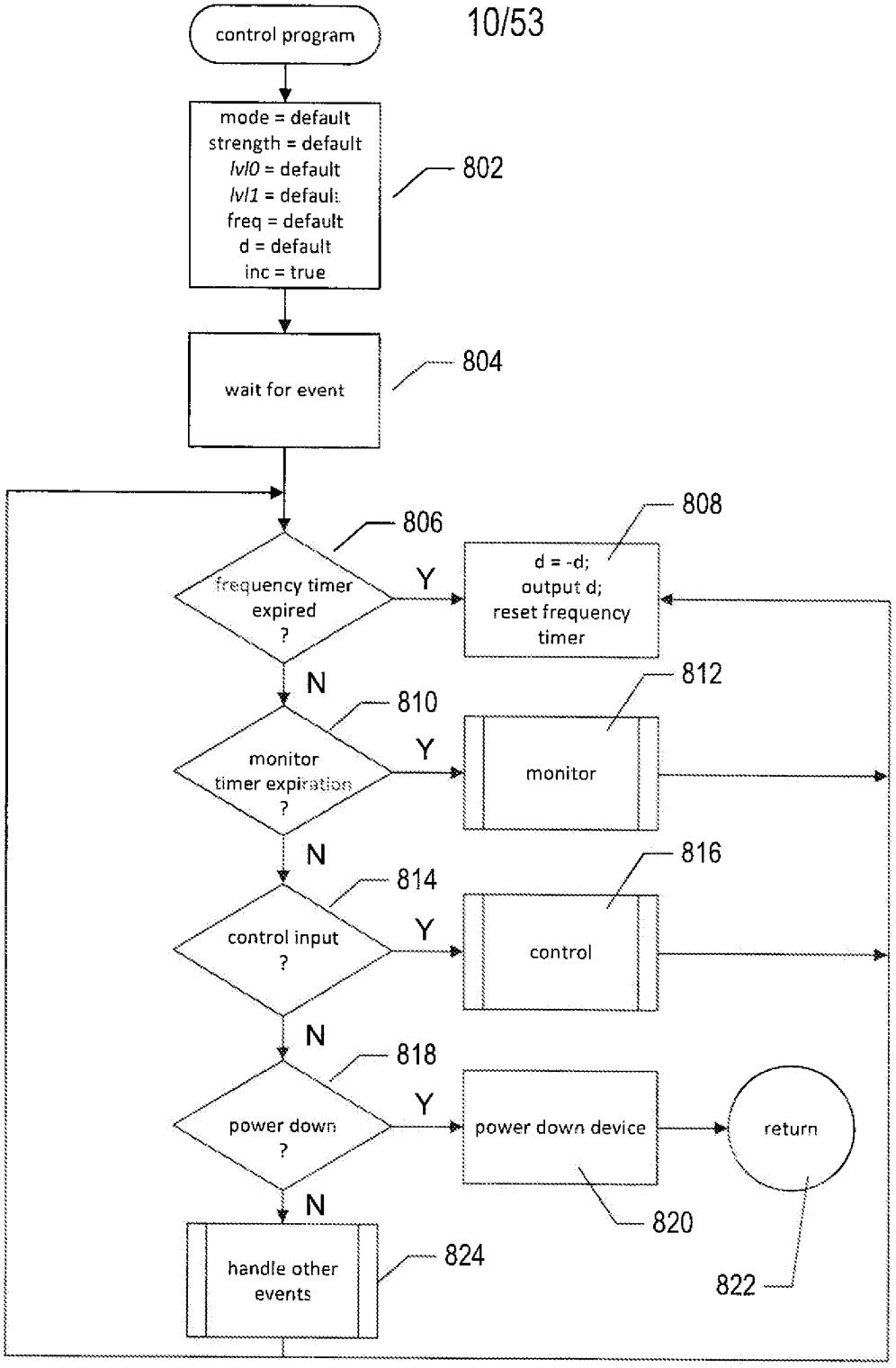

control program
mode = default
strength = default
lvl0 = default
lvl1 = default
freq = default
d = default
inc = true
802
wait for event
804
806
frequency timer expired ?
Y
808
d = -d;
output d;
reset frequency timer
N
810
monitor timer expiration ?
Y
812
monitor
N
814
control input ?
Y
816
control
N
818
power down ?
Y
power down device
820
return
822
N
handle other events
824

FIG. 8A

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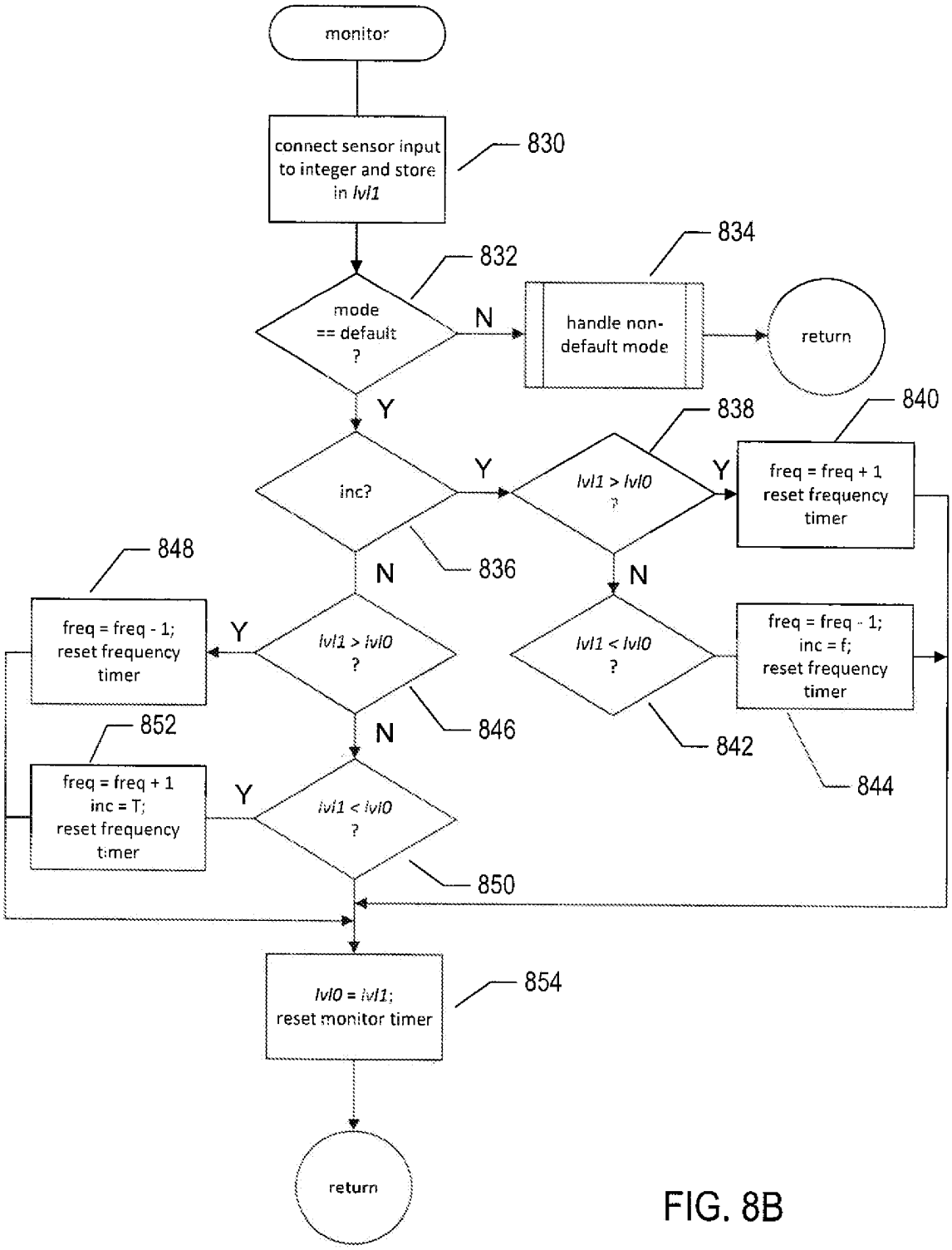

monitor
connect sensor input to integer and store in lvl1
830
832
mode == default ?
N
834
handle non-default mode
return
Y
inc?
Y
838
lvl1 > lvl0 ?
Y
840
freq = freq + 1 reset frequency timer
836
N
N
848
freq = freq - 1; reset frequency timer
Y
lvl1 > lvl0 ?
lvl1 < lvl0 ?
freq = freq - 1; inc = f; reset frequency timer
846
842
844
N
852
freq = freq + 1 inc = T; reset frequency timer
Y
lvl1 < lvl0 ?
850
lvl0 = lvl1; reset monitor timer
854
return

FIG. 8B

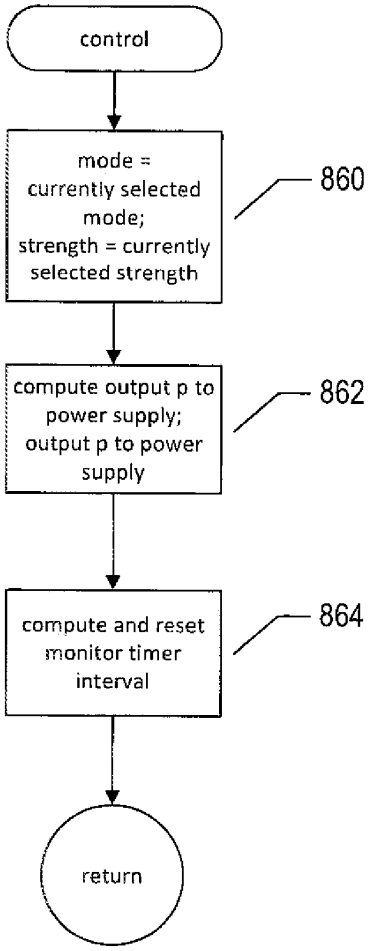

control
mode = currently selected mode; strength = currently selected strength
860
compute output p to power supply; output p to power supply
862
compute and reset monitor timer interval
864
return

FIG. 8C

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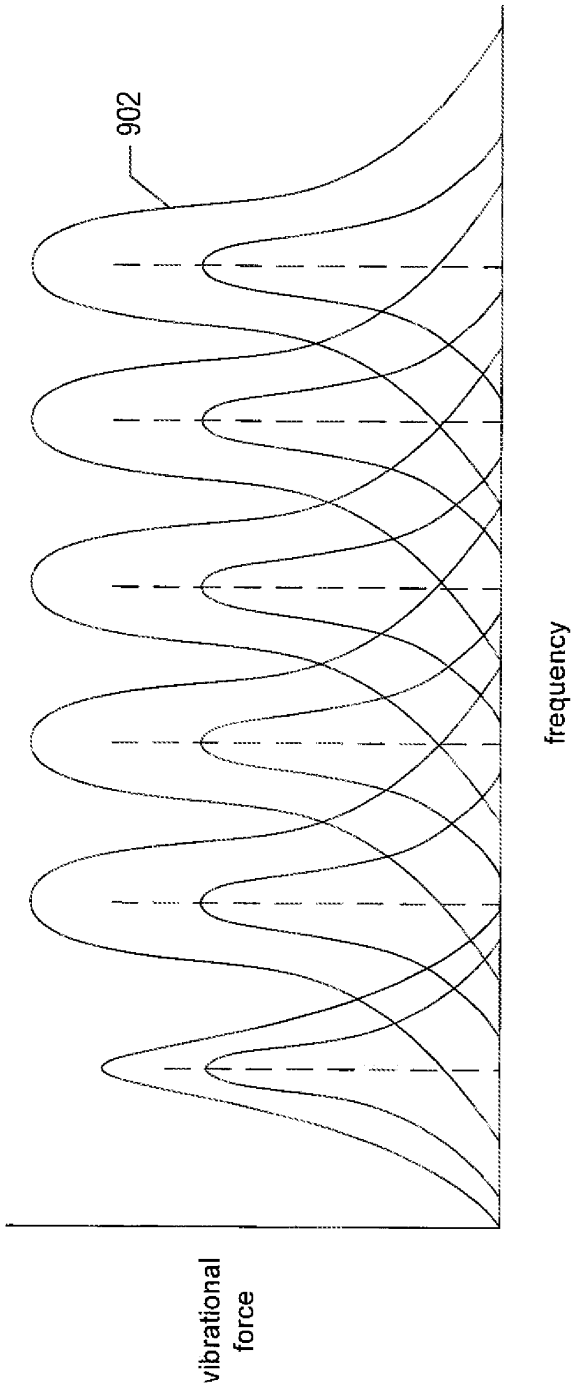


FIG. 9

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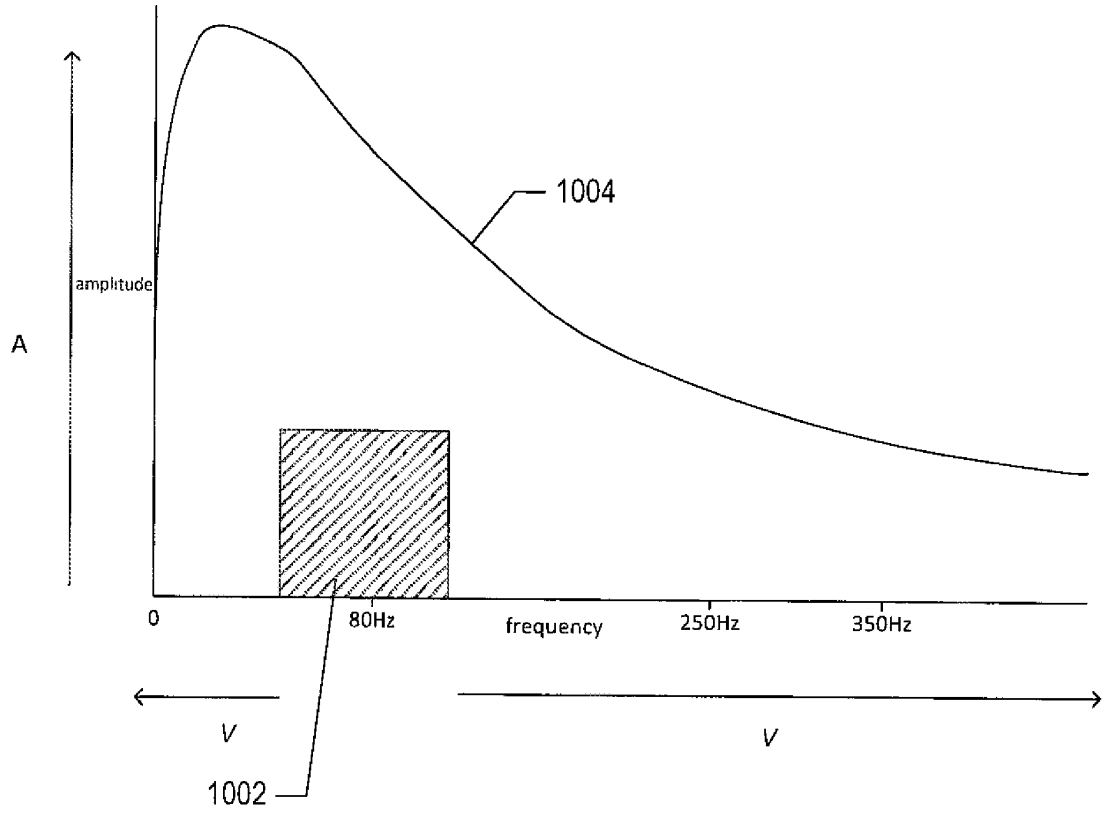


FIG. 10

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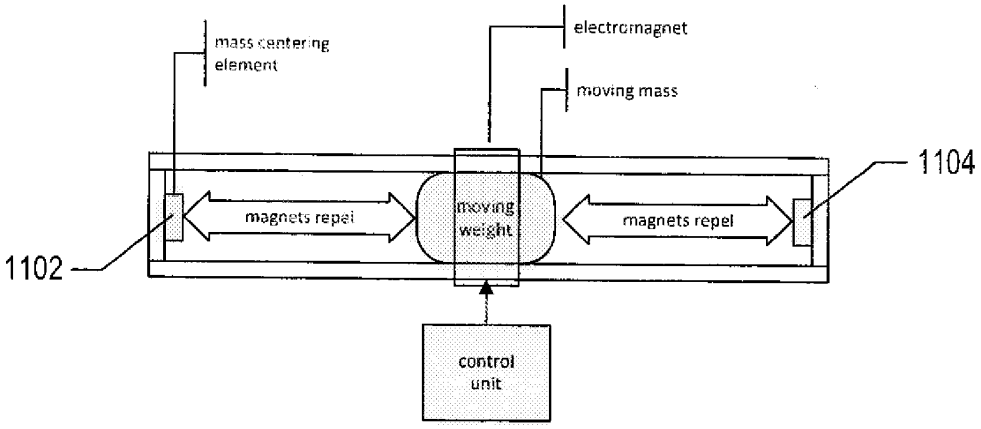


FIG. 11

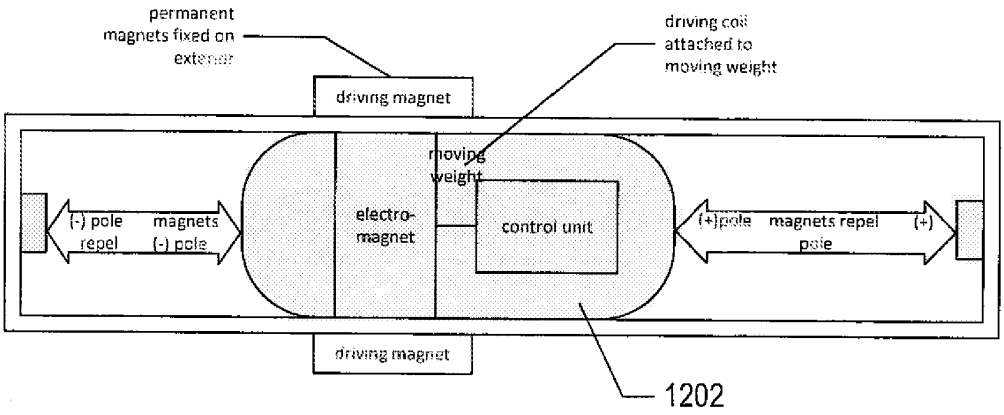


FIG. 12

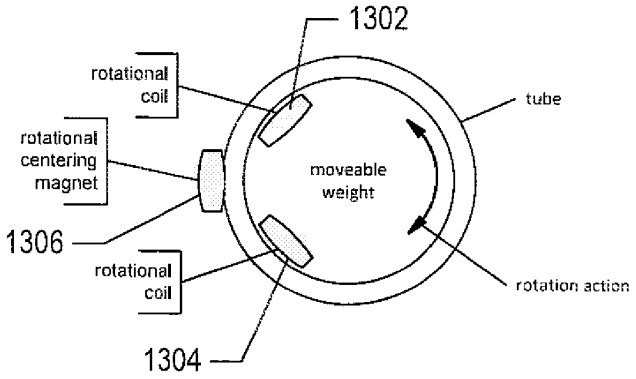


FIG. 13

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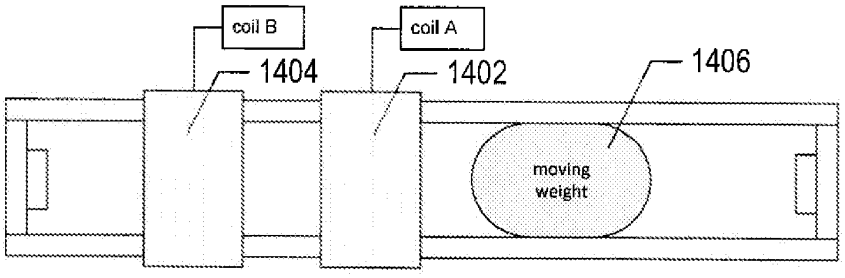


FIG. 14

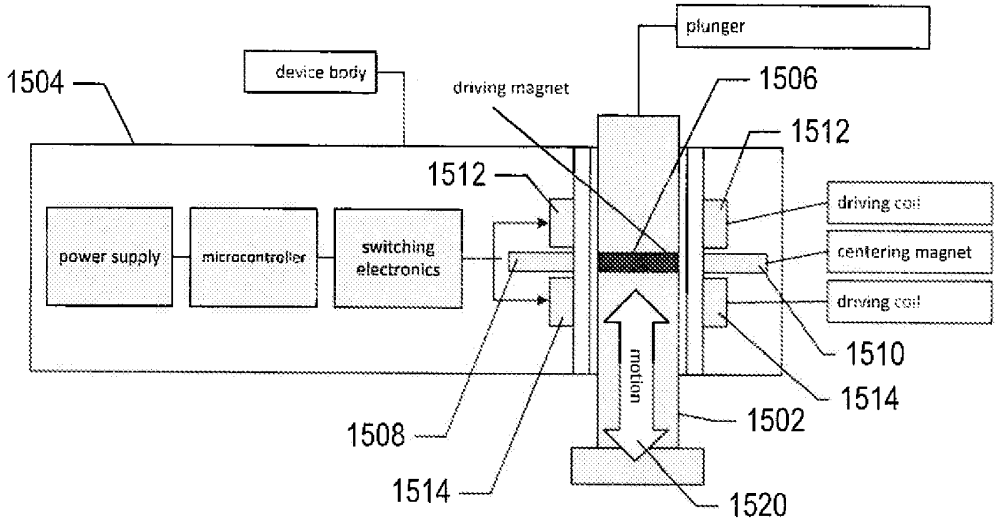


FIG. 15

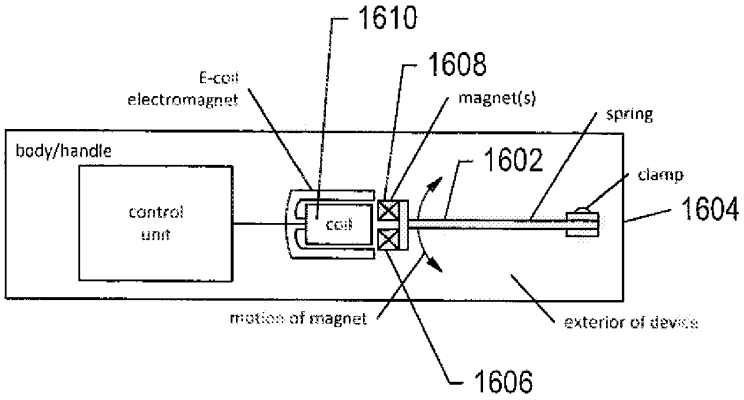


FIG. 16

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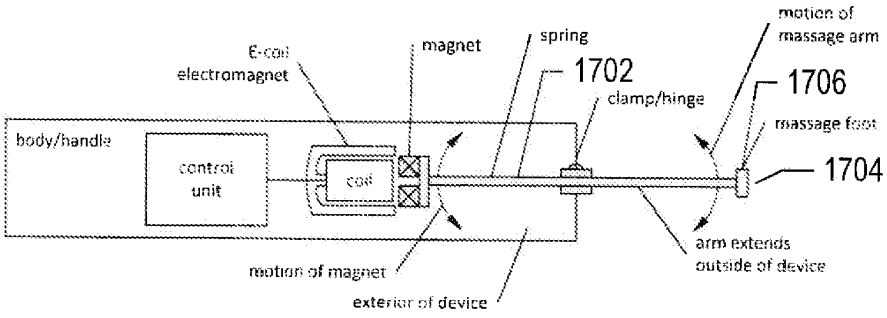


FIG. 17

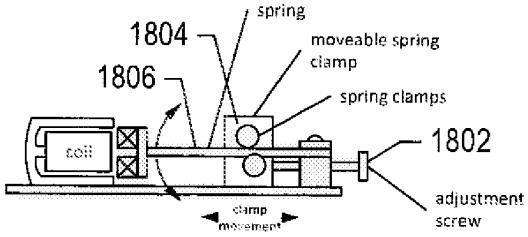


FIG. 18

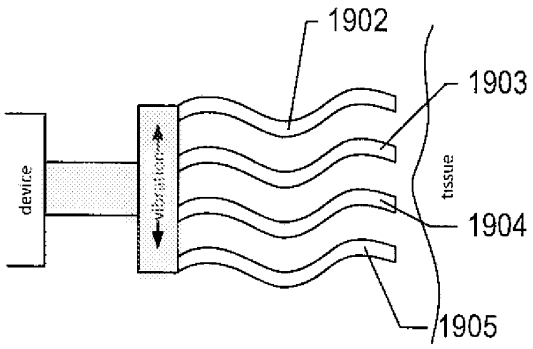


FIG. 19

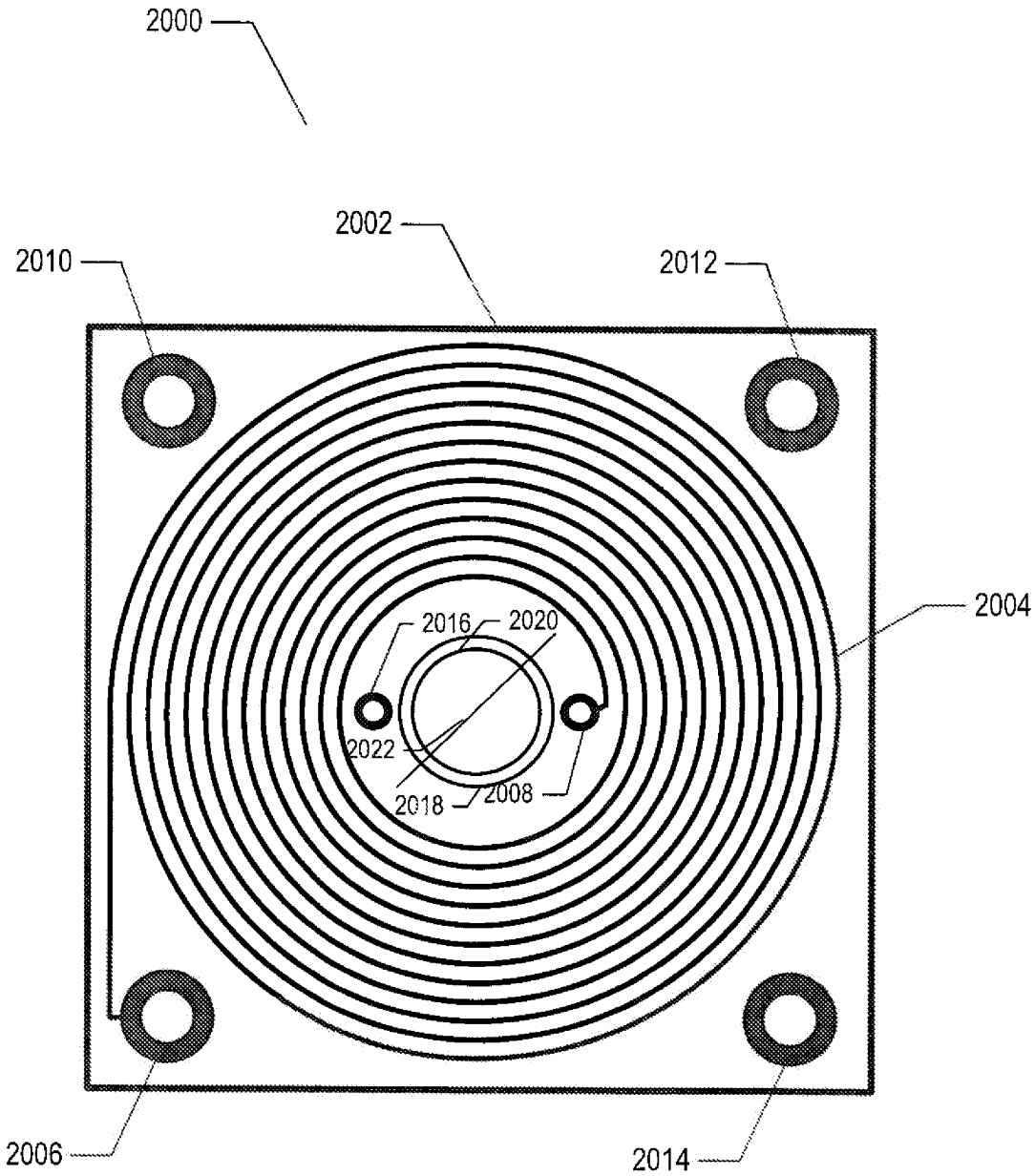


FIG. 20

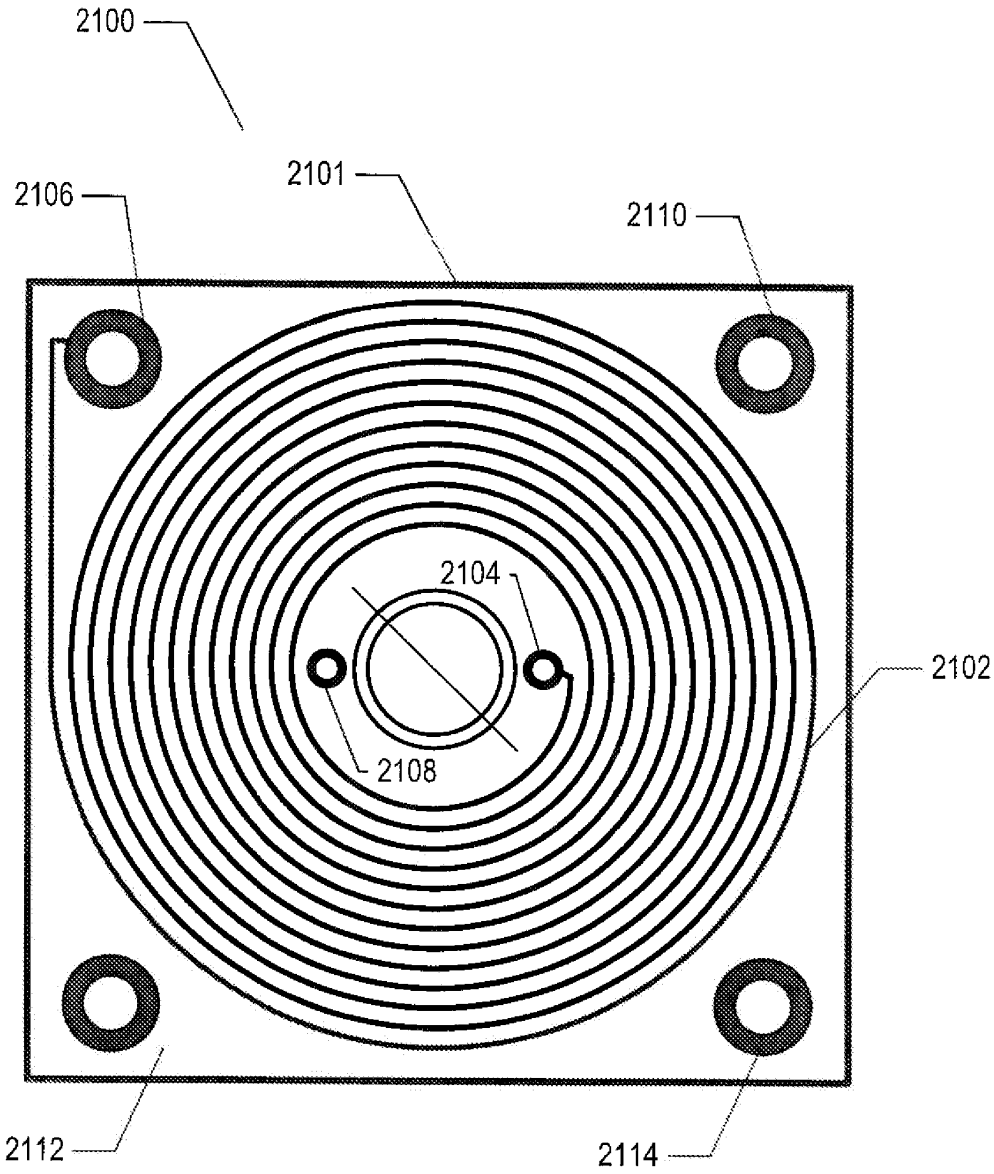


FIG. 21

20/53

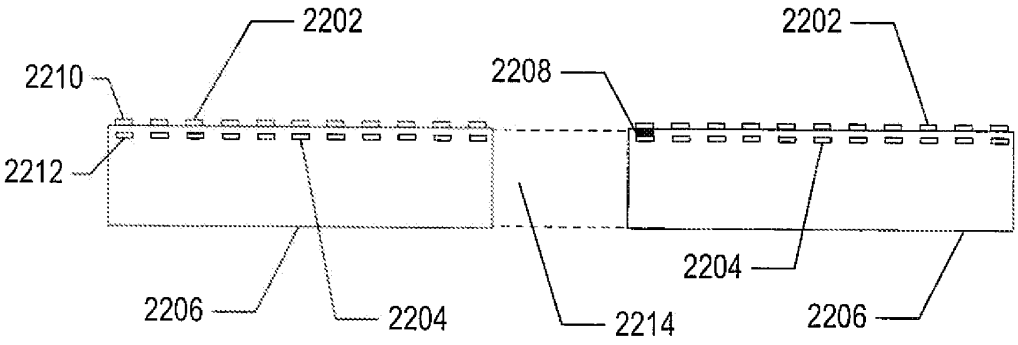


FIG. 22A

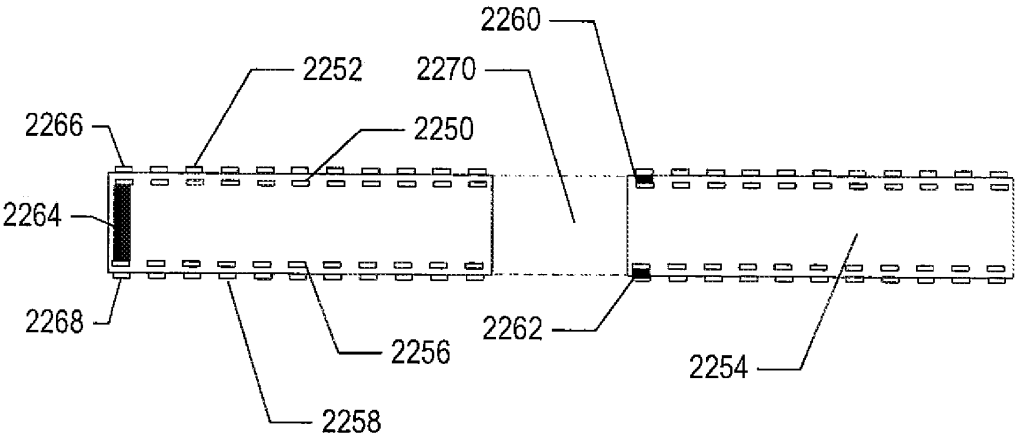


FIG. 22B

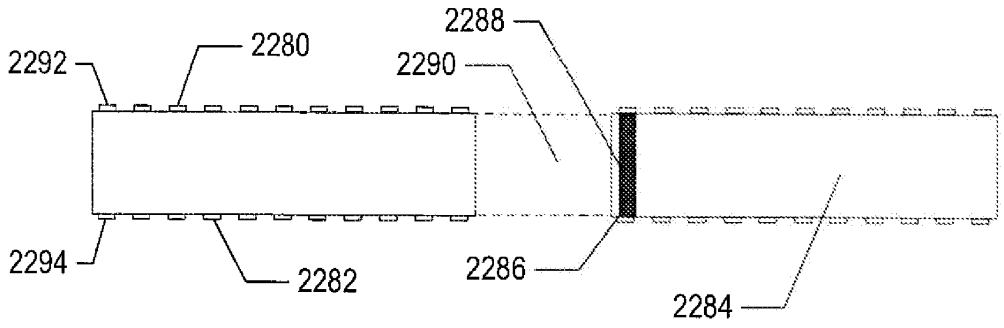


FIG. 22C

22/53

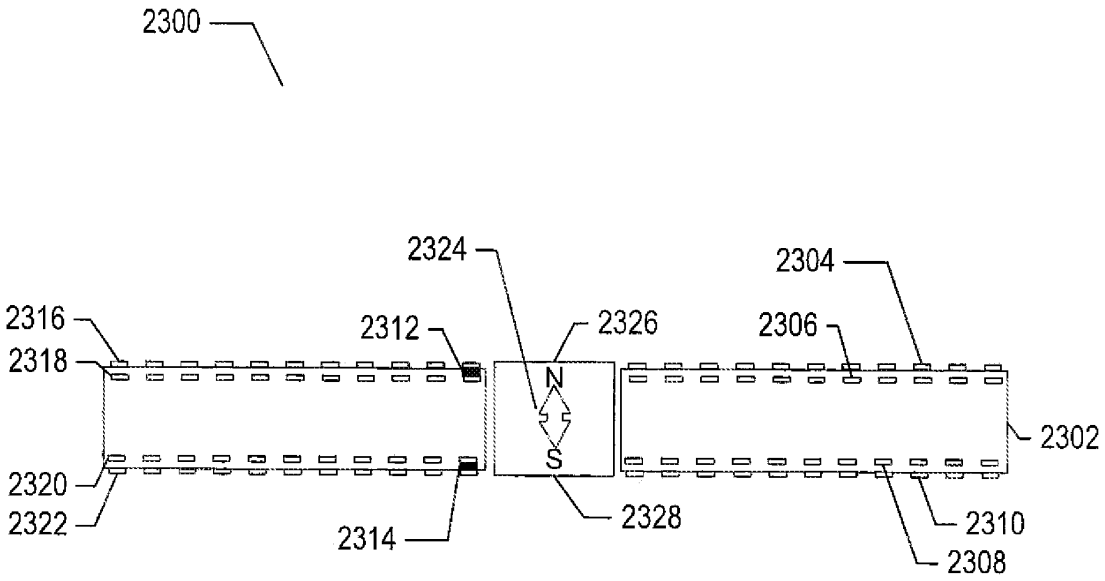

2300
2324
2304
2316
2312
2326
2306
2318
N
2302
S
2320
2322
2314
2328
2310
2308

FIG. 23A

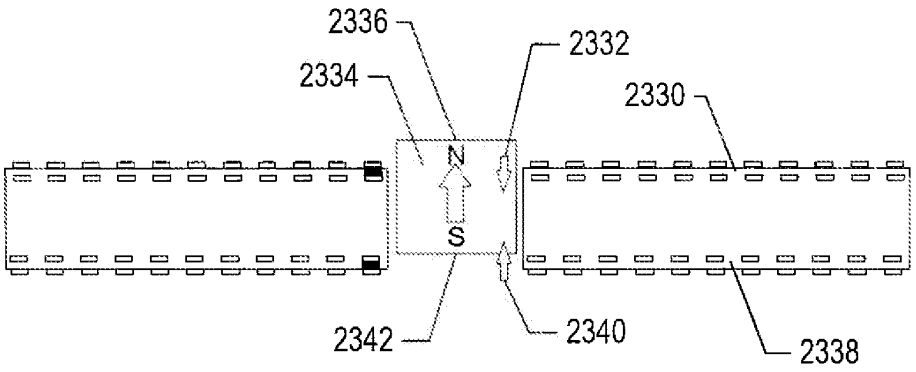


FIG. 23B

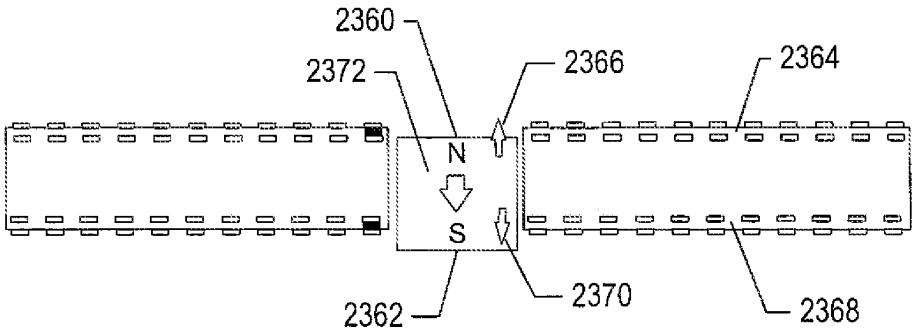


FIG. 23C

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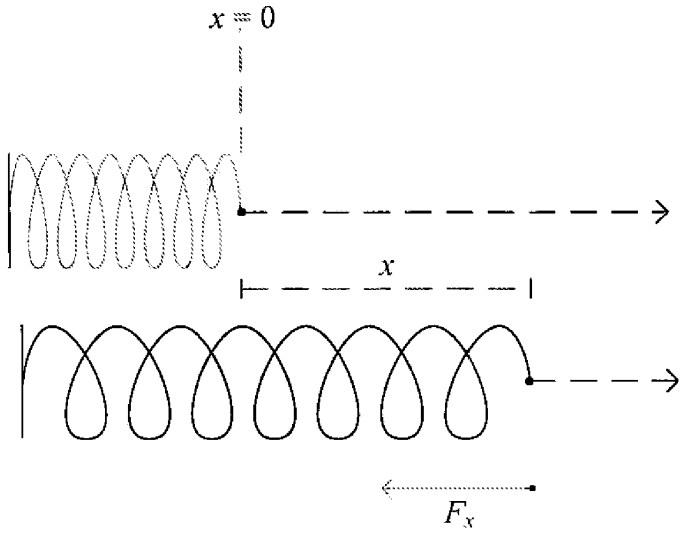


FIG. 24A

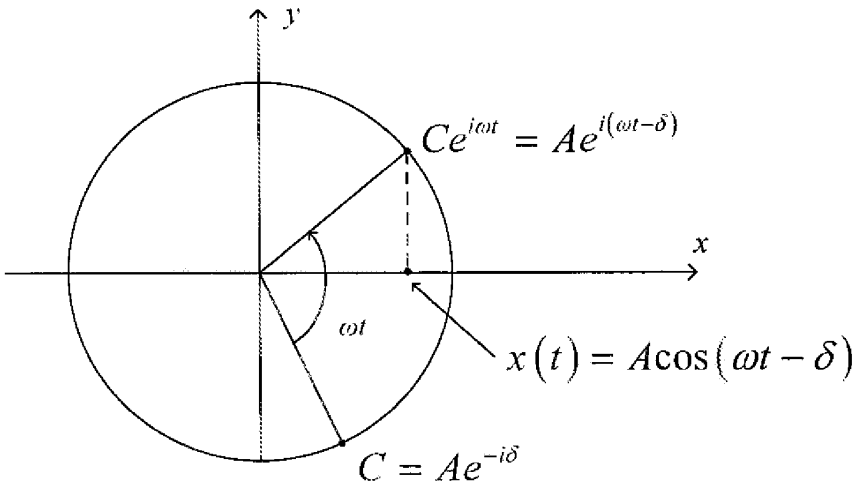


FIG. 24B

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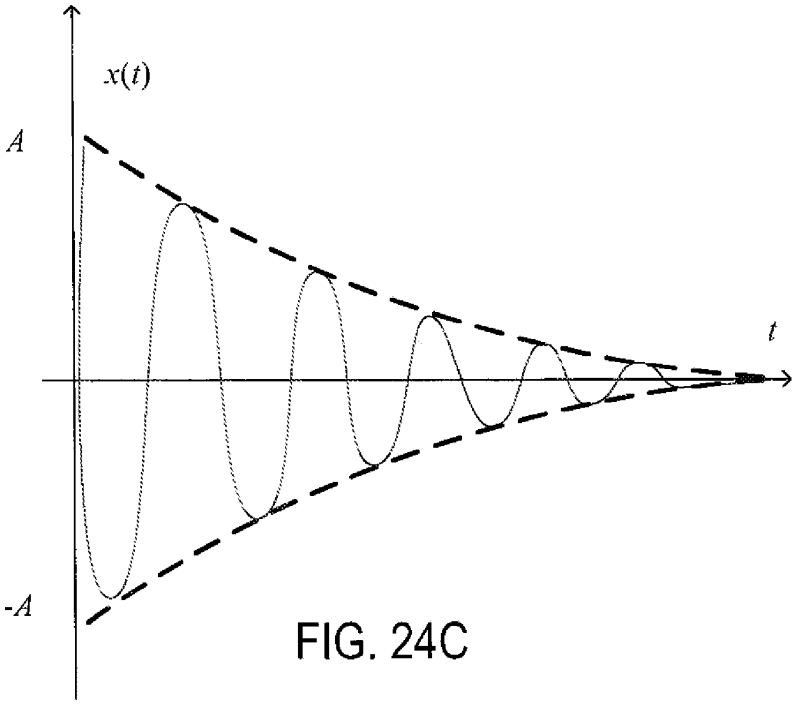


FIG. 24C

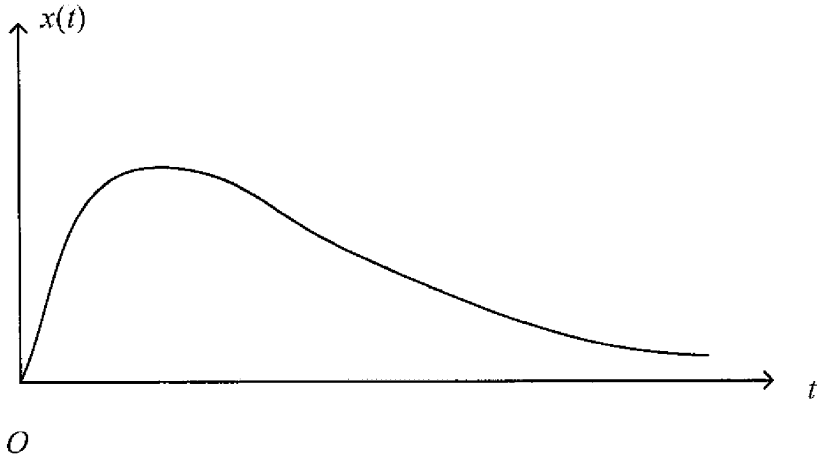


FIG. 24D

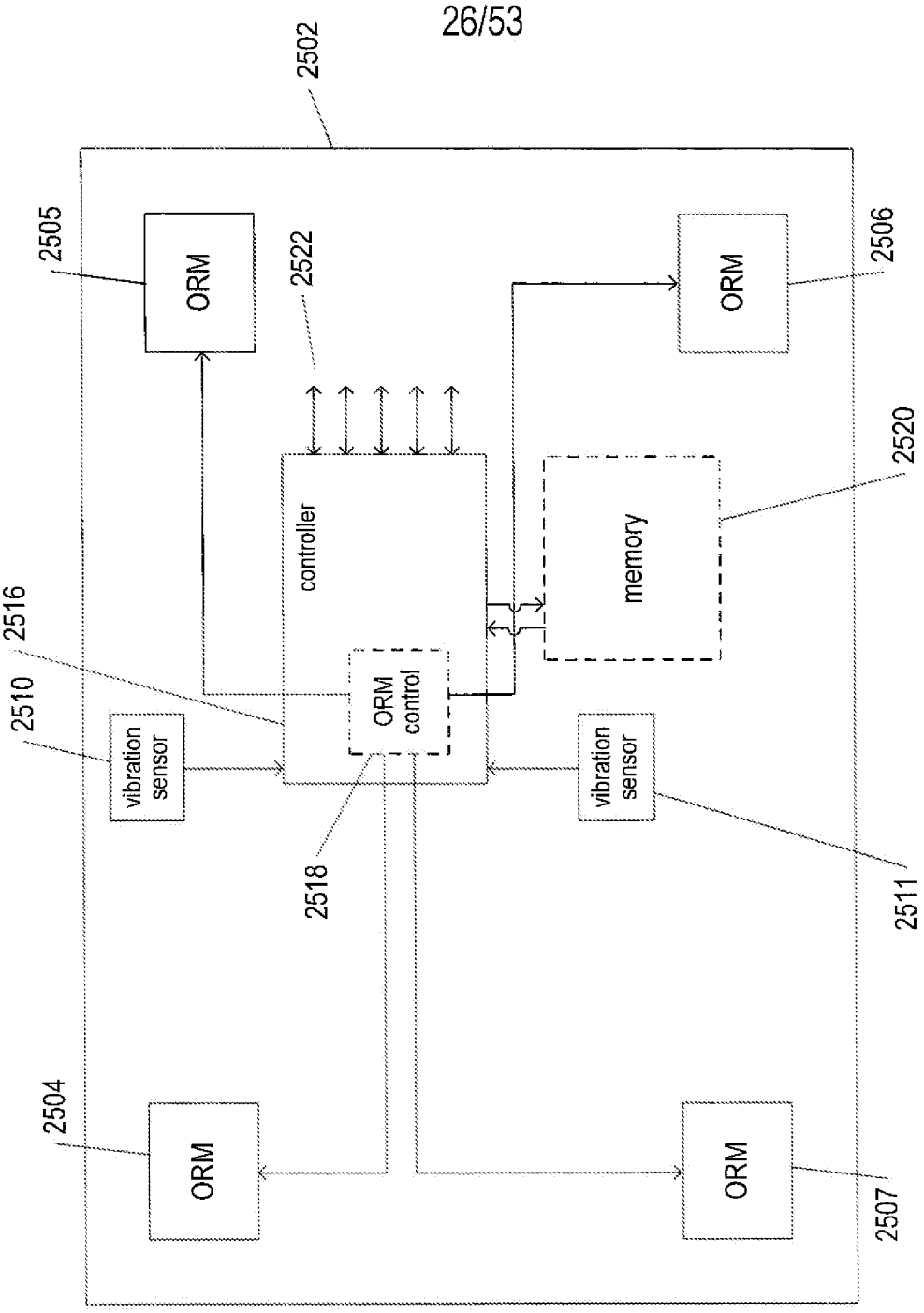

2502
2505
ORM
2522
2506
ORM
2520
memory
controller
2516
2510
ORM control
vibration sensor
vibration sensor
2518
2511
2504
ORM
ORM
2507

FIG. 25

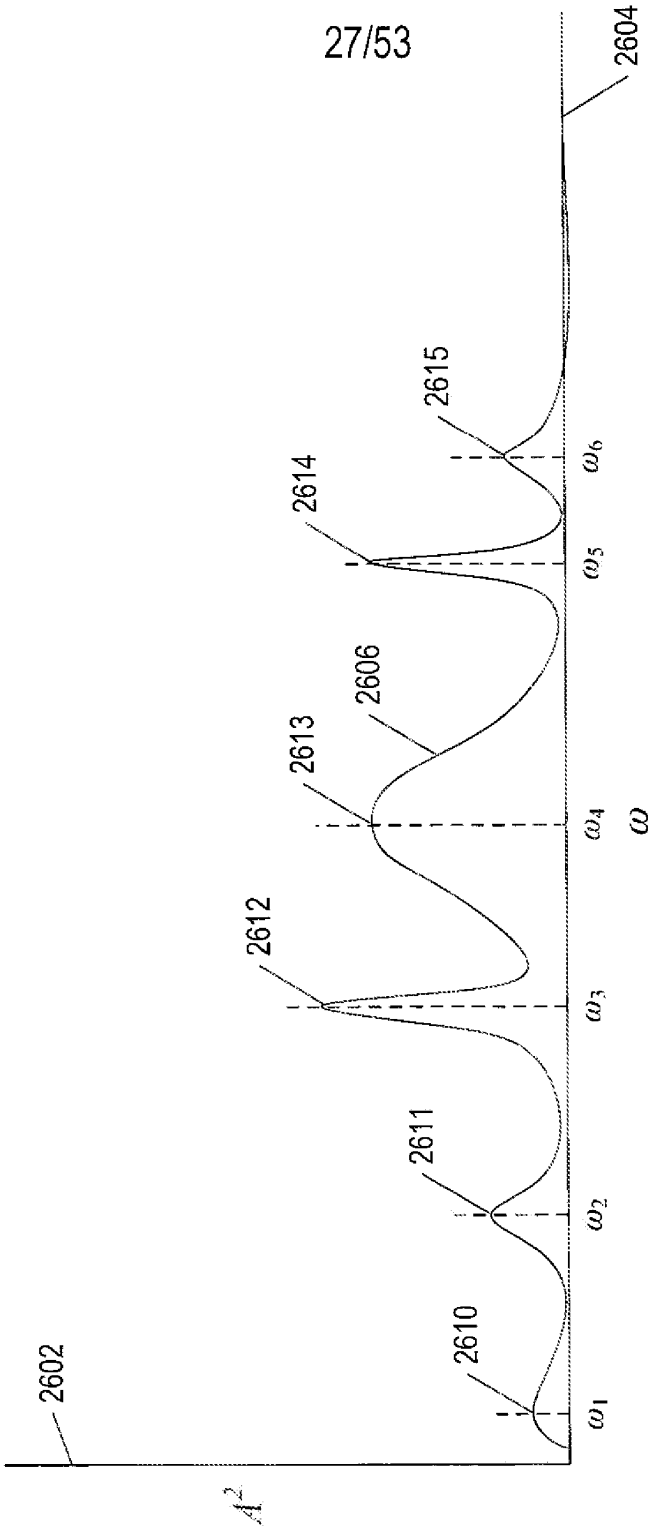

2604
2615
2614
2606
2613
2612
2611
2610
2602
ω_6
ω_5
ω_4
ω_3
ω_2
ω_1
ω
A^2

FIG. 26A

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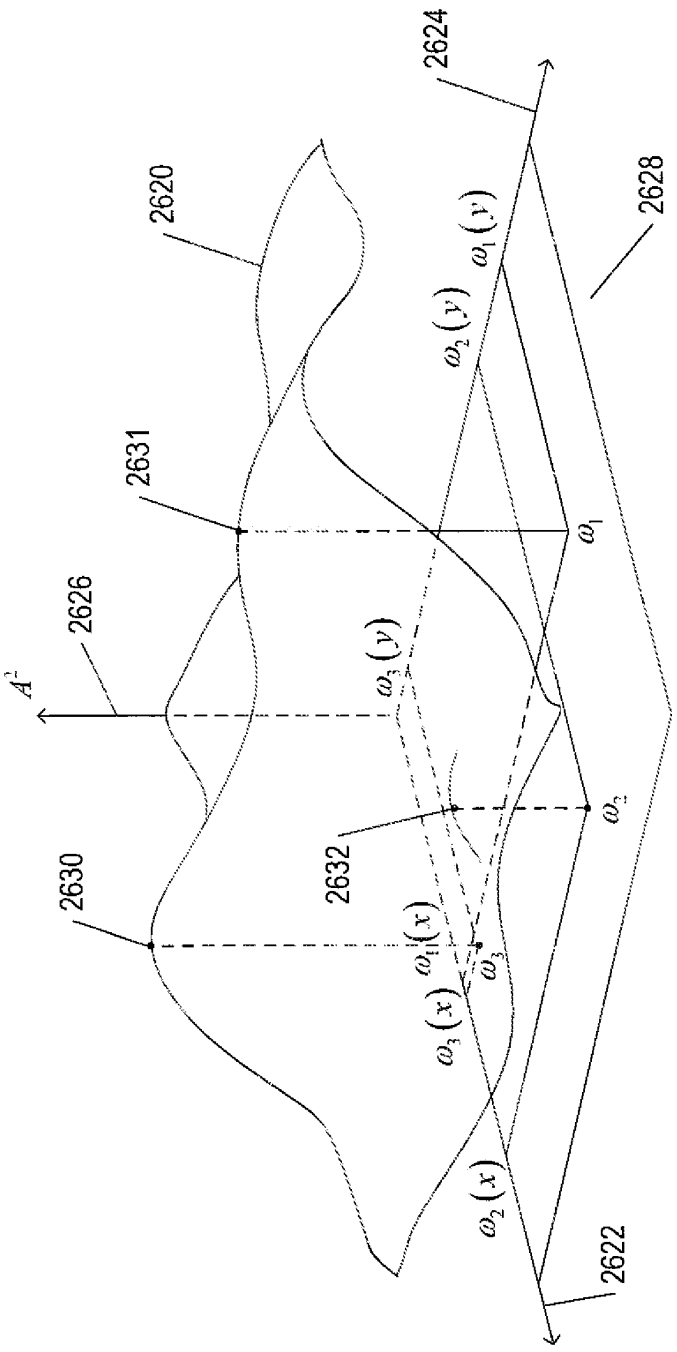

2624
2620
2628
2631
2626
2630
2632
2622
A^2
ω_1
ω_2
ω_3
$\omega_1(y)$
$\omega_2(y)$
$\omega_3(y)$
$\omega_1(x)$
$\omega_2(x)$
$\omega_3(x)$
2634
$\omega_1(x,y)$
$\omega_2(x,y)$
$\omega_3(x,y)$

FIG. 26B

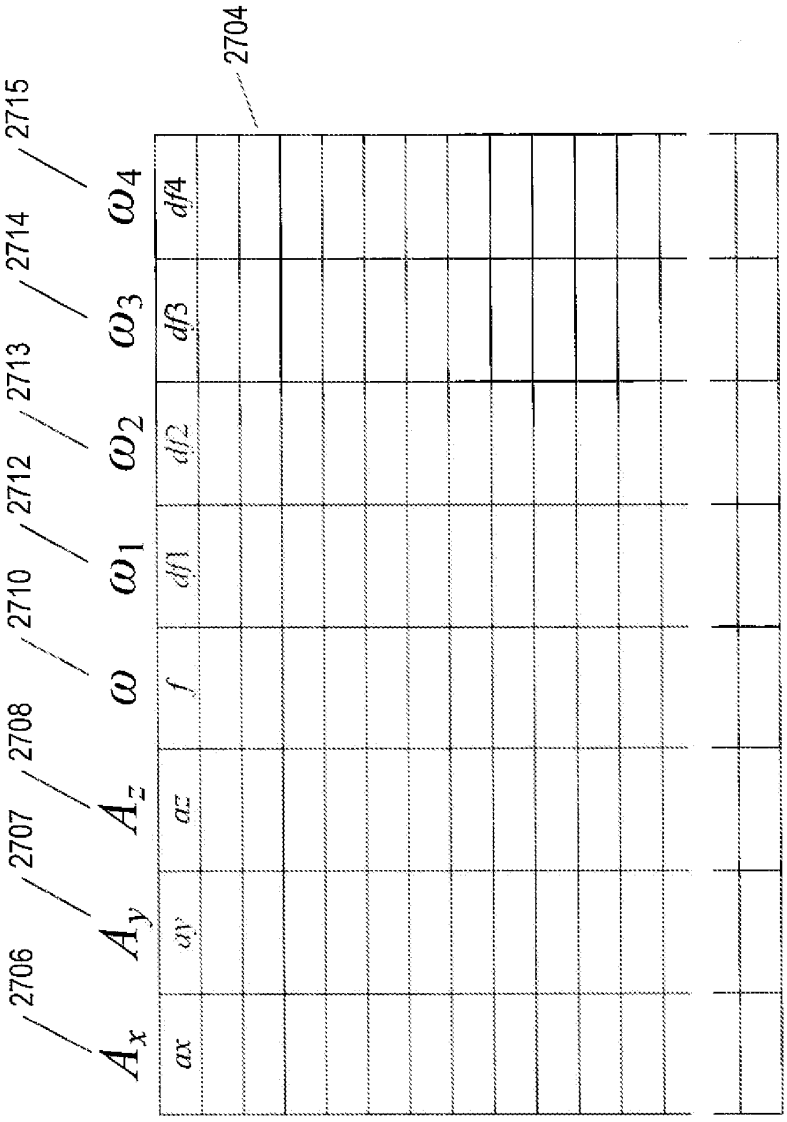

2704
2715
2714
2713
2712
2710
2708
2707
2706
2702
ω_4
ω_3
ω_2
ω_1
ω
A_z
A_y
A_x
df4
df3
df2
df1
f
az
ay
ax

FIG. 27

FIG. 28A

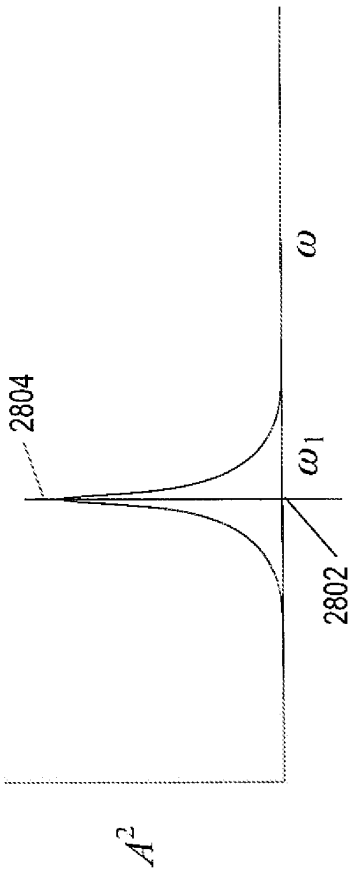


FIG. 28B

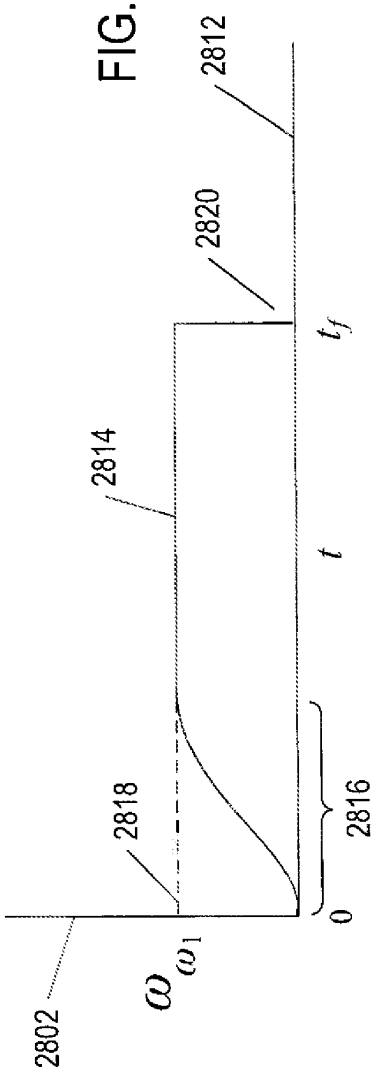
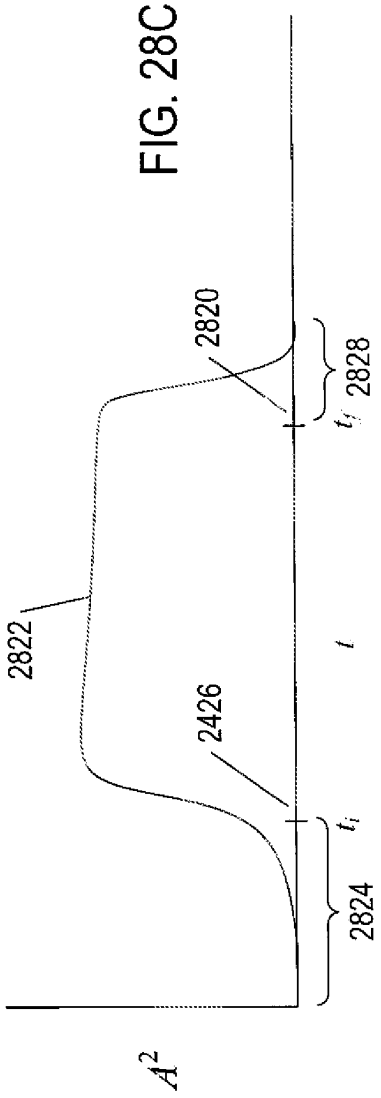


FIG. 28C



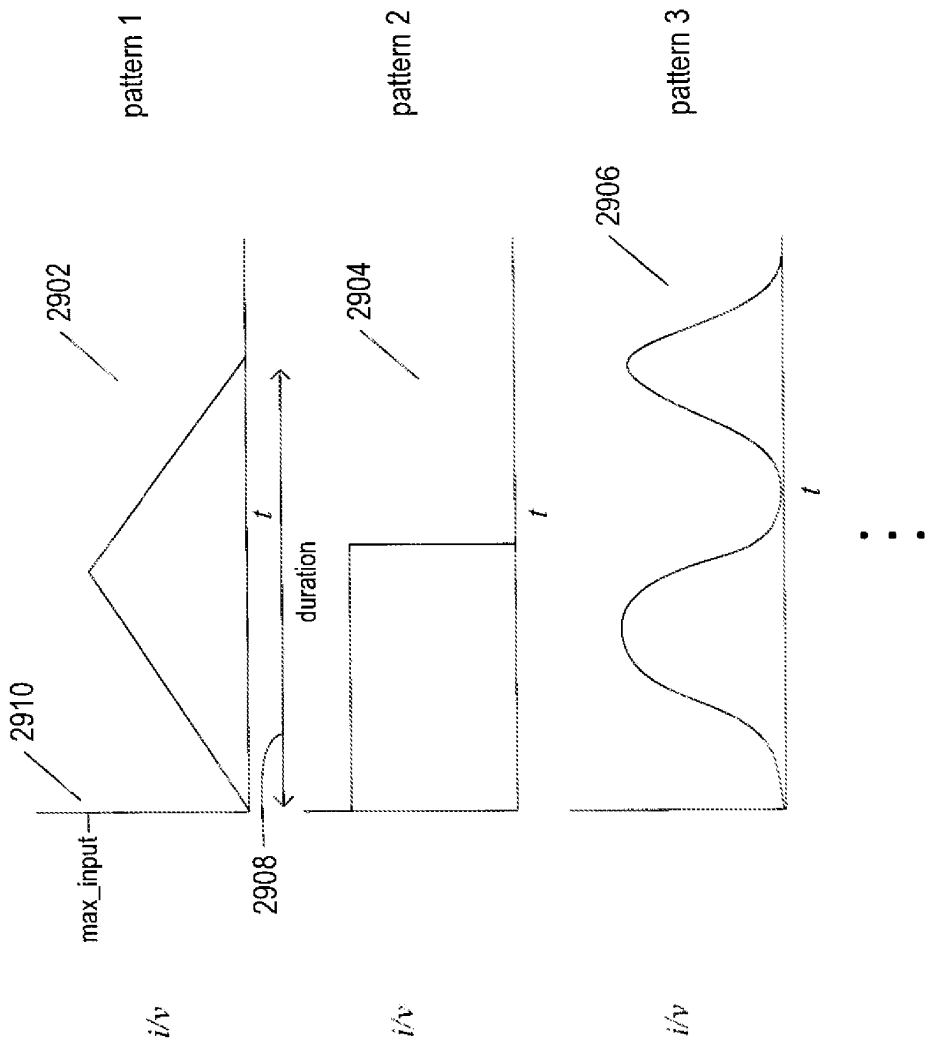

pattern 1
pattern 2
pattern 3
2902
2904
2906
2910
2908
max_input
duration
t
t
t
i/v
i/v
i/v

FIG. 29

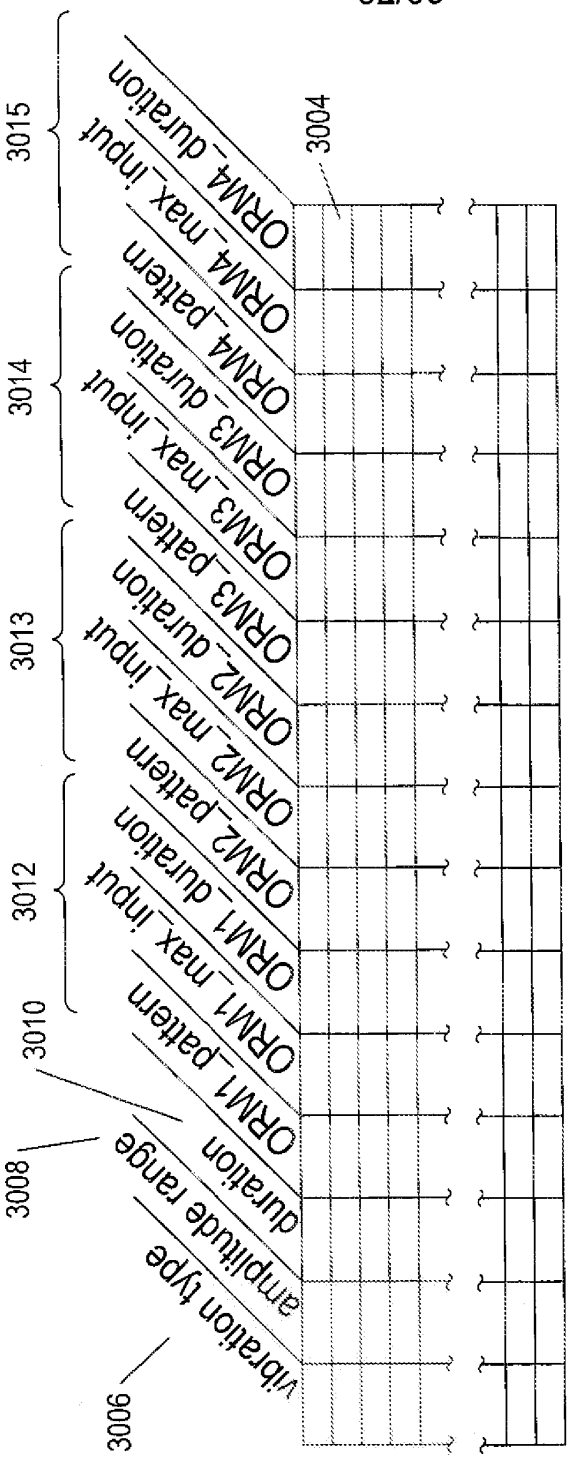

3015
3014
3013
3012
3010
3008
3006
3004
3002
ORM4_duration
ORM4_max_input
ORM4_pattern
ORM3_duration
ORM3_max_input
ORM3_pattern
ORM2_duration
ORM2_max_input
ORM2_pattern
ORM1_duration
ORM1_max_input
ORM1_pattern
duration
amplitude range
vibration type

FIG. 30

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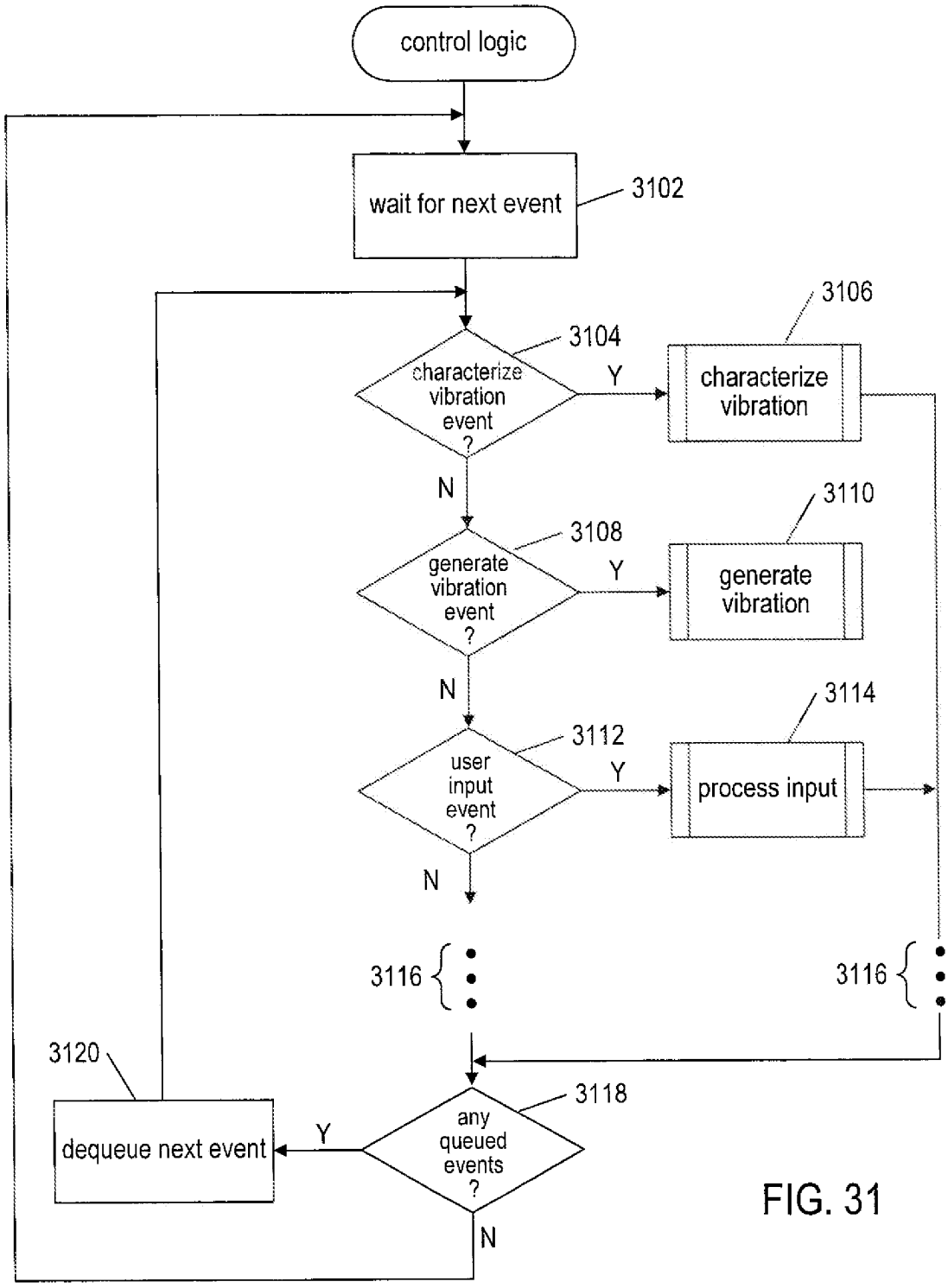

control logic
wait for next event
3102
3104
characterize vibration event ?
Y
3106
characterize vibration
N
3108
generate vibration event ?
Y
3110
generate vibration
N
3112
user input event ?
Y
3114
process input
N
3116
3116
3118
any queued events ?
Y
dequeue next event
3120
N

FIG. 31

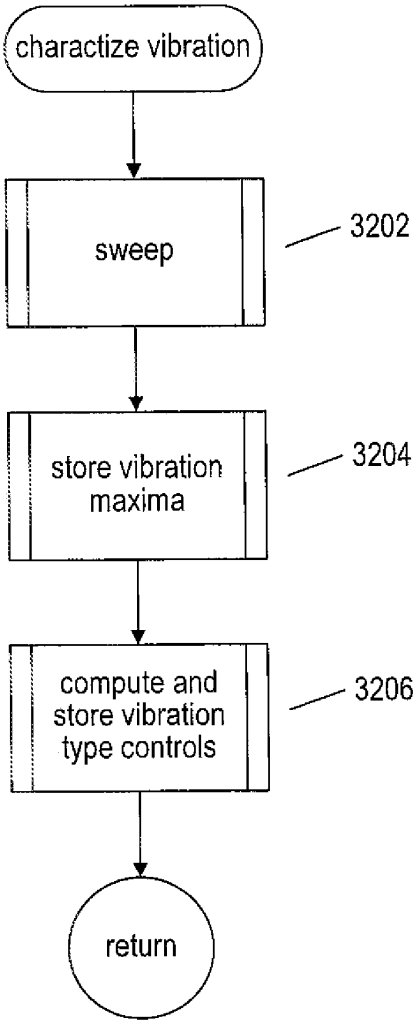

charactize vibration
sweep
3202
store vibration maxima
3204
compute and store vibration type controls
3206
return

FIG. 32

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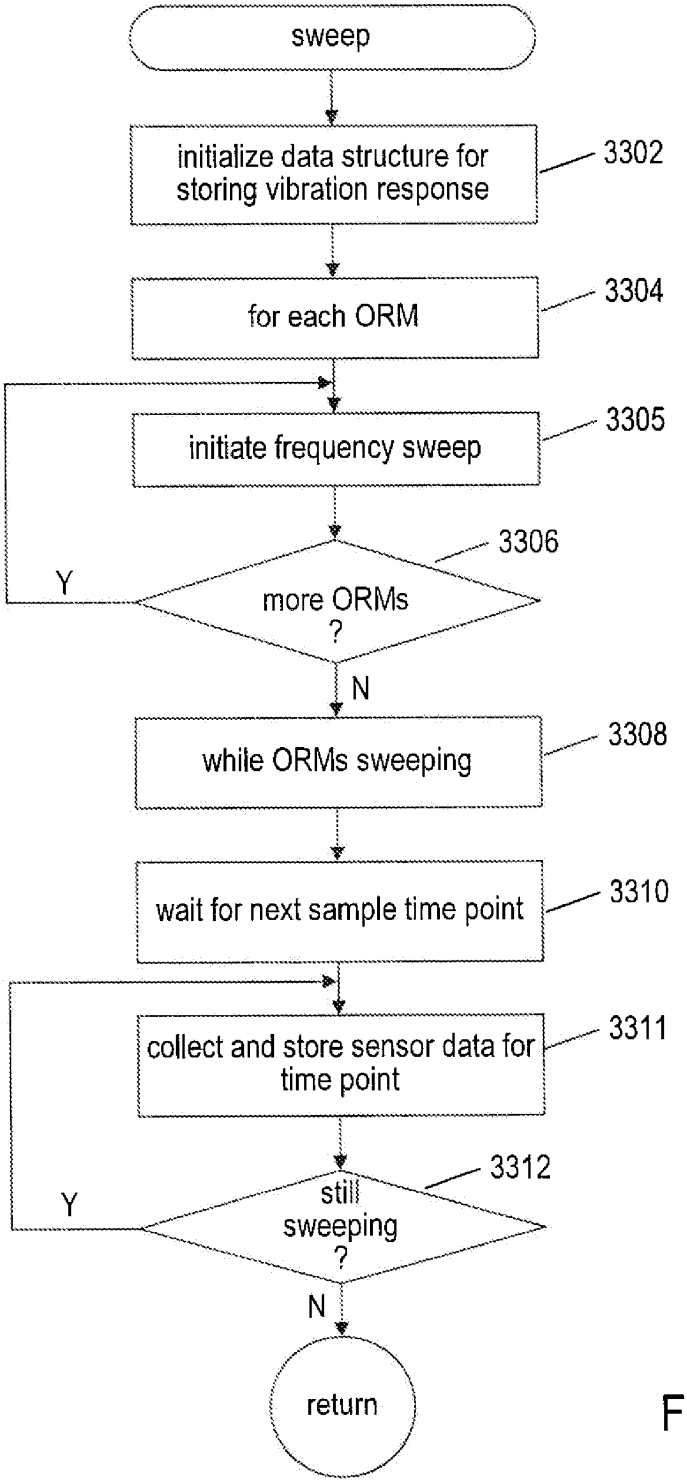

sweep
initialize data structure for storing vibration response
3302
for each ORM
3304
initiate frequency sweep
3305
more ORMs ?
3306
Y
N
while ORMs sweeping
3308
wait for next sample time point
3310
collect and store sensor data for time point
3311
still sweeping ?
3312
Y
N
return

FIG. 33

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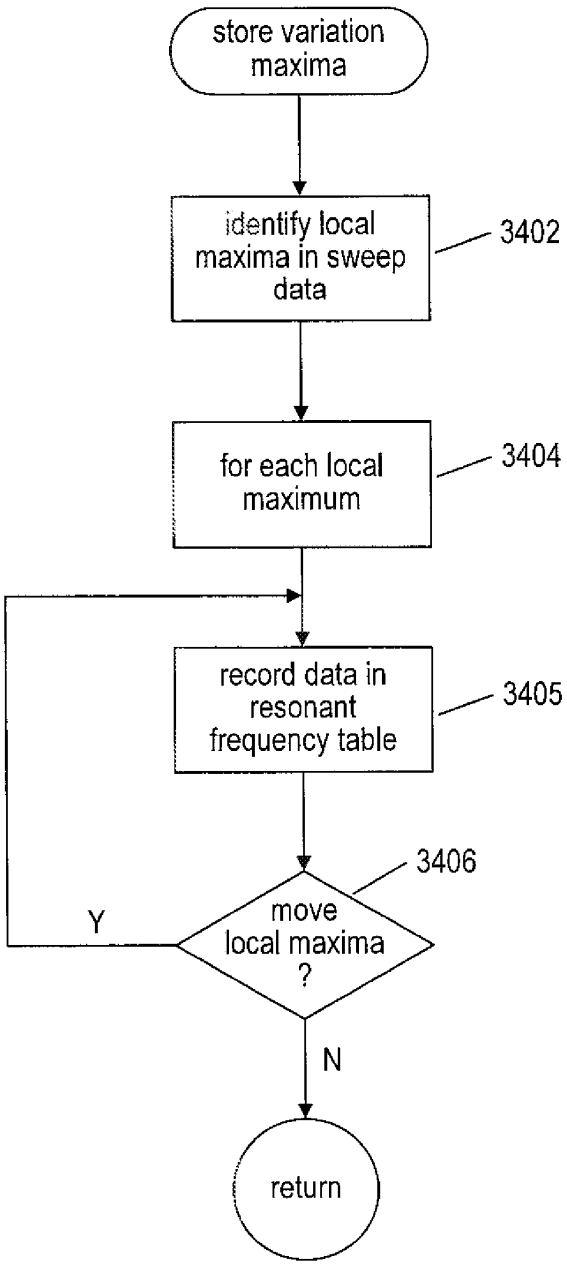

store variation maxima
identify local maxima in sweep data
3402
for each local maximum
3404
record data in resonant frequency table
3405
move local maxima ?
3406
Y
N
return

FIG. 34

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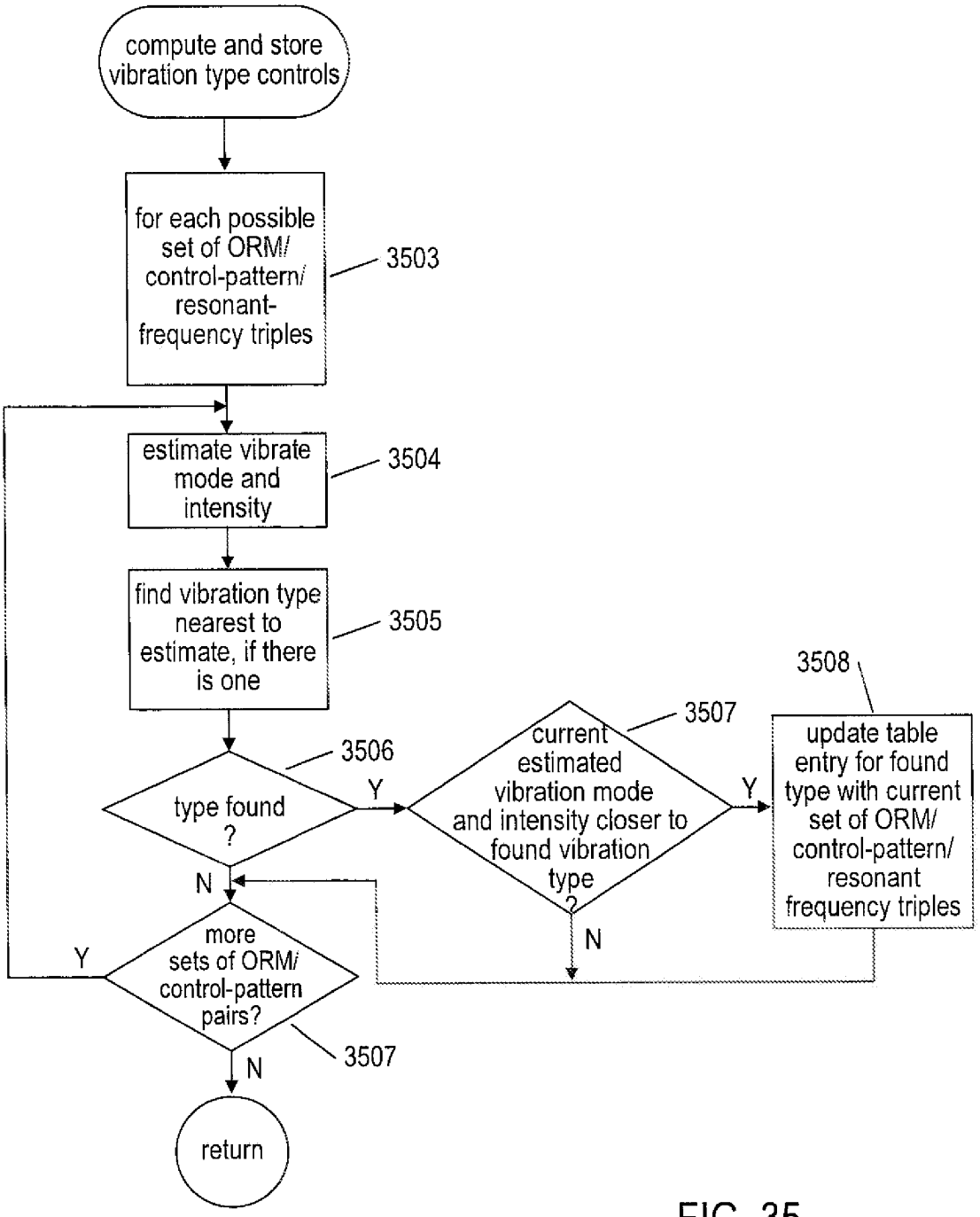

compute and store vibration type controls
for each possible set of ORM/ control-pattern/ resonant-frequency triples
3503
estimate vibrate mode and intensity
3504
find vibration type nearest to estimate, if there is one
3505
type found ?
3506
Y
N
current estimated vibration mode and intensity closer to found vibration type ?
3507
Y
N
update table entry for found type with current set of ORM/ control-pattern/ resonant frequency triples
3508
more sets of ORM/ control-pattern pairs?
3507
Y
N
return

FIG. 35

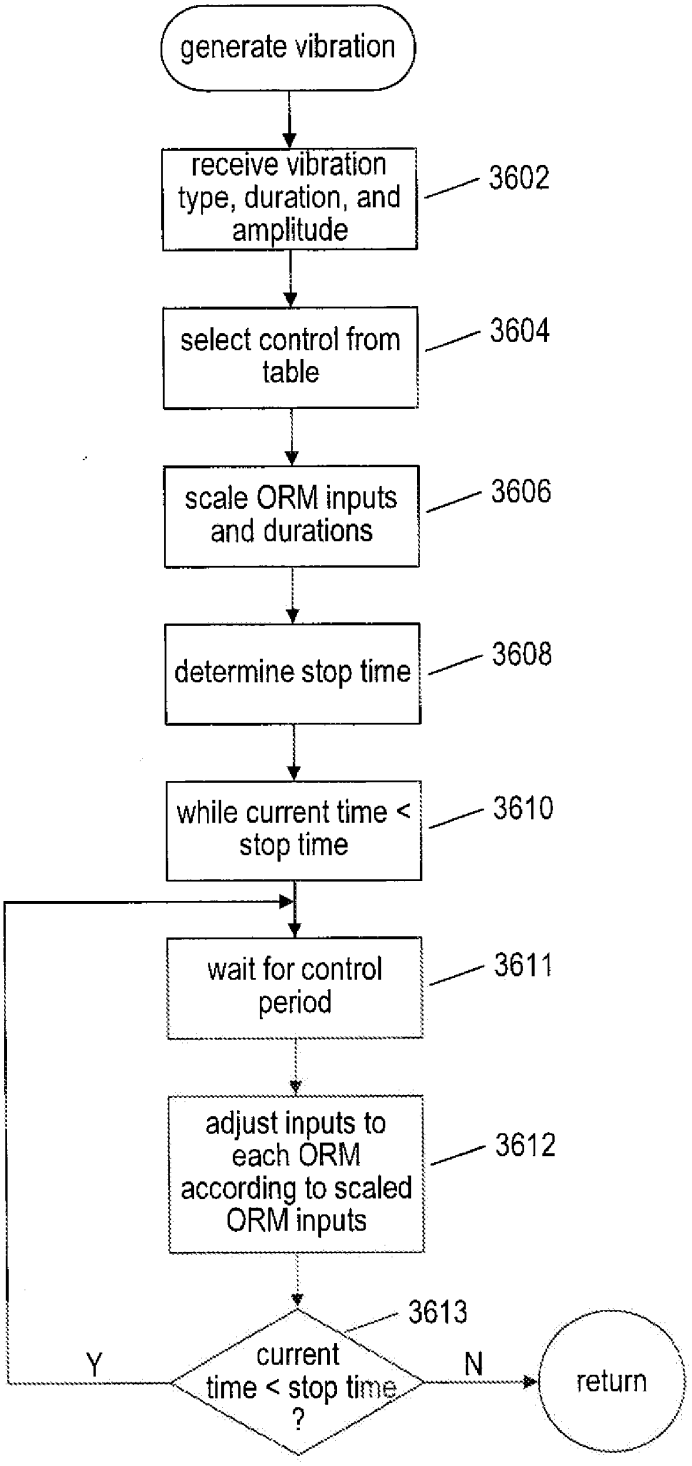

generate vibration
receive vibration type, duration, and amplitude
3602
select control from table
3604
scale ORM inputs and durations
3606
determine stop time
3608
while current time < stop time
3610
wait for control period
3611
adjust inputs to each ORM according to scaled ORM inputs
3612
3613
current time < stop time ?
Y
N
return

FIG. 36

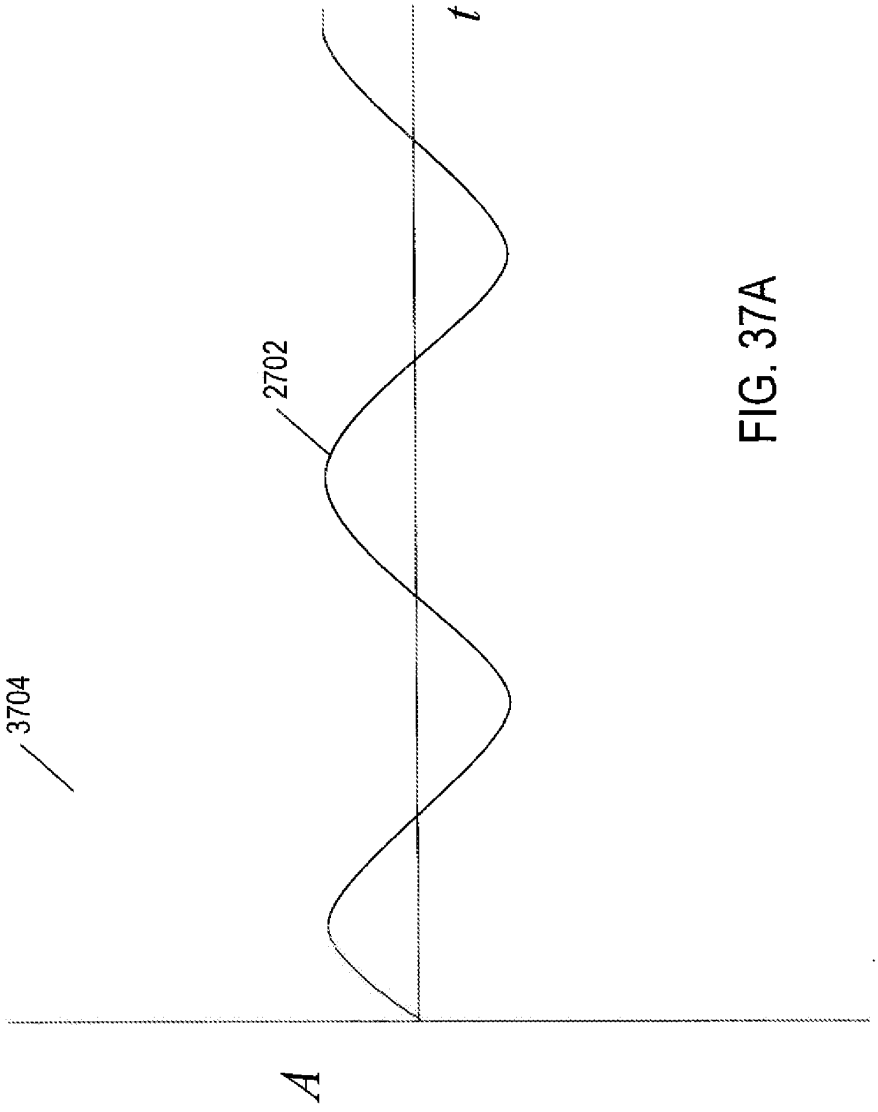


FIG. 37A

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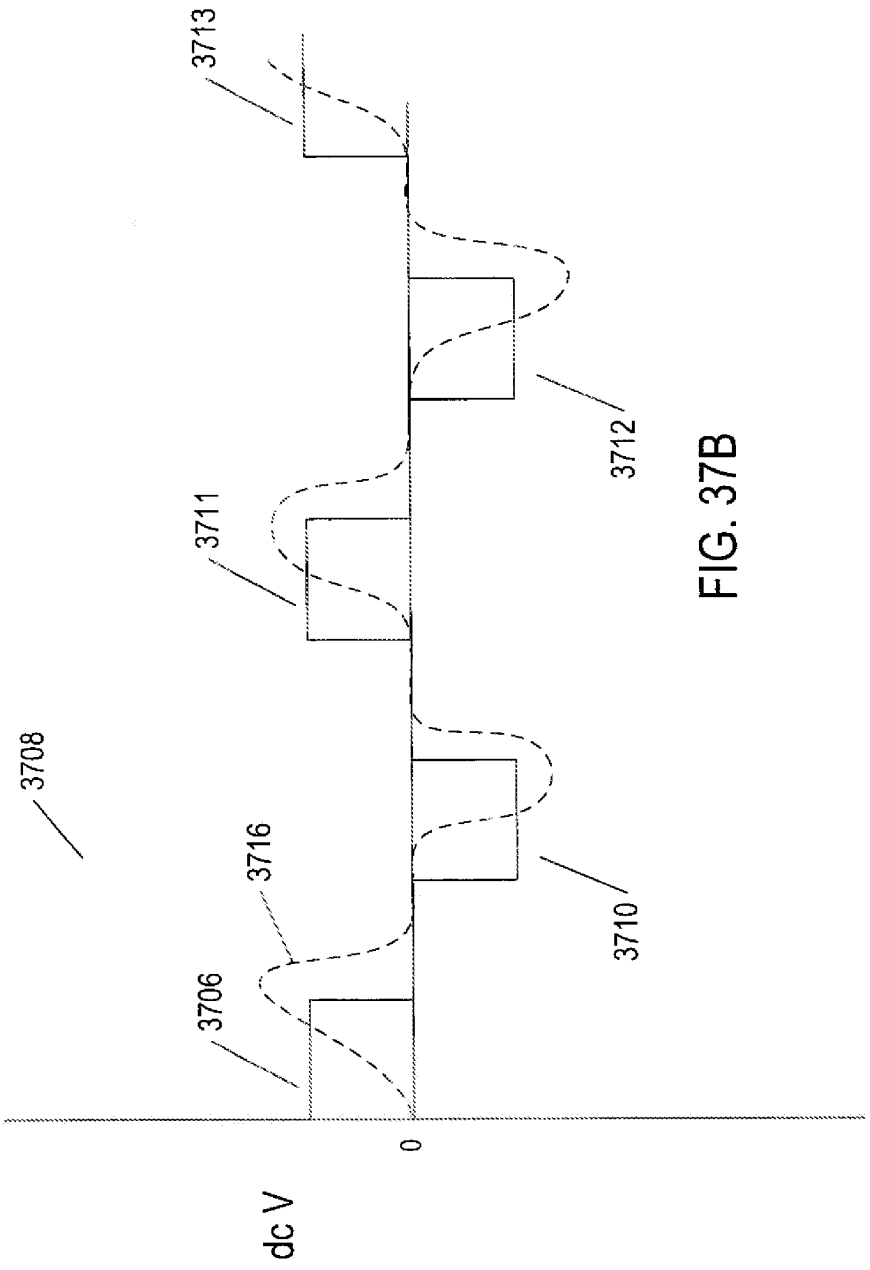


FIG. 37B

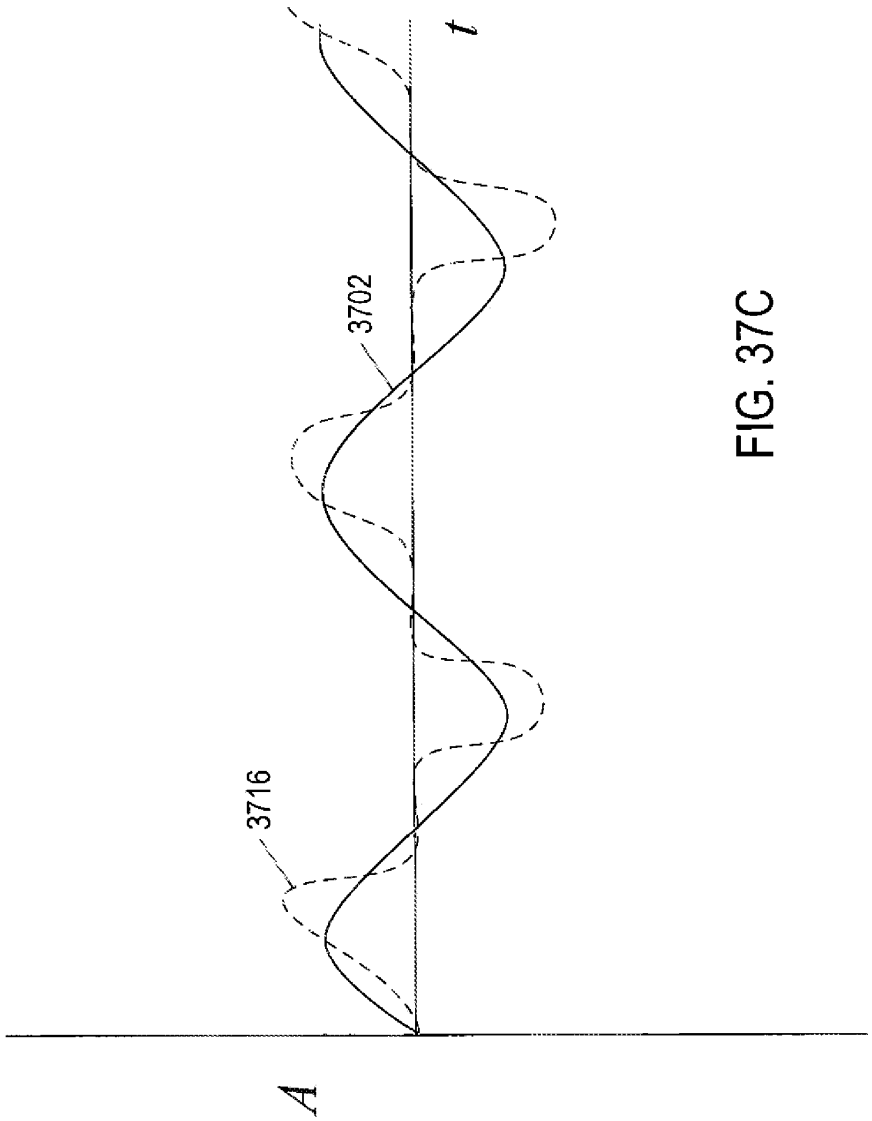


FIG. 37C

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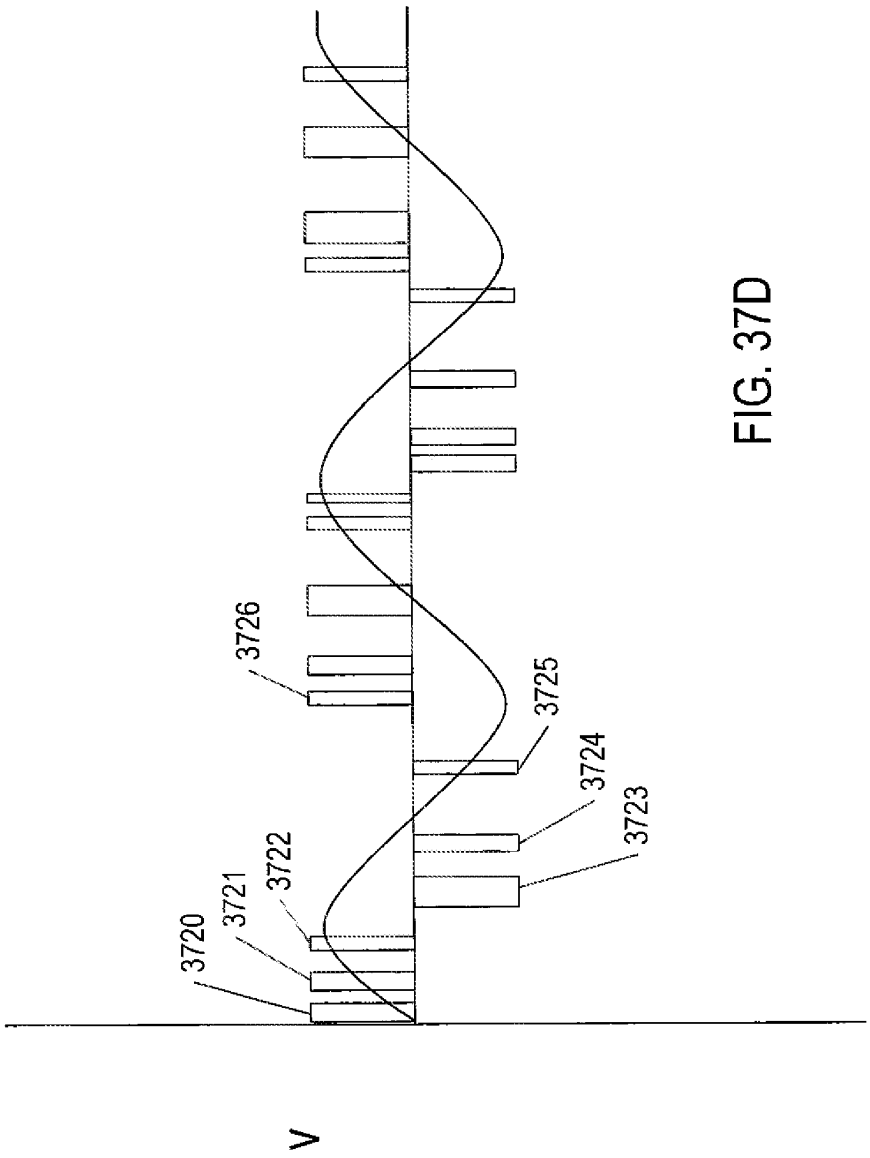


FIG. 37D

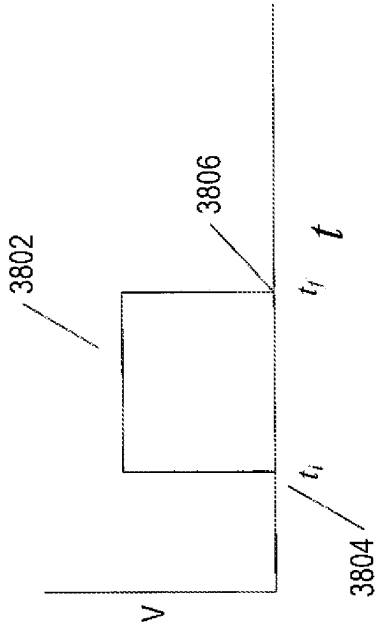


FIG. 38A

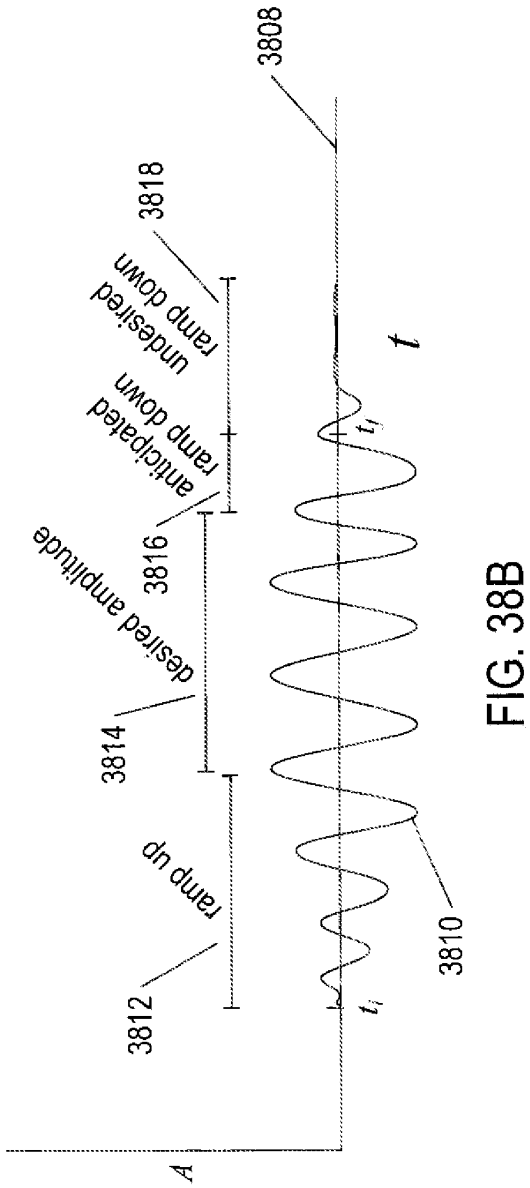
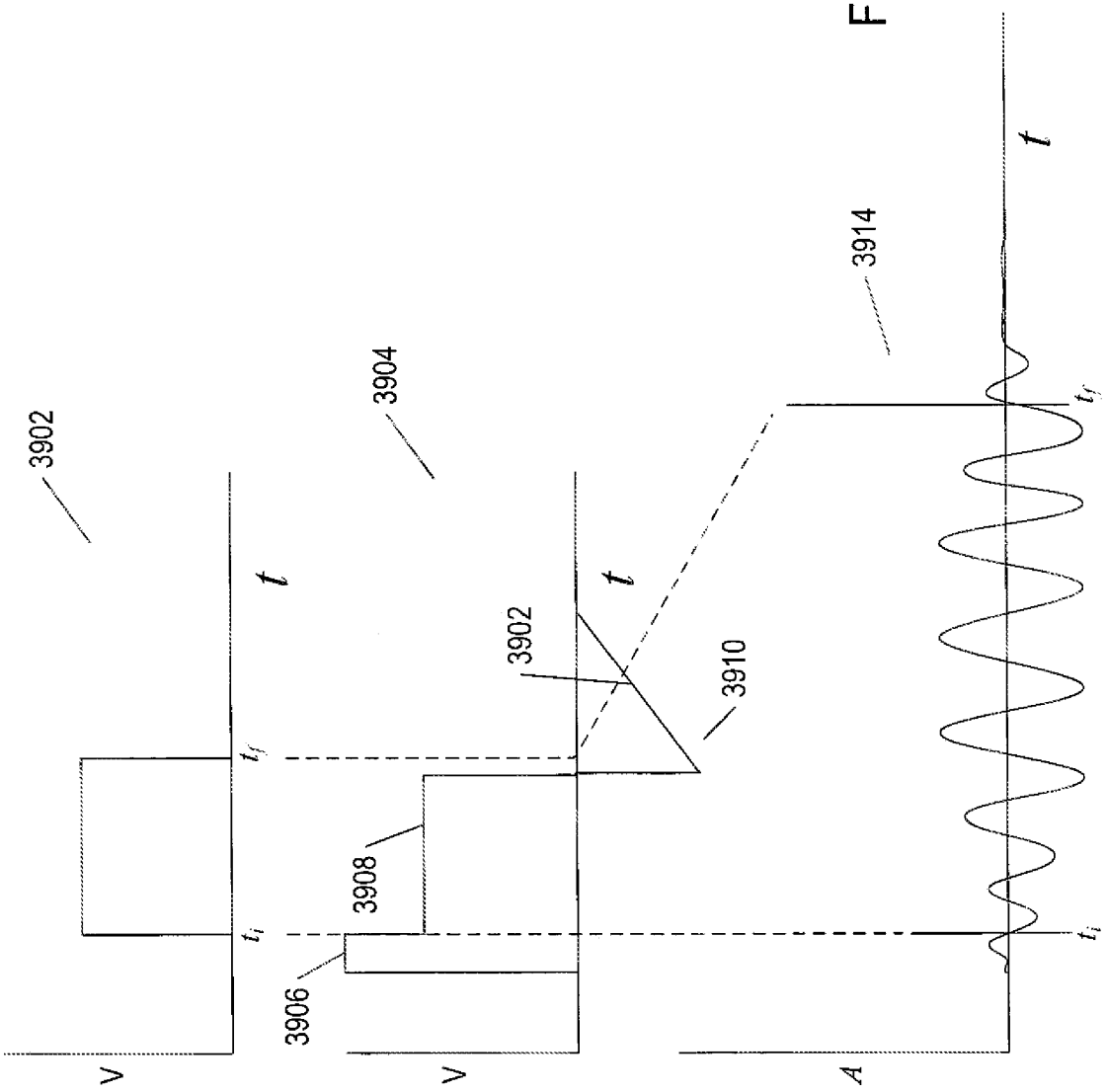


FIG. 38B

FIG. 39



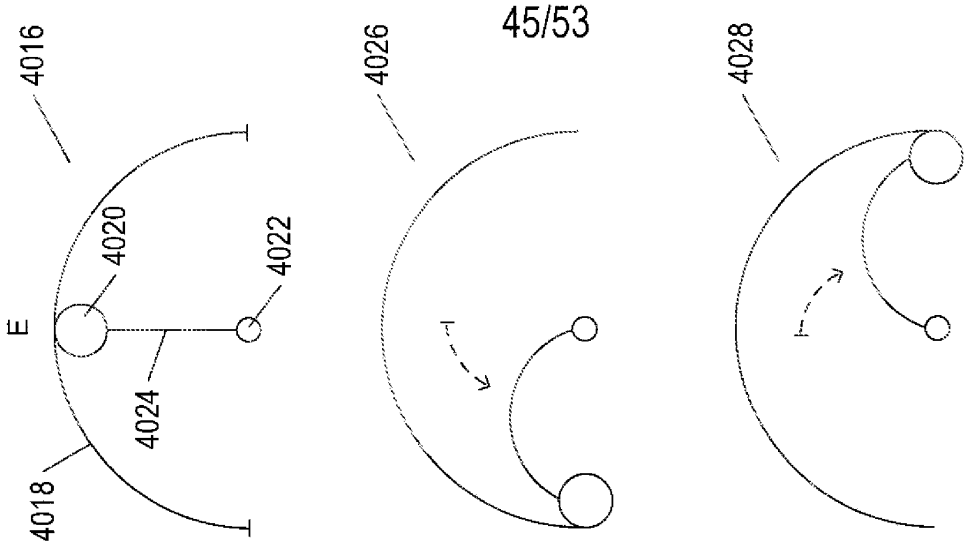


FIG. 40B

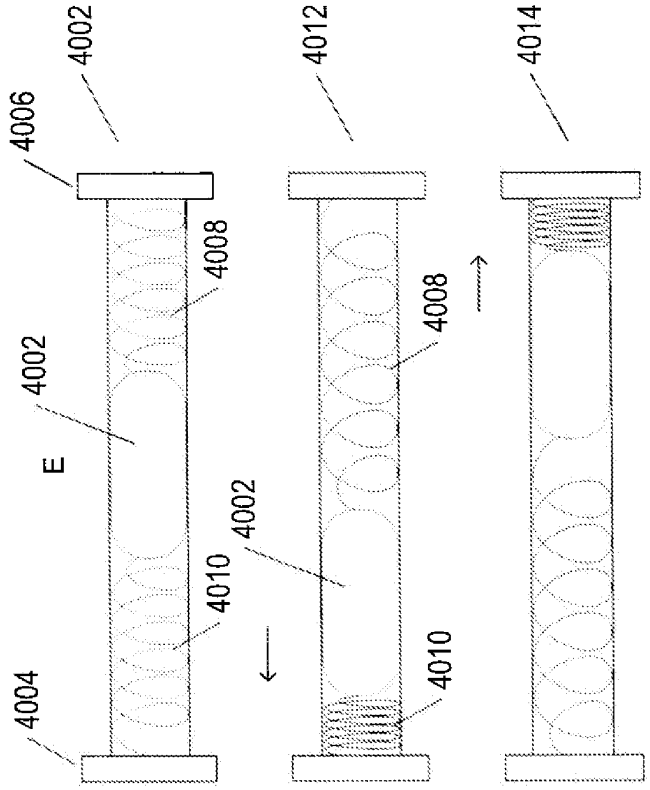


FIG. 40A

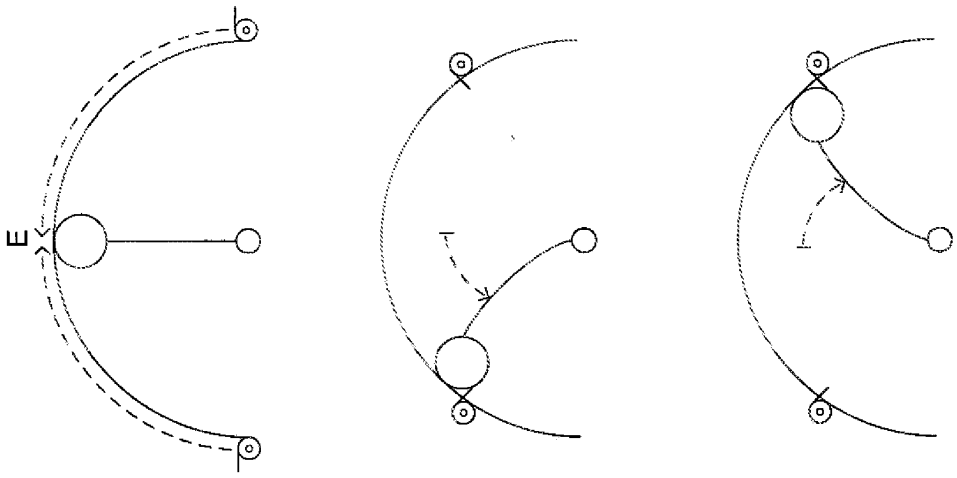


FIG. 40D

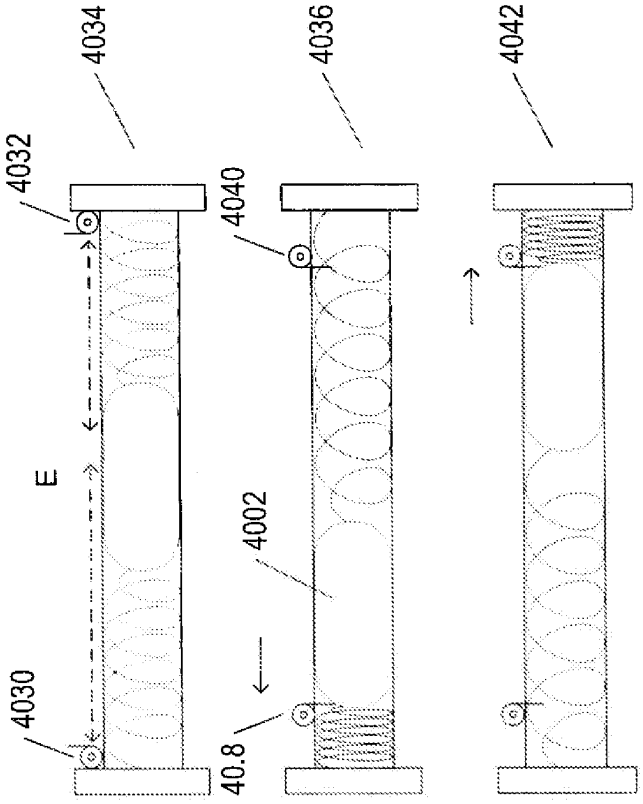


FIG. 40C

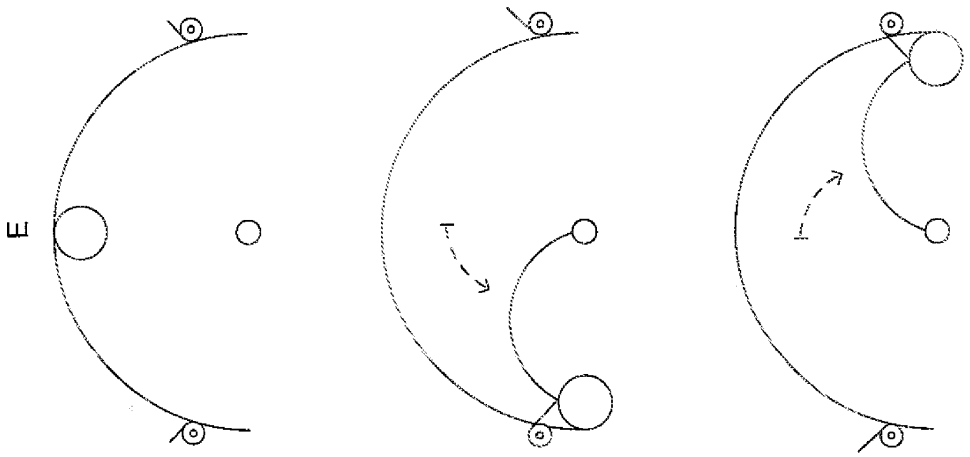


FIG. 40F

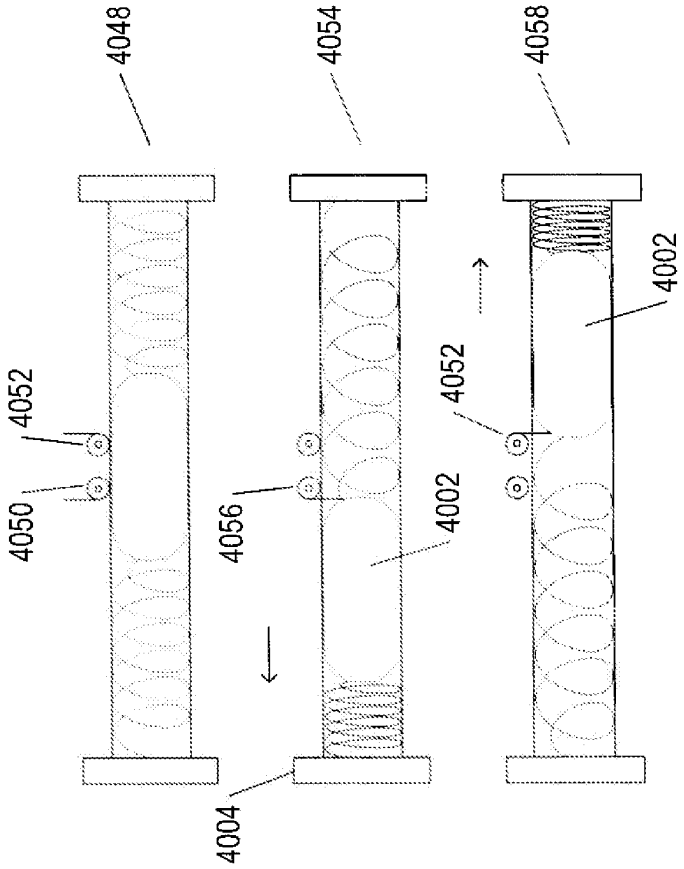


FIG. 40E

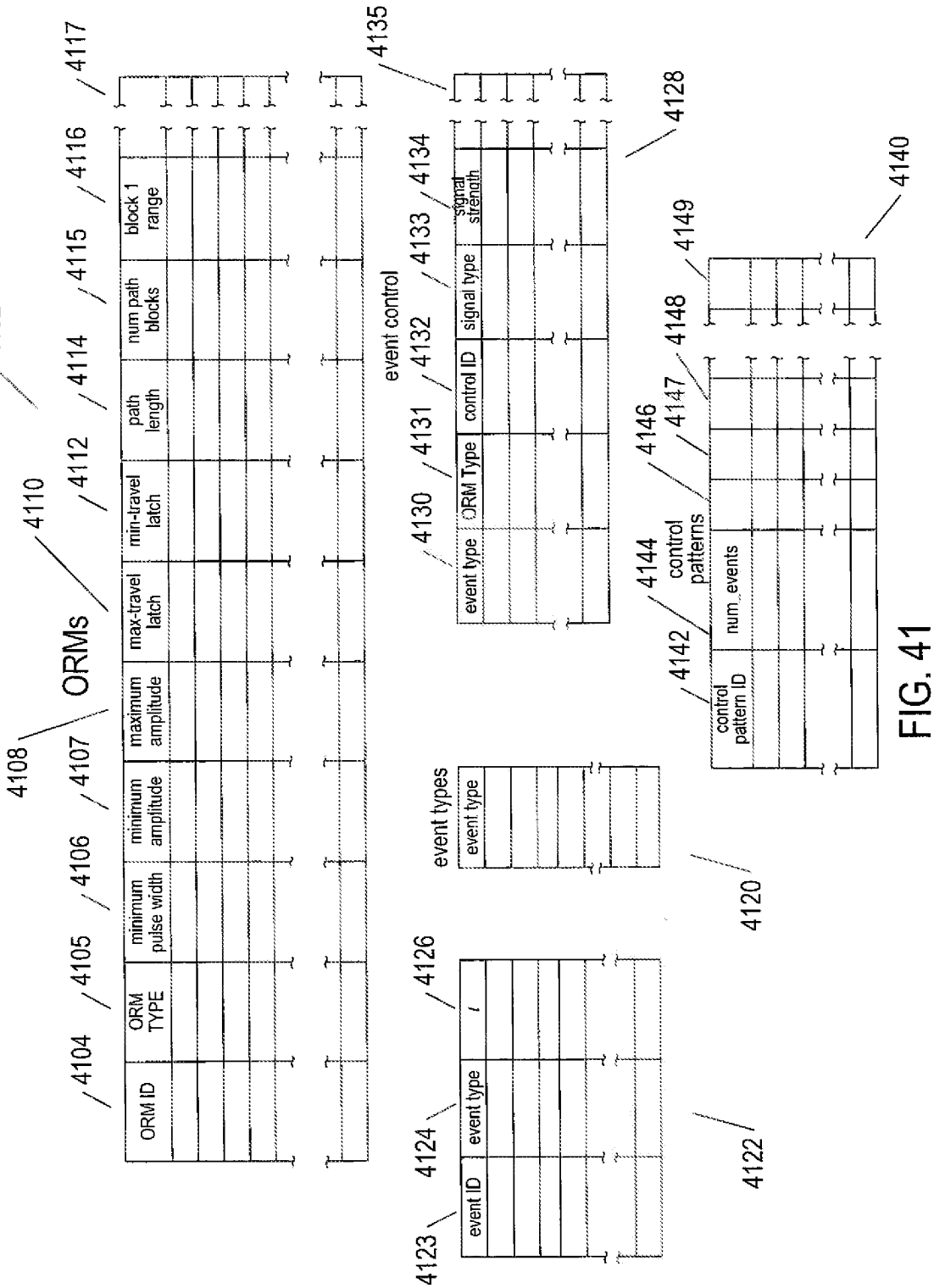

4102
4110
ORMs
4108
4107
4106
4105
4104
4112
4114
4115
4116
4117
4135
ORM ID
ORM TYPE
minimum pulse width
minimum amplitude
maximum amplitude
max-travel latch
min-travel latch
path length
num path blocks
block 1 range
event control
4130
4131
4132
4133
4134
4128
event type
ORM Type
control ID
signal type
signal strength
4140
4149
4148
4147
4146
4144
control patterns
num_events
4142
control pattern ID
event types
event type
4120
4126
4124
4123
4122
event ID
event type
t

FIG. 41

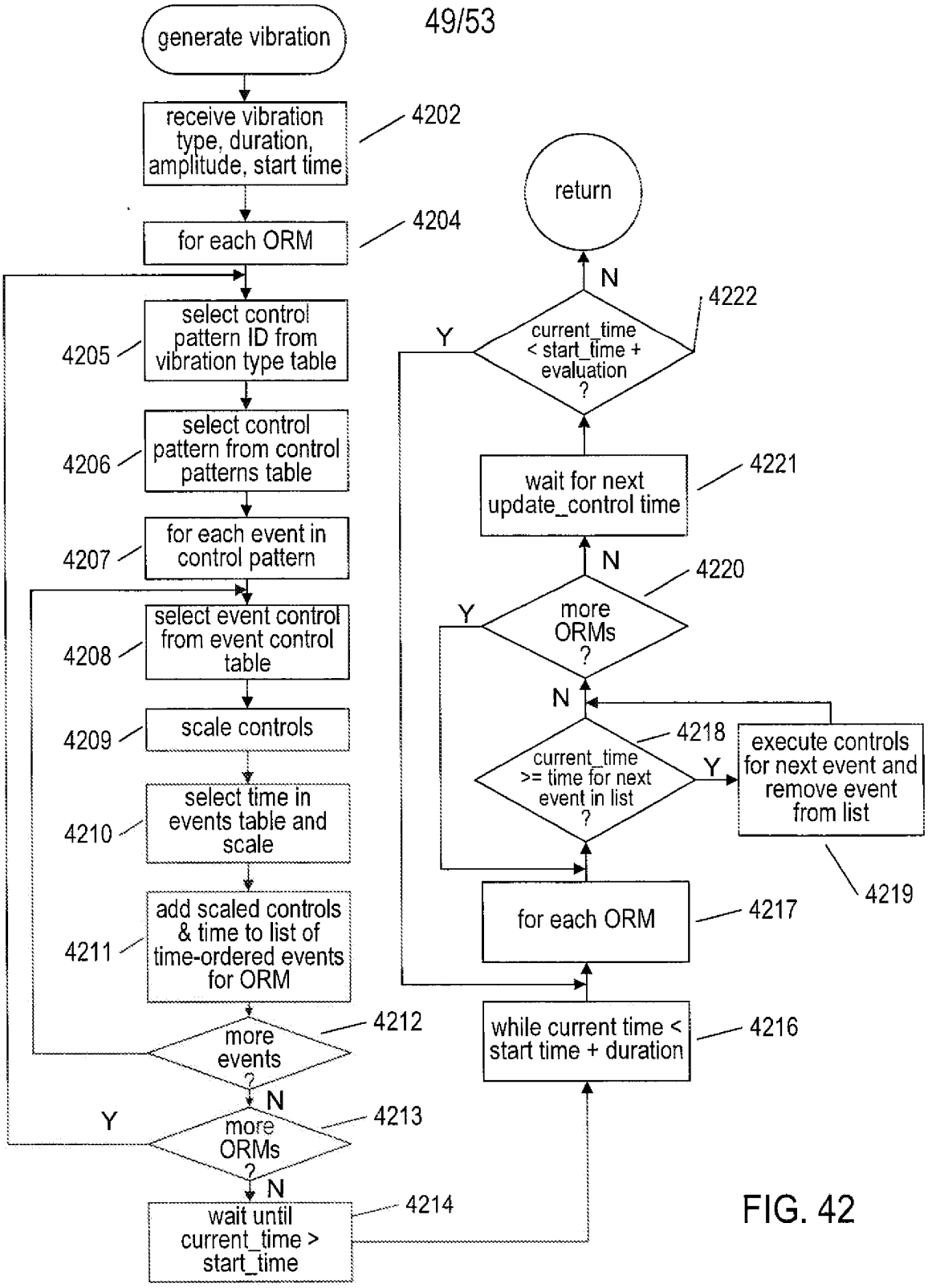

generate vibration
receive vibration type, duration, amplitude, start time
4202
for each ORM
4204
select control pattern ID from vibration type table
4205
select control pattern from control patterns table
4206
for each event in control pattern
4207
select event control from event control table
4208
scale controls
4209
select time in events table and scale
4210
add scaled controls & time to list of time-ordered events for ORM
4211
more events ?
4212
more ORMs ?
4213
wait until current_time > start_time
4214
while current time < start time + duration
4216
for each ORM
4217
current_time >= time for next event in list ?
4218
execute controls for next event and remove event from list
4219
more ORMs ?
4220
wait for next update_control time
4221
current_time < start_time + evaluation ?
4222
return
Y
N

FIG. 42

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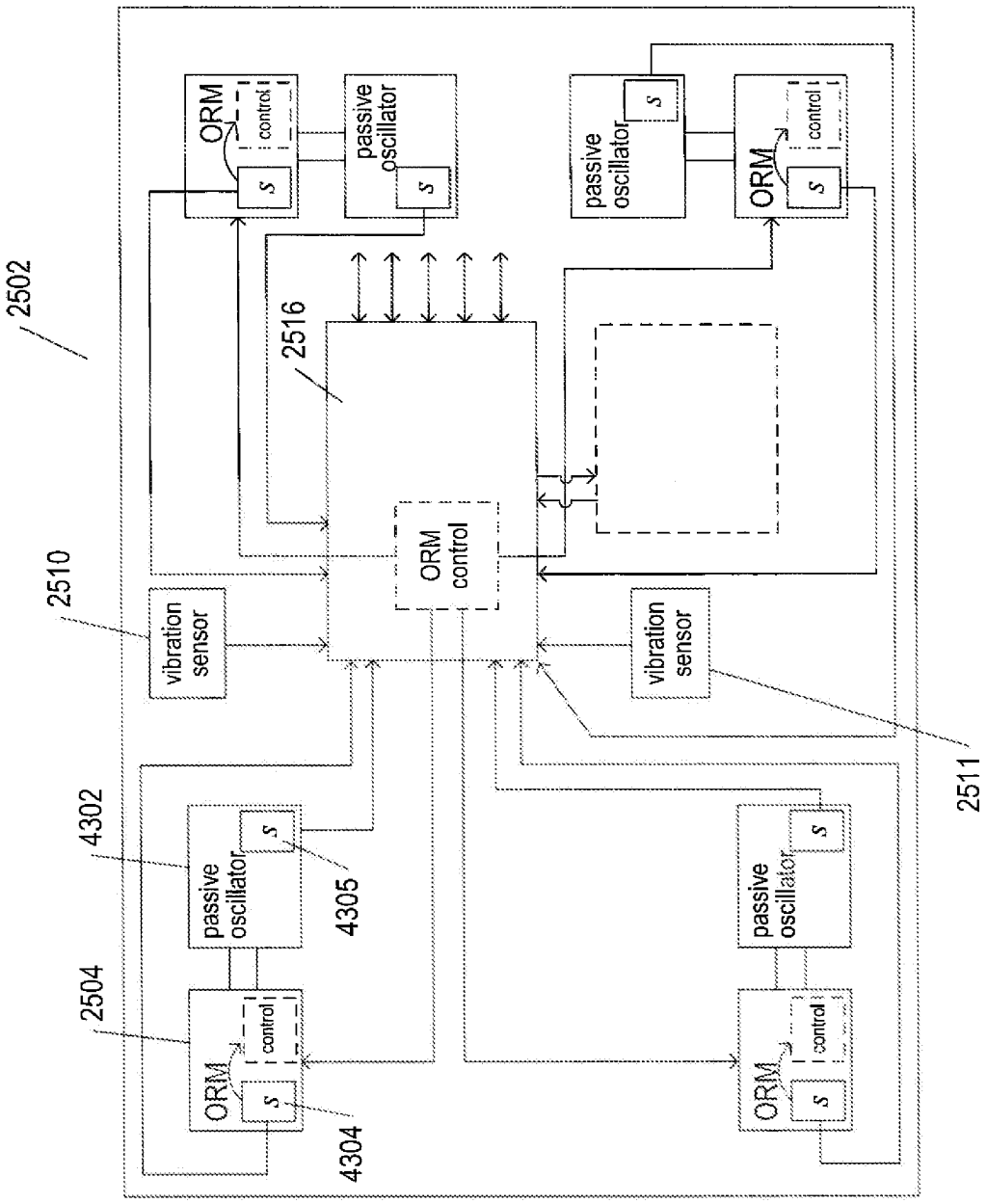

2502
2516
2510
2511
4302
4305
2504
4304
ORM
control
S
passive oscillator
ORM control
vibration sensor

FIG. 43

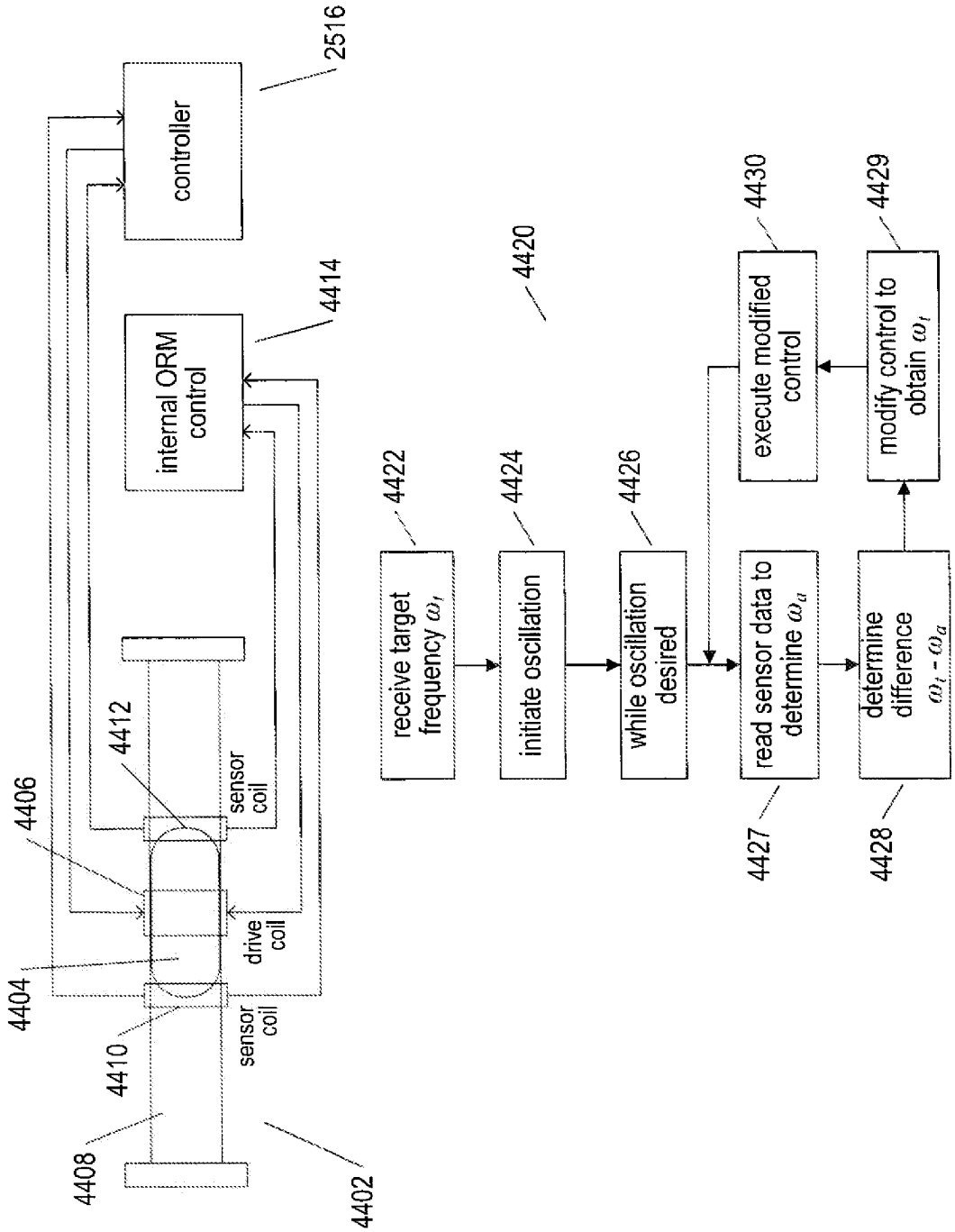

controller
2516
internal ORM control
4414
4420
4412
4406
sensor coil
drive coil
sensor coil
4404
4410
4408
4402
4422
receive target frequency ω_t
4424
initiate oscillation
4426
while oscillation desired
4427
read sensor data to determine ω_a
4428
determine difference $\omega_t - \omega_a$
4429
modify control to obtain ω_t
4430
execute modified control

FIG. 44

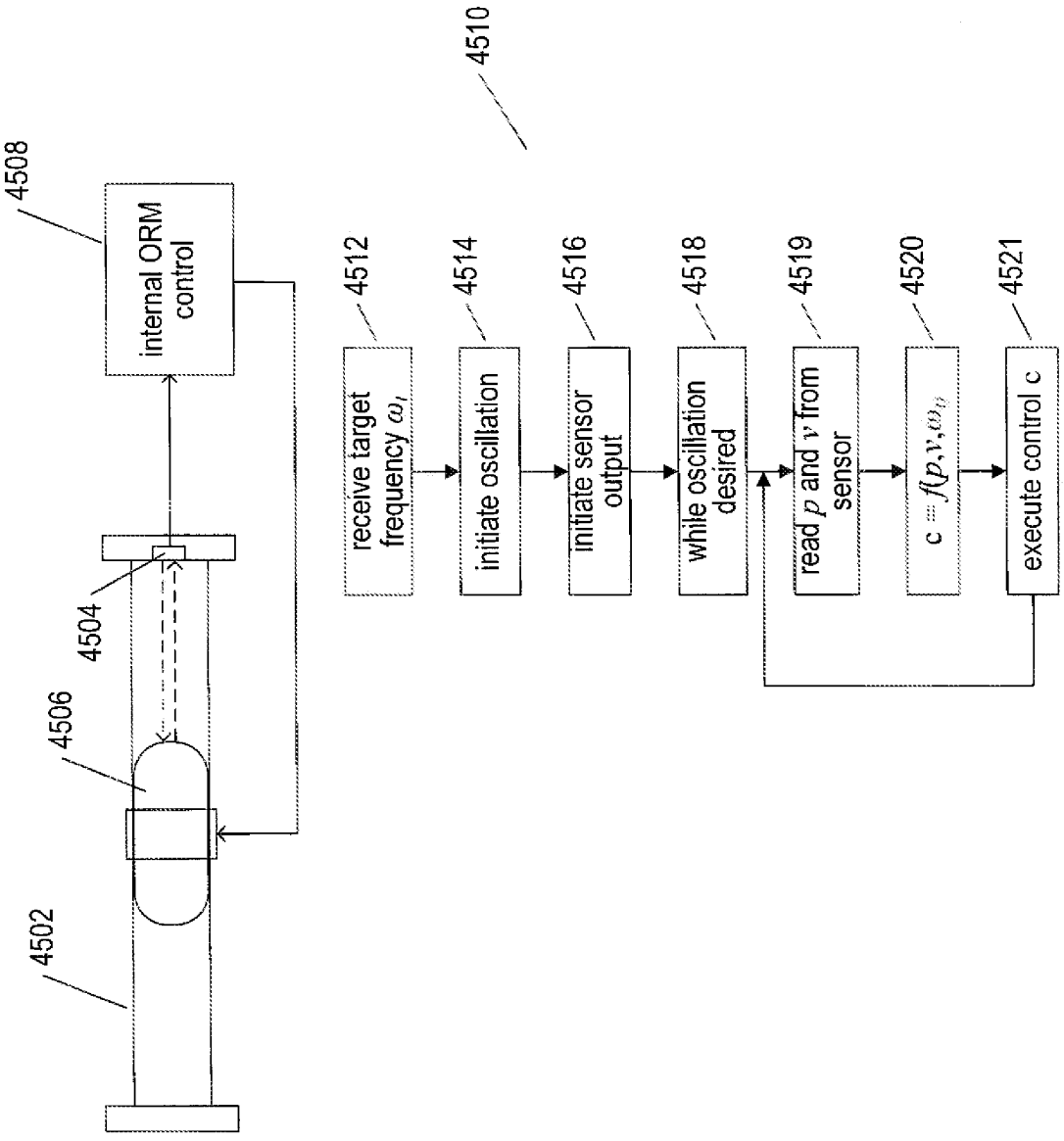

4508
internal ORM control
4504
4506
4502
4510
4512
receive target frequency ω_t
4514
initiate oscillation
4516
initiate sensor output
4518
while oscillation desired
4519
read p and v from sensor
4520
c = $f(p,v,\omega_0)$
4521
execute control c

FIG. 45

53/53

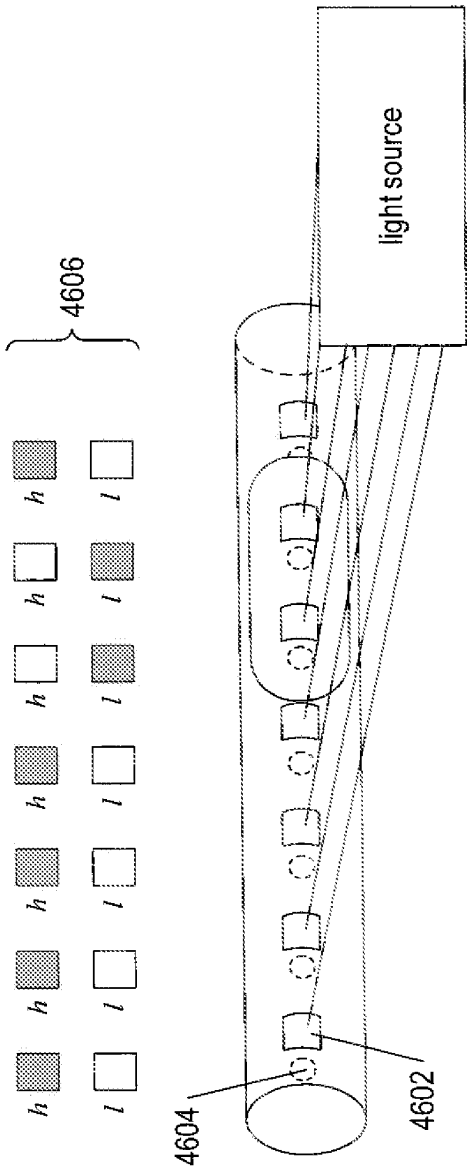


FIG. 46A

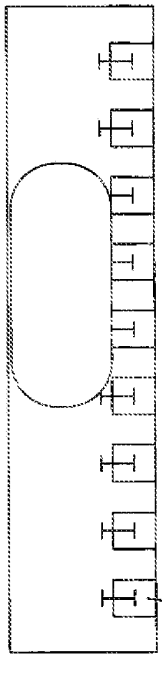


FIG. 46B

OSCILLATING-RESONANT-MODULE CONTROLLER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of Application No. 15/043,584, filed February 14, 2016, which claims the benefit of Provisional Patent Application No. 62/116,144, filed February 13, 2015.

TECHNICAL FIELD

The current document is related to vibration-generating devices and, in particular, to vibration modules that can be incorporated into a wide variety of different types of electromechanical devices and systems to produce predetermined vibration responses.

BACKGROUND

Vibration-inducing motors and mechanisms have been used for many years in a wide variety of different consumer appliances, toys, and other devices and systems. Examples include vibration signals generated by pagers, smart phones, vibration-driven appliances, such as hair-trimming appliances, electric toothbrushes, electric toy football games, and many other appliances, devices, and systems. The most common electromechanical system used for generating vibrations is an intentionally unbalanced electric motor.

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices. As shown in Figure 1A, a small, relatively low-power electric motor 102 rotates a cylindrical shaft 104 onto which a weight 106 is asymmetrically or mounted. Figure 1B shows the weight asymmetrically mounted to the shaft, looking down at the weight and shaft in the direction of the axis of the shaft. As shown in Figure 1B, the weight 106 is mounted off-center on the electric-motor shaft 104. Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B. As shown in Figures 2A-B, the asymmetrically-mounted weight creates an elliptical oscillation of the end of the shaft, normal to the shaft axis, when the shaft is rotated at relatively high speed by the electric motor. Figure 2A shows displacement of the weight and

shaft from the stationary shaft axis as the shaft is rotated, looking down on the weight and shaft along the shaft axis, as in Figure 1B. In Figure 2A, a small mark 202 is provided at the periphery of the disk-shaped end the of electric-motor shaft to illustrate rotation of the shaft. When the shaft rotates at high speed, a point 204 on the edge of the weight traces an ellipsoid 206 and the center of the shaft 208 traces a narrower and smaller ellipsoid 210. Were the shaft balanced, the center of the shaft would remain at a position 212 in the center of the diagram during rotation, but the presence of the asymmetrically-mounted weight attached to the shaft, as well as other geometric and weight-distribution characteristics of the electric motor, shaft, and unbalanced weight together create forces that move the end of the shaft along the elliptical path 210 when the shaft is rotated at relatively high speed. The movement can be characterized, as shown in Figure 2B, by a major axis 220 and minor axis 222 of vibration, with the direction of the major axis of vibration equal to the direction of the major axis of the ellipsoids, shown in Figure 2A, and the length of the major axis corresponding to the amplitude of vibration in this direction. In many applications, in which oscillation back and forth along a defined path is desired, designers seek to force the major-axis-amplitude/minor-axis-amplitude ratio to be as large as possible, to approach a linear path, but, because the vibration is produced by a rotational force, it is generally not possible to achieve oscillation back and forth along a defined path. In many cases, the path traced by the shaft center may be close to circular. The frequency of vibration of the unbalanced electric motor is equal to the rotational frequency of the electric-motor shaft, and is therefore constrained by the rate at which the motor can rotate the shaft. At low rotational speeds, little vibration is produced.

While effective in producing vibrations, there are many problems associated with the unbalanced-electric-motor vibration-generating units, such as that shown in Figure 1A, commonly used in the various devices, systems, and applications discussed above. Unbalancing the shaft of an electric motor not only produces useful vibrations that can be harnessed for various applications, but also produces destructive, unbalanced forces within the motor that contribute to rapid deterioration of motor parts. Enormous care and effort is undertaken to precisely balance rotating parts of motors, vehicles, and other types of machinery, and the consequences of unbalanced rotating

parts are well known to anyone familiar with automobiles, machine tools, and other such devices and systems. The useful lifetimes of many devices and appliances, particularly hand-held devices and appliances, that employ unbalanced electric motors for generating vibrations may range from a few tens of hours to a few thousands of hours of use, after which the vibrational amplitude produced by the devices declines precipitously as the electric motor and other parts deteriorate. Unbalanced electric motors are relatively inefficient at producing vibrational motion. A far greater amount of power is consumed by an unbalanced electrical motor to produce a given vibrational force than the theoretical minimum power required to produce the given vibrational force. As a result, many hand-held devices that employ unbalanced electric motors for generating vibrations quickly consume batteries during use. Unbalanced electric motors, as discussed above, oscillating motion back and forth along a predefined path, or space curve, cannot generally be produced by unbalanced electric motors. Unbalanced electric motors generate vibrations in only a very limited portion of the total vibrational-force/frequency space. Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors. The graph is shown as a continuous hypothetical curve, although, of course, actual data would be discrete. As shown in Figure 3, for relatively low-power electric motors used in hand-held appliances, only a fairly narrow range of frequencies centered about 80 Hz (302 in Figure 3) generate a significant vibrational force. Moreover, the vibrational force is relatively modest. The bulk of energy consumed by an unbalanced electric motor is used to spin the shaft and unbalanced weight and to overcome frictional and inertial forces within the motor. Only a relatively small portion of the consumed energy is translated into desired vibrational forces.

Because of the above-discussed disadvantages with the commonly employed unbalanced-electric-motor vibration-generation units, designers, manufacturers, and, ultimately, users of a wide variety of different vibration-based devices, appliances, and systems continue to seek more efficient and capable vibration-generating units for incorporation into many consumer appliances, devices, and systems.

SUMMARY

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A-B illustrate an unbalanced electric motor typically used for generating vibrations in a wide variety of different devices.

Figures 2A-B illustrate the vibrational motion produced by the unbalanced electric motor shown in Figures 1A-B.

Figure 3 shows a graph of vibrational force with respect to frequency for various types of unbalanced electric motors.

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document.

Figures 5A-G illustrate one particular type of ORM.

Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs.

Figure 10 shows a plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by ORMs.

Figures 11-18 show a variety of different alternative implementations of ORMs.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17.

Figure 20 illustrates a first coil layer.

Figure 21 illustrates a second coil layer.

Figure 22A illustrates a cross-section of a stator having two coil layers.

Figure 22B illustrates a cross-section of a stator having four coil layers.

Figure 22C illustrates a cross-section of a stator having two coil layers.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate.

Figure 23B illustrates the motor with a magnetic armature in an upward position.

Figure 23C illustrates the motor with a magnetic armature in a downward position.

Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation.

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration.

Figures 26A-B illustrate multiple resonant frequencies within a device or system.

Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response.

Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device.

Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figures 37A-D illustrate pulse-width modulation control of an ORM.

Figure 38A illustrates a control pattern that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806.

Figure 38B illustrates the actual vibration response of the ORM.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f.

Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs.

Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM.

Figures 46A-B illustrate several possible direct-sensing approaches.

DETAILED DESCRIPTION

The current document is directed to various oscillating resonant modules ("ORMs"), including various types of linear oscillating resonant modules ("linear ORMs"), that can be used within a wide variety of different types of appliances, devices, and systems, to generate vibrational forces. ORMs produce vibrational forces by oscillation of a weight or component within the ORM along a segment of a space curve, rather than as a by-product of an unbalanced rotation, as in the case of unbalanced electric motors. The oscillatory nature of the ORM vibration-inducing motion effectively addresses many problems associated with unbalanced electric motors. Combining an ORM with feedback control, so that the driving frequency produced by the ORM falls close to the resonant frequency of a device in which the ORM is included, results in optimal power consumption with respect to the amplitude and frequency of vibration produced by the ORM as well as maximal vibration energy of the device. Oscillation within a ORM may translate into highly directional driving forces produced by the ORM to drive a vibration response in an appliance or device that incorporates the ORM. The current document includes a first subsection, in which various types of ORMs are described, a second subsection on which an ORM controller is discussed, and a third subsection in which accurate methods for ORM control, to which the current document is directed, are described in detail.

ORMs

Figures 4A-D illustrate, in part, what is meant by the phrase "oscillating resonant module" in the current document. In contrast to the above-discussed unbalanced electric motors often used to generate vibrations in vibration-driven appliances, an oscillating resonant module contains a weight, or mass, that oscillates back and forth along a path. The path may be a linear path, or line segment, but, in the general case, can be potentially any particular segment of a space curve. Figure 4A illustrates operation of a linear oscillating resonant module. In a first diagram 402, labeled with the time "0," the linear ORM is depicted at time 0 (404 in Figure 4A), with the mass or weight 406 centered within a linear path 408 bounded by two stops 410 and 412. When the linear ORM is activated, the weight begins moving to the left, as shown in diagram 414. The small arrow 415 within the disk-like mass 406 indicates

the direction of movement. The mass continues to move, as shown in diagram 416, until the mass strikes the left-hand stop 410, at which point the direction of travel of the mass reverses and the mass begins moving back in the opposite direction, as shown in diagram 418. In diagrams 419 and 420, the mass continues in its rightward direction of travel during time intervals 4 and 5. At time 6, as shown in diagram 421, the mass strikes the right-hand stop 404 and reverses direction, traveling back in the leftward direction, as shown in diagram 422. Ellipses 424 indicate that this process continues indefinitely during operation of the linear ORM. The mass oscillates back and forward along the linear path. The period of oscillation and the maximum amplitude of oscillation can generally be controlled by control signals input to an ORM.

Figure 4B illustrates a mapping of a continuous logical movement of the weight along a circle to the actual linear motion of the weight within a linear ORM, as discussed above with reference to Figure 4A. In Figure 4B, the position of the weight is plotted along a circle 430. At time 0, represented by point 432, the weight position is vertically mapped, as indicated by dotted line 434 as well as by the solid line 436 within the circle 430, to a central point 438 on the linear path 440 shown below the circle. The position of the weight travels along the circle, in a counter-clockwise direction, as long as the linear ORM operates, as indicated by the dashed circular arrow 442. At time 1, indicated by point 444 on circle 430, the position of the mass is mapped, by vertical dashed line 446, to point 448 on linear path 440. At time 2, represented by point 450, the position of the mass on the linear path 440 is point 452. At time 3, represented by point 454 along the circle, the position of the mass is again point 448. Thus, as the position of the mass plotted along the circle has moved from point 444 to point 454, the direction of movement of the mass has reversed and the mass is now continuing in the opposite direction from the direction in which it originally moved. Small horizontal arrows, such as arrow 456, shown below the linear path 440, illustrate the linear motion of the mass of the linear ORM between each pair of adjacent time points. Thus, the back-and-forth oscillation of the mass in a linear ORM can be described by a logical revolution of a mass about a circle. If the circle has a radius of 1, then the position x at time t of the mass along the actual path of travel can be expressed as:

$$x(t) = \cos\left(\omega t - \frac{\pi}{2}\right),$$

where ω is the angular velocity at which the point representing the mass moves around the circle.

Figure 4C illustrates a general space-curve segment path. In Figure 4C, a short space-curve segment 460 is shown plotted in a three-dimensional Cartesian coordinate system 462. The weight or mass of an oscillating resonant module ("ORM") may oscillate back and forth along such a space-curve-segment path. In the first plot in Figure 4C 458, the weight or mass moves from left to right along the path, as indicated by the small curved arrows, such as curved arrow 460. As shown in the second plot 462 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it reverses directions and move to the left. As shown in the third plot 464 in Figure 4C, once the weight or mass reaches the left-hand end of the space-curve segment, it again reverses direction and moves to the right. Ellipses 466 indicate that this back-and-forth oscillation continues while the ORM operates. The space-curve-segment path of the weight in an ORM is defined by the physical implementation and operation of the ORM.

Figure 4D illustrates two additional example paths along which the weight or mass of an ORM may oscillate. The first path is a circular arc 470 and the second path is a partially elliptical arc-like path 472. As mentioned above, many additional different types of space-curve-segment paths for ORMs are possible.

Figures 5A-G illustrate one particular type of ORM. Figures 5A-G all use the same illustration conventions, next discussed with reference to Figure 5A. The ORM includes a cylindrical housing 502 within which a solid, cylindrical mass 504, or weight, can move linearly along the inner, hollow, cylindrically shaped chamber 506 within the cylindrical housing or tube 502. The weight is a magnet, in the described an implementation, with polarity indicated by the "+" sign 510 on the right-hand end and the "-" sign 512 on the left-hand end of the weight 504. The cylindrical chamber 506 is capped by two magnetic disks 514 and 516 with polarities indicated by the "+" sign 518 and the "-" sign 519. The disk-like magnets 514 and 518 are magnetically oriented opposite from the magnetic orientation of the weight 504, so that when the

weight moves to either the extreme left or extreme right sides of the cylindrical chamber, the weight is repelled by one of the disk-like magnets at the left or right ends of the cylindrical chamber. In other words, the disk-like magnets act much like springs, to facilitate deceleration and reversal of direction of motion of the weight and to minimize or prevent mechanical-impact forces of the weight and the end caps that close off the cylindrical chamber. Finally, a coil of conductive wire 520 girdles the cylindrical housing, or tube 502 at approximately the mid-point of the cylindrical housing.

Figures 5B-G illustrate operation of the ORM shown in Figure 5A. When an electric current is applied to the coil 520 in a first direction 522, a corresponding magnetic force 524 is generated in a direction parallel to the axis of the cylindrical chamber, which accelerates the weight 504 in the direction of the magnetic force 524. When the weight reaches a point at or close to the corresponding disk-like magnet 514, as shown in Figure 5C, a magnetic force due to the repulsion of the disk-like magnet 514 and the weight 504, 526, is generated in the opposite direction, decelerating the weight and reversing its direction. As the weight reverses direction, as shown in Figure 5D, current is applied in an opposite direction 530 to the coil 520, producing a magnetic force 532 in an opposite direction from the direction of the magnetic force shown in Figure 5B, which accelerates the weight 504 in a direction opposite to the direction in which the weight is accelerated in Figure 5B. As shown in Figure 5E, the weight then moves rightward until, as shown in Figure 5F, the weight is decelerated, stopped, and then accelerated in the opposite direction by repulsion of the disk-like magnet 516. An electrical current is then applied to the coil 520 in the same direction 534 as in Figure 5B, again accelerating the solid cylindrical mass in the same direction as in Figure 5B. Thus, by a combination of a magnetic field with rapidly reversing polarity, generated by alternating the direction of current applied to the coil, and by the repulsive forces between the weight magnet and the disk-like magnets at each end of the hollow, cylindrical chamber, the weight linearly oscillates back and forth within the cylindrical housing 502, imparting a directional force at the ends of the cylindrical chamber with each reversal in direction.

Clearly, the amplitude of the vibration and other characteristics of the vibrational forces produced within the ORM are related to the length of the hollow chamber in which the weight oscillates, the current applied to the coil, the mass of the weight, the acceleration of the weight produced by the coil, and the mass of the entire ORM. All of these parameters are essentially design parameters for the ORM, and thus the ORM can be designed to produce a wide variety of different amplitudes.

The frequency of the oscillation of the solid, cylindrical mass is determined by the frequency at which the direction of the current applied to the coil is changed. Figures 6A-B illustrate an H-bridge switch that can be used, in various ORMs, to change the direction of current applied to a coil that drives back-and-forth oscillation within the ORM. Figures 6A-B both use the same illustration conventions, described next with respect to Figure 6A. The H-bridge switch receives, as input, a directional signal *d* 602 and direct-current ("DC") power 604. The direction-control signal *d* 602 controls four switches 606-609, shown as transistors in Figure 6A. When the input control signal *d* 602 is high, or "1," as shown in Figure 6A, switches 608 and 609 are closed and switches 606 and 607 are open, and therefore current flows, as indicated by curved arrows, such as curved arrow 610, from the power-source input 604 to ground 612 in a leftward direction through the coil 614. When the input-control signal *d* is low, or "0," as shown in Figure 6B, the direction of the current through the coil is reversed. The H-bridge switch, shown in Figures 6A-B, is but one example of various different types of electrical and electromechanical switches that can be used to rapidly alternate the direction of current within the coil of an ORM.

Figure 7 provides a block diagram of the ORM, illustrated in Figures 5A-G. The ORM, in addition to the cylindrical housing, coil, and internal components shown in Figure 5A, includes a power supply, a user interface, generally comprising electromechanical buttons or switches, the H-bridge switch, discussed above with reference to Figures 7A-B, a central processing unit ("CPU"), generally a small, low-powered microprocessor, and one or more electromechanical sensors. All of these components are packaged together as an ORM within a vibration-based appliance, device, or system.

As shown in Figure 7, the ORM 700 is controlled by a control program executed by the CPU microprocessor 702. The microprocessor may contain sufficient on-board memory to store the control program and other values needed during execution of the control program, or, alternatively, may be coupled to a low-powered memory chip 704 or flash memory for storing the control program. The CPU receives inputs from the user controls 706 that together comprise a user interface. These controls may include any of various dials, pushbuttons, switches, or other electromechanical-control devices. As one example, the user controls may include a dial to select a strength of vibration, which corresponds to the current applied to the coil, a switch to select one of various different operational modes, and a power button. The user controls generate signals input to the CPU 708-710. A power supply 712 provides power, as needed, to user controls 714, to the CPU 716 and optional, associated memory, to the H-bridge switch 718, and, when needed, to one or more sensors 732. The voltage and current supplied by the power supply to the various components may vary, depending on the operational characteristics and requirements of the components. The H-bridge switch 720 receives a control-signal input *d* 722 from the CPU. The power supply 712 receives a control input 724 from the CPU to control the current supplied to the H-bridge switch 718 for transfer to the coil 726. The CPU receives input 730 from one or more electromechanical sensors 732 that generate a signal corresponding to the strength of vibration currently being produced by the linearly oscillating mass 734. Sensors may include one or more of accelerometers, piezoelectric devices, pressure-sensing devices, or other types of sensors that can generate signals corresponding to the strength of desired vibrational forces.

Figures 8A-C provide control-flow diagrams that illustrate the control program, executed by the CPU, that controls operation of an ORM. Figure 8A provides a control-flow diagram for the high-level control program. The program begins execution, in step 802, upon a power-on event invoked by a user through a power button or other user control. In step 802, various local variables are set to default values, including the variables: (1) *mode*, which indicates the current operational mode of the device; (2) *strength*, a numerical value corresponding to the current user-selected strength of operation, corresponding to the electrical current applied to the coil; (3)

lvl0, a previously sensed vibrational strength; (4) *lvl1*, a currently sensed vibrational strength; (6) *freq*, the current frequency at which the direction of current is alternated in the coil; (6) *d*, the control output to the H-bridge switch; and (7) *inc*, a Boolean value that indicates that the frequency is currently being increased. Next, in step 804, the control program waits for a next event. The remaining steps represent a continuously executing loop, or event handler, in which each event that occurs is appropriately handled by the control program. In certain implementations of the control program, events may be initiated by interrupt-like mechanisms and stacked for execution while, in more primitive implementations, certain events that overlap in time may be ignored or dropped. In the implementation illustrated in Figures 8A-C, two timers are used, one for controlling the change in direction of the current applied to the coil, at a currently established frequency, and the other for controlling a monitoring interval at which the control program monitors the vibrational force currently produced. Rather than using a formal timer mechanism, certain implementations may simply employ counted loops or other simple programming techniques for periodically carrying out tasks. When an event occurs, the control program begins a series of tasks, the first of which is represented by the conditional step 806, to determine what event has occurred and appropriately handle that event. When the frequency timer has expired, as determined in step 806, the value of the output signal *d* is flipped, in step 808, and output to the H-bridge switch, with the frequency timer being reset to trigger a next frequency-related event. The frequency-timer interval is determined by the current value of the variable *freq*. Otherwise, when the event is a monitor timer expiration event, as determined in step 810, then a routine "monitor" is called in step 812. Otherwise, when the event corresponds to a change in the user input through the user interface, as determined in step 814, the routine "control" is called in step 816. Otherwise, when the event is a power-down event, as determined in step 818, resulting from deactivation of a power button by the user, then the control program appropriately powers down the device, in step 820, and the control program terminates in step 822. Any other of various types of events that may occur are handled by a default event handler 824. These events may include various error conditions that arise during operation of the device.

Figure 8B provides a control-flow diagram for the routine "monitor," called in step 812 of Figure 8A. In step 830, the routine "monitor" converts the sensor input to an integer representing the current vibrational force produced by the ORM and stores the integer value in the variable *lvl1*. Next, in step 832, the routine "monitor" determines whether or not the ORM is currently operating in the default mode. In the default mode, the ORM uses continuous feedback control to optimize the vibrational force produced by the ORM by continuously seeking to operate the ORM at a frequency as close as possible to the resonant frequency for the ORM. Other, more complex operational modes may be handled by various more complex routines, represented by step 834 in Figure 8B. More complex vibrational modes may systematically and/or periodically alter the frequency or produce various complex, multi-component vibrational modes useful in certain applications, appliances, devices, and systems. These more complex modes are application dependent, and are not further described in the control-flow diagrams. In the case that the operational mode is the default mode, in which the control program seeks to optimize the vibrational force generated by the device, in step 836, the routine "monitor" determines whether the local variable *inc* is set to TRUE. If so, then the control program is currently increasing the frequency at which the device operates in order to obtain the resonance frequency. When *lvl1* is greater than *lvl0*, as determined in step 838, then the vibrational force has been recently increased by increasing the frequency, and so the routine "monitor" increases the frequency again, in step 840, and correspondingly resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 842, then the control program has increased the frequency past the resonance frequency, and therefore, in step 844, the control program decreases the frequency, sets the variable *inc* to FALSE, and correspondingly resets the frequency timer. In similar fashion, when the variable *inc* is initially FALSE, as determined in step 836, and when *lvl1* is greater than *lvl0*, as determined in step 846, the routine "monitor" decreases the value stored in the variable *freq*, in step 848 and resets the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as determined in step 860, then the routine "monitor" increases the value stored in the variable *freq*, sets the variable *inc* to TRUE, and resets

the frequency timer in step 862. Finally, the value in *lvl1* is transferred to *lvl0* and the monitor timer is reset, in step 864.

Figure 8C provides a control-flow diagram for the routine "control," called in step 816 in Figure 8A. This routine is invoked when a change in the user controls has occurred. In step 860, the variables *mode* and *strength* are set to the currently selected mode and vibrational strength, represented by the current states of control features in the user interface. Next, in step 862, the routine "control" computes an output value *p* corresponding to the currently selected strength, stored in the variable *strength*, and outputs the value *p* to the power supply so that the power supply outputs an appropriate current to the coil. Finally, in step 864, the routine "control" computes a new monitor timer interval and resets the monitor timer accordingly.

The control program described with reference to Figures 8A-C is one example of many different implementations of the control program that can be carried out, depending on requirements of the ORM, the parameters and characteristics inherent in a particular ORM, the types of control inputs received from a particular user interface, the nature of the power supply, and the types of operational modes that are implemented for the ORM.

Figure 9 represents the range of frequencies and vibrational forces that can be achieved by different implementations of ORM and ORM control programs. Figure 9 has the same axes as the graph shown in Figure 3. However, unlike Figure 3, Figure 9 includes many different curves, such as curve 902, each representing the vibrational forces and frequencies that can be obtained from a particular ORM implementation. Again, an ORMs generally has at least one resonant frequency that is characteristic of the geometry and weights of various components of the ORM, and each ORM is naturally operated at a frequency close to this resonant frequency in order to achieve maximum vibrational force. Thus, rather than being restricted, over all possible implementations, to a relatively narrow range of frequencies and vibrational forces, as in the case of unbalanced electrical motors, ORMs can be designed and implemented to produce desired vibrational forces over a wide range of vibrational frequencies, and desired vibrational frequencies over a wide range of desired vibrational forces. The contrast is perhaps best seen in Figure 10. Figure 10 shows a

plot of the amplitude/frequency space and regions in that space that can be operationally achieved by unbalanced electrical motors and by linear ORMs. Unbalanced electric motors can be implemented to produce amplitude/frequency combinations roughly within the cross-hatched square region 1002 within amplitude/frequency space. By contrast, linear ORMs can be designed and implemented to produce amplitude/frequency combinations underlying curve 1004. Thus, linear ORMs can achieve much higher operational frequencies and much lower operational frequencies than can be practically obtained by unbalanced electric motors, and can produce much higher amplitudes and vibrational forces than can be achieved by relatively low-powered unbalanced electrical motors used in hand-held appliances and other commonly encountered devices and systems. Furthermore, when larger vibrational forces are needed, balanced electrical motors are generally impractical or infeasible, due to the destructive forces produced within the electrical motors. In general, a single implemented linear ORM can access a much larger region of amplitude/frequency space than currently available vibration modules, which generally operate at fixed amplitudes and/or fixed frequencies, as further discussed below.

Figures 11-18 show a variety of different alternative implementations of ORMs. Figure 11 provides a schematic illustration of an ORM similar to that discussed above with reference to Figure 4A. Note that, in place of the end magnets 1102 and 1104, mechanical springs may alternatively be used. These may be traditional helical springs made from metal or springs made from a compressible and durable material or mechanical device that seeks to restore its initial shape when depressed or compressed. Note that the weight and chamber may be cylindrical, in cross section, as discussed above with reference to Figure 5A, or may have other shapes, including rectangular or hexagonal cross-sections.

Figure 12 shows a similar implementation in which the control unit and power supply are incorporated into the moving mass 1202. In this implementation, the relative masses of the moving mass 1202 and remaining components of the ORM is maximized, thus maximizing the vibrational forces produced at a given level of power consumption.

Figure 13 shows yet an alternative ORM. In this alternative implementation, additional coils 1302 and 1304 are incorporated in the moving mass, and a centering magnet or coil 1306 is positioned in a fixed location on the housing so that, when the direction of the current applied to the coils 1302 and 1304 is alternated, an oscillating rotational force is generated to cause the movable weight to oscillate both in a plane perpendicular to the axis of the chamber as well as linearly oscillating the direction of the chamber.

Figure 14 illustrates an ORM in which multiple electromagnetic coils are employed. In Figure 14, two coils 1402 and 1404 are placed in two different positions on the housing. The first coil 1402 may be used to drive linear oscillation of the moving mass 1406, while the second coil may be activated in order to shorten the length of the chamber within which the moving mass linearly oscillates, essentially serving as a second repelling magnet. In this implementation of the ORM, the moving mass may linearly oscillate with at least two different amplitudes, depending on whether or not the second coil 1404 is activated to repel the moving mass. Additionally more complex patterns of current reversal in the two coils can be employed to produce complex multi-component vibrational modes of the moving mass.

When the housing is fully enclosed, air within the chamber serves to dampen oscillation of the moving mass. This dampening may be minimized by providing channels, on the sides of the moving mass, to allow air to pass from one side of the moving mass to the other, by channels through the moving mass, or by providing openings in the housing to allow air to be forced from the housing and drawn into the housing. Additionally, different fluids or liquids may be employed within the chamber to change the dampening effect produced by displacement of the fluids and gasses as the moving mass linearly oscillates.

Figure 15 illustrates an alternative ORM an implementation of the linear-resonant vibration module to which current document is directed in which a plunger linearly oscillates to produce a vibration. The plunger 1502 is slideably contained within a moveable-component track orthogonal to a long axis of the main housing 1504 of the ORM that includes the power supply, microcontroller, and other control components. The plunger is girdled by, or includes, a driving magnet 1506 that

is attracted to, and seeks to be positioned in alignment with, a centering magnet 1508 mounted within the housing. Applying current to one of two driving coils 1512 and 1514 forces the driving magnet away from the equilibrium position shown in Figure 15. By rapidly switching the direction of current applied to the driving coils, the microcontroller can control the plunger to linearly oscillate in an up-and-down fashion, as indicated by arrow 1520.

Figure 16 shows yet another ORM an implementation of the linear-resonant vibration module to which current document is directed. In this an implementation of the linear-resonant vibration module to which current document is directed, a spring-like member 1602 is clamped at one end 1604 to the housing. Driving magnets 1606 and 1608 are fixed to the spring-like member 1602, and when current is rapidly reversed in a coil 1610, the spring-like member 1602 is induced to vibrate at a relatively high frequency.

Figure 17 shows another ORM similar to the ORM shown in Figure 16. In this ORM, the spring member 1702 is extended to provide an external massage arm 1704 that extends out from the housing to provide a linearly oscillating massage-foot member 1706 for massaging human skin or some other substrate, depending on the application.

Figure 18 shows a mechanical vibration adjustment feature that can be added to either of the ORMs shown in Figures 16 and 17. An adjustment screw 1802 can be manipulated to alter the position of a movable spring clamp 1804 that acts as a movable clamping point for the spring-like member 1806. Moving the movable spring clamp 1804 leftward, in Figure 18, shortens the length of the spring-like member and thus tends to increase the resonant frequency at a particular power-consumption level. Conversely, moving the movable spring clamp rightward, in Figure 18, lengthens the spring-like member and decreases the vibrational frequency.

Figure 19 illustrates an enhancement of an implementation of the ORM shown in Figure 17. In this implementation, the massage foot is enhanced to include elastomer bristles 1902-1906 to transfer the linear oscillation of the massage foot to human skin or another substrate. The elastomeric bristles, or pad or brush comprising numerous elastomeric bristles, allow transmission of vibration to a surface even at low

operational powers, when a rigid or even semi-compliant massage foot would instead simply stop moving for inability to overcome frictional forces.

Figure 20-23C illustrate a different type of ORM. This ORM comprises a motor incorporated within a printed circuit board ("PCB"). The motor includes moving and non-moving components that interact via electromagnetic forces to produce motion. The non-moving components include a stator that generates a magnetic field. A stator can be created by using one or more coils. In certain implementations, a stator adapted to integration with a planar substrate is produced using combinations of one or more spiral-shaped conductive traces.

Figure 20 illustrates a first coil layer. The first coil layer 2000 includes a substrate 2002 and a spiral-shaped trace 2004 that is wound in a clockwise direction from the outside of the spiral to the inside of the spiral. The spiral-shaped trace 2004 surrounds a central core and overlays the substrate 2002. In some implementations, the substrate 2002 is a printed circuit board. The width and thickness of the trace influence the conductivity of the resulting coil. In general, thicker and wider traces have lower electrical resistance and result in coils with lower resistance and higher current carrying capacity. Spirals with a larger core diameter and spirals having a larger number of turns produce coils with correspondingly higher inductance. The inductance of the spiral-shaped trace 2004 with an air core at the center of the spiral is expressed as:

$$L(uH) = \frac{r^2 N^2}{8r + 11W}$$

where :

r is the core radius in inches;

N is the number of turns; and

W is the total width of the windings in inches.

The inductance of the resulting coil can be adjusted by altering the above parameters, as well as through the selection of core materials.

A first connection pad 2006 and a second connection pad 2008 terminate the ends of the spiral-shaped trace 2004. In certain implementations, the first

connection pad 2006 and/or the second connection pad 2008 are incorporated into one or more conductive vias connecting the first coil layer to other coil layers or to electrical circuits constructed on the substrate. Additional connection pads 2010, 2012, 2014, and 2016 can provide connection points or can be incorporated into vias that connect multiple layers of traces.

Figure 20 additionally illustrates the placement of a number of motor elements in a particular motor implementation. At the center of the spiral-shaped trace 2004 is a circular opening 2018. The circular opening provides a space for an armature 2020. The armature 2020 can be made from a ferrous metal or a magnetic material and moves in a direction substantially perpendicular to the surface of the substrate 2002 in response to a drive current applied to the coil layer. A centering spring 2022 retains the armature 2020 in the circular opening 2018 in the substrate 2002, and allows limited movement perpendicular to the substrate.

In certain implementations, the traces and connection pads are made from conductive material, such as metal, copper, aluminum, or conductive alloys. The traces and connection pads on the first coil layer 2000 can be fabricated using printed-circuit-board manufacturing techniques. In some implementations, foil decals are created and laminated onto the substrate 2002. The construction of multi-layer coils is achieved using a number of techniques, including: multi-layer PCB construction; laminated foil decals separated by insulating layers; and 2-sided PCB construction. In some implementations, the traces and connection pads are embedded into the substrate 2002.

Figure 21 illustrates a second coil layer. The second coil layer 2100 is constructed using techniques already described for the construction of the first coil layer 2000. A spiral-shaped trace 2102 winds in a clockwise direction from the starting connection pad 2104 to the ending connection pad 2106. The coil layer of Figure 20 is positioned over the coil layer of Figure 21 and the two layers are aligned with one another so that the second connection pad 2008 in Figure 20 overlays the starting connection pad 2104 in Figure 21, and the connection pad 2010 in Figure 20 aligns with the ending connection pad 2106 in Figure 21. PCB vias form electrical connections between the second connection pad 2008 in Figure 1 and the starting

connection pad 2104. When the first coil layer 2000 in Figure 20 and the second coil layer 2100 in Figure 21 are connected in this way and energized, the inductance of the layers is additive. In one mode of operation, current flows into the coil layer of Figure 20 starting at the first connection pad 2006, clockwise around the coil to the second connection pad 2008, through a via to the starting connection pad 2104, and clockwise to the ending connection pad 2106. Adding additional coil layers increases the total inductance of the resulting coil. Additional connection pads 2108, 2110, 2112, and 2114 provide connection points and support for vias that connect to additional coil layers. In certain implementations, additional coil layers can be added to the coil using similar methods to those described above. The additional coil layers are separated by insulating layers or placed on opposite sides of an insulating substrate. In certain implementations, the multi-layer coil is used as a stator in a motor.

Figure 22A illustrates a cross-section of a stator having two coil layers. A first coil layer 2202 and a second coil layer 2204 are laminated onto an insulating planar substrate 2206, such as a PCB. The first and second coil layers 2202 and 2204 are separated by an insulating layer and electrically connected to each other with a via 2208. The stator is driven by a first connection pad 2210 and a second connection pad 2212. In certain implementations, the second connection pad 2212 is routed to the front surface of the PCB using a via. An opening 2214 is provided for an armature that moves perpendicularly to the surface of the substrate in response to energizing the stator. The first and second coil layers can be constructed using the coil layers illustrated in Figures 20 and 21, or with similar trace patters arranged so that the coil layers produce a single direction of rotation around the opening 2214. The implementations illustrated in Figure 22A can be extended to include additional coil layers laminated to both sides of a planar substrate.

Figure 22B illustrates a cross-section of a stator having four coil layers. A first-front coil layer 2250 and a second-front coil layer 2252 are laminated onto a front surface of an insulating planar substrate 2254, such as a PCB. A first-back coil layer 2256 and a second-back coil layer 2258 are laminated onto a back surface of the insulating planar substrate 2254. A first via 2260 electrically connects the end of the first-front coil layer 2250 to the beginning of second-front coil layer 2252. A second

via 2262 electrically connects the end of the first-back coil layer 2256 to the beginning of second-back coil layer 2258. Cross-substrate via 2264 connects the end of first-front coil layer 2250 to the end of first-back coil layer 2256. When current enters at an entry connection pad 2266 and passes through the four coil layers, the current travels with a single direction of rotation until the current exits at an exit connection pad 2268. The inductance of the stator in Figure 22B is approximately double that of the stator shown in Figure 22A.

Figure 22C illustrates a cross-section of a stator having two coil layers. A front coil layer 2280 and a back coil layer 2282 are laminated onto opposing sides of an insulating planar substrate 2284, such as a PCB. A via 2288 electrically connects the front coil layer 2280 to the back coil layer 2282 forming a coil wound in a single direction around the opening 2290. Connection pads 2292 and 2294 provide electrical contacts for connecting the coil to a drive current.

In some implementations, the coil layers that make up the stator are not interconnected to form a single coil. For example, cross-substrate via 2264 may be omitted, and the two front coil layers 2250 and 2252 are electrically driven independently from the two back coil layers 2256 and 2258. In other implementations, the two front coil layers 2250 and 2252 are counter-wound with respect to the two back coil layers 2256 and 2258. In this configuration, the magnetic fields generated in the opening 2270 by the two front coil layers oppose the magnetic field generated by the two back coil layers.

PCBs are suitable substrates for making the coils and motors described in the current document. A PCB can be constructed using a PCB process where layers of printed copper are separated by a hard laminate core, for example, using FR-4 glass-reinforced epoxy. A PCB made from polyimide can support a greater density of coils and increased mechanical flexibility. A PCB made from a ceramic, such as aluminum oxide, provides increased heat resistance. The stators described above can be constructed with any of these PCB materials.

In certain implementations, the coil layers described above are arranged to form one or more coils that overlay the front and/or back surfaces of a PCB. The coils form a stator that drives the armature of a motor.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate. The motor 2300 is constructed on a substrate 2302 , such as a PCB. A first front coil layer 2304 and a second front coil layer 2306 overlay the front surface of the substrate 2302. A first back coil layer 2308 and a second back coil layer 2310 overlay the back surface of the substrate. A first via 2312 electrically connects the first front coil layer 2304 to the second front coil layer 2306 to form a front coil, and a second via 2314 electrically connects the first back coil layer 2308 to the second back coil layer 2310 to form a back coil. Front coil connections 2316 and 2318 provide electrical connectivity for driving the front coil, and back coil connections 2320 and 2322 provide electrical connectivity for driving the back coil.

A magnetic armature 2324 having a north pole 2326 and a south pole 2328 is positioned in an opening in the substrate 2302 through the center of the front and back coils. In order to drive the magnetic armature 2324 into vibration, a first oscillating current is applied to the front coil connections 2316 and 2318, and a second oscillating current is applied to the back coil connections 2320 and 2322. When the motor is operated, the current that flows through the front coil and the current that flows through the back coil flow with opposite directions of rotation. In certain implementations, this is accomplished by applying the same oscillating current to both front and back coils provided the coils are counter-wound. In an alternative implementation, where the coils are not counter-wound, the second oscillating current is 180 degrees out of phase with the first oscillating current. The resulting oscillating magnetic field provides a magneto-motive force to the north pole 2326 and the south pole 2328 in synchrony, driving the magnetic armature 2324 into vibration at a frequency proportional to the frequency at which the oscillating current is applied. In an alternative implementation, the second front coil layer 2306 is connected to the first back coil layer 2308 with a third conductive via to form a single-drive counter-wound stator that is driven with a single oscillating current to produce vibratory motion of the armature.

The magnetic armature is constructed from an axially polarized magnet. In one implementation, the magnet is a neodymium grade N-42 disk magnet. The size

and shape of the magnet is adapted based, in part, on the desired vibration profile of the motor.

Figure 23B illustrates the motor with the magnetic armature in an upward position. When a first driving current is applied to a front coil 2330, the front coil 2330 generates a downward magnetic flux 2332. In response to the downward magnetic flux 2332, an upward vertical force is exerted on the north pole 2336. As the first driving current is applied, a second driving current is applied to a back coil 2338 and an upward magnetic flux 2340 is generated. In response to the upward magnetic flux 2340, an upward vertical force is exerted on the south pole 2342 of the magnet. In response to the upward forces, the magnetic armature 2334 moves upwards as illustrated in Figure 23B.

Figure 23C illustrates the motor with the magnetic armature in a downward position. When the direction of the first and second driving currents is reversed, the forces on the north pole 2360 and south pole 2362 are reversed. When the first reversed current is applied to a front coil 2364, the front coil 2364 generates an upward magnetic flux 2366, and a downward vertical force is exerted on the north pole 2360. When the second reversed current is applied to a back coil 2368 a downward magnetic flux 2370 is generated. A downward vertical force is exerted on the south pole 2362 of the magnetic armature 2372. In response to these two forces, the magnetic armature 2372 moves downwards as illustrated in Figure 23C.

The drive currents are alternated to cause the magnetic armature to vibrate perpendicularly to the surface of the substrate at a chosen frequency. In one implementation, the front coil and back coil are counter-wound with respect to each other. The front and back coils are connected with a conductive via or wire and driven with one drive current. This arrangement causes the front and back coils to generate simultaneous magnetic flux signals in opposing directions, which, in turn, acts on the north and south poles of the magnetic armature to drive the magnetic armature into vibration.

In alternative implementations, additional coil layers are employed. For example, an 8-layer PCB can have four front coil layers and four back coil layers. The four front coil layers are connected to form a front coil, and the four back coil layers

are connected to form a back coil. In certain implementations, the front coil and back coil are counter wound, and driven with a single drive current as explained above.

Next, a slightly more mathematically descriptive explanation of oscillation, resonance, and the Q factor is provided. Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation. Great insight into harmonic oscillators can be provided by considering a simple, one-dimensional spring. Figure 24A illustrates a spring that can be extended in the x direction. In a first diagram 2402, the spring is shown in an equilibrium, resting state with a point or mass 2404 at the end of the spring located at the position $x = 0$. In a second diagram 2406, the spring has been pulled rightward, along the x direction, with the mass 2404 now located at a position x. As is well known, the extended spring has potential energy that results in a force F_x 2408 that points in the opposite direction. In other words, were the spring released, the mass would travel leftward, oscillate back and forth, and eventually settle back to the 0 position shown in diagram 2402. Were the spring frictionless, however, the mass would continue to oscillate back and forth, in a manner similar to the linear ORM described in Figures 4A-B, indefinitely.

The frictionless spring can be mathematically modeled as follows:

$$F_x(x) = -kx,$$

where $F_x(x)$ is the force exerted by the spring;
x is the position of the spring end; and
k is the force constant.

The force constant k is a property of the spring, including all of the parameters that contribute to its elasticity, compressibility, and other physical characteristics of the spring. In more complex, realistic situations, many different factors may contribute to the force constants associated with harmonic oscillators, including interaction with other harmonic-oscillation modes within a physical device or module.

The potential energy of the spring system illustrated in Figure 24A can be modeled as:

$$U(x) = \frac{1}{2}kx^2,$$

where $U(x)$ is the potential energy of the spring system.

Using Newton's second law, the equation that models the force exerted by the spring when it is extended or compressed can be modeled as a simple, second-order differential equation:

$$m\ddot{x} = Fx = -kx,$$

where m = mass of oscillator; and

$$\ddot{x} = \frac{d^2x}{dt^2}.$$

This differential equation can be simplified as:

$$\ddot{x} = \frac{-k}{m}x = -\omega^2 x,$$

where $\omega = \sqrt{\frac{k}{m}}$.

The general solution for this simple, second-order differential equation is, in one form:

$$x(t) = C_1 e^{i\omega t} + C_2 e^{-i\omega t}.$$

In this equation, C_1 and C_2 are arbitrary constants that are determined by the initial conditions of a particular spring system. This solution can be recast as:

$$x(t) = B_1 \cos(\omega t) + B_2 \sin(\omega t),$$

where $B_1 = C_1 + C_2$; and

$$B_2 = i(C_1 - C_2).$$

A final, perhaps most elegant form of the solution is:

$$x(t) = \mathrm{Re}[Ae^{i(\omega t - \delta)}],$$

where $Ae^{-i\delta} = B_1 - iB_2 = C$.

In this equation, A is the amplitude of the oscillation, ω is an angular velocity of the oscillation, as discussed above with reference to Figure 24B, and δ is an initial phase offset. This final expression describes the mapping of a rotation to linear harmonic oscillation, as discussed above with reference to Figure 4B, shown again, in Figure 24B, with annotations taken from final expression for the solution to the differential equation.

As mentioned above, a frictionless spring would continue to oscillate indefinitely after being released from an extended position. However, in actual systems, there are always resistive forces, such as friction, that dampen the oscillation so that, over time, the amplitude of the oscillation decreases and the oscillation finally stops. This more complex and more realistic scenario can be modeled by including a resistive-force term in the second-order differential equation:

$$m\ddot{x} + b\dot{x} + kx = 0,$$

where $-b\dot{x}$ is a resistive force; and

$$\dot{x} = \frac{dx}{dt}.$$

Defining several new constants as follows:

$$\beta = \frac{b}{2m} = \text{ damping constant, and}$$

$$\omega_0 = \sqrt{\frac{k}{m}} = \text{ natural frequency}$$

and solving the above modified second-order ordinary differential equation, the following result is obtained:

$$x(t) = Ae^{-\beta t}\cos(\omega_1 t - \delta)$$

where $\omega_1 = \sqrt{\omega_0^2 - \beta^2}$; and

$\beta < \omega_0$.

when, as indicated above, the damping constant β has a value less than the value of the natural frequency ω_0, the system in under-damped and the amplitude of the oscillations decrease non-linearly, as shown in Figure 24C. When β is greater than ω_0, the system is over-damped, in which case only a single oscillation may occur, as shown in Figure 24D.

Most physical systems have one or more natural frequencies at which they oscillate, when mechanically perturbed from their equilibrium states. In ORMs, a motor is used to continuously perturb the system in order to drive the ORM to oscillate and generate vibration. A device in which an ORM is incorporated vibrates in response to a driving vibration generated by the ORM. In this case, an external

driving force $F(t)$ is applied by the ORM to drive continuous oscillation of the device in which it is included. An external-force-driven linear oscillator can be modeled by the following expression:

$$m\ddot{x} + b\dot{x} + kx = F(t),$$

where $F(t)$ is an external driving force.

With the definition:

$$f(t) = \frac{F(t)}{m},$$

the mathematical model becomes:

$$\ddot{x} + 2\beta\dot{x} + \omega_0^2 x = f(t).$$

A solution for this expression is:

$$x(t) = A\cos(\omega t - \delta)$$

where $f(t) = f_0\cos(\omega t)$;

$$A^2 = \frac{f_0^2}{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2}\text{; and}$$

$$\delta = \arctan\left(\frac{2\beta\omega}{\omega_0^2 - \omega^2}\right).$$

In this expression, the constant ω is the driving frequency of the driving force, which is somewhat less than the natural frequency ω_0. As can be seen in the expression for the square of the amplitude, which is proportional to the energy of the vibration, the amplitude is maximized when the denominator of this expression is a value approaching 0. Maximizing the expression can be carried out either by varying the physical device in order to vary the natural frequency ω_0, while the external-driving-force frequency remains fixed ω, or by varying the driving frequency ω when the natural frequency ω_0 is fixed. When ω_0 varies and ω is fixed, A is maximum when $\omega_0 = \omega$; and when ω varies and ω_0, A is maximum when $\omega = \sqrt{\omega_0^2 - 2\beta^2}$. This is where the term "resonance" arises. The resonant frequency is the frequency at which the amplitude A is maximized. As can be seen, this occurs, in general, when the driving frequency of the motor or other mechanical-force-input mechanism has a frequency

close to or equal to the natural frequency ω_0 of the physical system. A quality factor Q can be expressed, in terms of the natural frequency and damping factor, as:

$$Q = \frac{\omega_0}{2\beta}.$$

This is the reciprocal of the ratio of the width of the amplitude peak at half its maximum value to the natural frequency ω_0.

An ORM Controller

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration. The vibration may be generated for application to people, animals, or objects for various purposes, including therapeutic purposes, or may instead be generated to provide haptic feedback, such as vibration in mobile phones, vibration-based notification, or vibration-based communications. Thus, the current document is directed to particular features of a generic ORM-containing device or system that may be used in a wide variety of different types of applications or included in larger devices and systems. In Figure 25, the device, appliance, or system is represented by an outer rectangle 2502. The device includes four ORMs 2504-2507. The ORMs may be of any of many different types, including the types of ORM discussed above. In general, the ORMs convert input energy, such as an electrical current, to mechanical vibration. The device also includes several vibration sensor 2510-2511. There are a variety of different types of vibration sensors, including piezoelectric accelerometers that measure acceleration in one, two, or three different orthogonal directions. Other types of sensors may include membranes attached to moving coils that generate electronic signals when the membrane vibrates, similar to a reverse audio speaker. In addition, the device or system contains a controller 2516. The controller includes ORM control logic 2418 that transmits control signals, in certain cases electrical signals that also serve to power the ORMs. The ORM control logic may be implemented as a sequence of processor instructions, when the controller 2516 is a processor or processor-controlled controller subsystem. In many of the ORM devices and systems, the controller accesses some type of electronic memory 2520, which stores processor instructions and other types of data for

implementing ORM control logic 2518. Not shown in Figure 25 are various standard components and signal lines, including a power supply and power-transmitting circuitry, display screens, push buttons, other user-interface-related components, and other types of logic and logic-controlled subcomponents particular to particular types of devices, such as transceivers and communications subsystems within mobile phones. A set of double-headed arrows, such as double-headed arrow 2522, represent the fact that the controller may control many other subcomponents and features of the device or system in addition to the ORMs.

In the previous discussion of oscillation, vibration, and resonance, simple mathematical models for one-dimensional harmonic oscillation were developed. However, in the generic ORM-containing device or system, there may be multiple ORMs, activation of which produce very complex three-dimensional spatial vibration. Vibration modes of individual ORMs may couple to produce a large number of complex spatial-vibration modes. The physical characteristics of these vibration modes may be highly dependent on the exact geometry, weight and balance, and the material type of the housing and internal components of a particular device or system. As a result, there may be numerous different natural resonant frequencies for the device or system.

Figures 26A-B illustrate multiple resonant frequencies within a device or system. In Figure 26A, the vibrational energy, or square of the amplitude of the vibration, is plotted with respect to frequency. The vertical axis represents the energy and vibration 2602 and the horizontal axis represents the frequency of vibration 2604. The plotted curve 2606 shows numerous different vibration-energy peaks 2610-2615. The heights and positions of these peaks along the frequency axis 2604 may vary considerably with slight changes to the physical characteristics of a device or system that is vibrated by ORM components.

Figure 26B shows a more complex type of vibration-response plot. The vibration response is represented by a surface 2620 in the plot shown in Figure 26B. Measured amplitudes or vibration energies produce a surface 2620 in a three-dimensional Cartesian coordinate system that includes an x-direction vibration frequency axis 2522, a y-direction frequency axis 2624, and a vibration-energy axis

2626. The device or system for which the vibration-response surface 2620 is obtained includes two ORMs, one of which generates vibrations in the *x* direction and one of which generates vibrations in the *y* direction. The two ORMs can be independently controlled to generate vibrations in their respective directions at different frequencies. The *x*, *y* plane 2628 below the plotted vibration-energy surface 2620 represents all possible *x*-direction vibration frequencies and *y*-direction vibration frequencies that can be generated by the two ORMs within the device or system. As shown in Figure 26B, the surface includes three local vibration-energy maxima 2630-2632. These three local maxima are each associated with *x*-direction frequency and *y*-direction frequency components 2634. Thus, in the case shown in Figure 26B, two ORMs which generate vibrations in two different directions within the device or system may generate a complex vibration-response surface with respect to the frequencies at which the two ORMs are operated. Depending on the types and numbers of ORMs, the vibration response may be a hyper-dimensional surface in a much higher dimensional frequency space. In all cases, however, the device or system generally has some number of characteristic resonant frequencies that represent maximal vibration energy or amplitude with respect to the frequencies at which individual ORMs are driven with the device or system. In general, the number of resonant frequencies is equal to the number of vibrational degrees of freedom in the device, appliance, or system.

A vibration-response obtained for a device or system by measuring sensor output can be used to identify and tabulate the natural resonant frequencies for the device or system. Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25. Each row in the resonant-frequency table 2702, such as row 2704, represents a local maxima, or peak, in the vibration response for the generic device. In the example table shown in Figure 27, each peak is characterized by an amplitude in the *x* 2706, *y* 2707, and *z* 2708 directions as well as by the frequency of vibration represented by the peak ω 2710 and by the frequency at which each of the four ORMs are driven by the ORM control logic 2712-2715. Thus, to achieve maximum vibration energy of the vibration of the generic device at any of the resonant frequencies for the device, the ORMs are driven at the control frequencies for that resonant frequency.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response. Figure 28A shows the vibration-response for a simple device, vibration of which is stimulated by a single ORM. There is a single natural frequency ω_1 2802 corresponding to the vibration-energy peak 2804 in the vibration-response plot of vibration energy with response to frequency. Figure 28B shows a plot of the frequency of vibration generated by an ORM with respect to time over a time interval that represents an ORM control scheme. In Figure 28B, the vertical axis 2810 represents the frequency at which the ORM is driven by ORM-control input and the horizontal axis 2812 represents time. The control curve 2814 indicates that the ORM is non-linearly driven over an initial time period 2816 to the natural frequency ω_1 2818 for the device in which the ORM is included. At a final point in time t_f 2820, input to the ORM is discontinued. Figure 28C shows a vibration-response curve for the device containing the ORM when the ORM is operated according to the control curve 2814 discussed above with reference to Figure 28B. As shown in the vibration-response curve 2822, there is an initial lag time 2824 following initiation of the control scheme before a perceptible device vibration occurs, at time t_i 2826. The vibrational energy, or amplitude of vibration, very steeply increases from this point on as the ORM is controlled to approach and equal the natural frequency ω_1 for the device. At time t_f 2820, the vibrational energy of the device relatively steeply falls, since the ORM is no longer being driven. However, the vibrational energy does not immediately fall to 0, as in the control curve, but over a short period of time 2828 after the ORM ceases to be driven.

The generic device, as discussed above, contains a memory that may store various types of control schemes, or control patterns, for the ORMs that are controlled by the ORM control logic. Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device. The example patterns include a linear ramp-up and ramp-down pattern 2802, a constant control over a specified duration of time 2904, and an oscillating control 2906. The patterns may be parameterized by the duration of the pattern 2908 and the maximum input to the ORM 2910. The input may be specified as the current or voltage, for certain types of ORMs. Other ORMs may be controlled by digital control signals in

which numerically encoded commands are transmitted to the ORM. The control patterns can be scaled in both time and frequency in order to generate a variety of equivalent vibration responses for the ORM with similar forms, but different maximum amplitudes and over different periods of time.

A set of scalable control patterns, such as those shown in Figure 29, and a table of resonant frequencies, such as that shown in Figure 27, can be used to generate a table of different types of vibration that can be generated in the generic device by controlling the ORMs within the device according to scaled control patterns. Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25. Each row in the table, such as row 3004, represents a different vibration type that can be produced in the generic device by controlling the ORMs within the device. For example, a cell phone may use a variety of different haptic vibration signals to alert the cell phone user of many different types of events. Each different vibration signal corresponds to a different vibration- type. Each vibration type is characterized by a vibration-type identifier 3006, an amplitude range for the vibration 3008, a reference duration for the vibration 3010, and the control pattern and scaling parameters for the pattern for each of the ORMs 3012-3015. Each vibration type can be scaled within the amplitude range and may also be scaled for a desired duration.

By using either external or internal sensors to characterize the natural resonant frequencies for a physical device or system that contains ORMs, a large number of different vibration responses for the physical device or system can be compiled based on the resonant frequencies as well as a set of ORM control patterns. In alternative vibration-control approaches, the different types of vibration responses may be computed, on the fly, rather than tabulated based on a set of control patterns. However, in all cases, characterization of the resonant frequencies of the device or system that is vibrated by the ORMs contained within the device or system is a necessary step in producing predictable vibration responses via ORM control.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figure 31 illustrates the inner control loop of the control logic within the physical device shown in Figure 25. The inner control loop waits, in step 3102, for a next event and then handles the event that occurs. When the event is a characterize-vibration event, as determined in step 3104, the routine *characterize vibration* is called to handle the event in step 3106. When the event is a generate-vibration event, as determined in step 3108, a generate-vibration routine is called in step 3110 to generate a vibration in response to the generate-vibration event. When the next event is a user-input event, as determined in step 3112, a process-input routine is called, in step 3114, to handle the input from the user. Ellipses 3116 are used in Figure 31 to indicate that many other types of events are handled by the inner event loop of the control logic. When, after handling the most recently occurring event, there are other events that are queued for handling which arose while handling the most recently handled event, as determined in step 3118, then a next event is dequeued in step 3120 with control flowing back to step 3104. Otherwise, control flows back to step 3102 where the inner event loop waits for a next event to occur.

The characterize-vibration event 3104 is an event that is raised by control-logic routines, timer-expiration handlers, and by other control logic in order to control the ORMs and sensors within the generic device to carry out a re-characterization of the vibration-response for the physical device, as discussed above with reference to Figures 26A-B, in order to update the resonant-frequency table, such as the resonant-frequency table discussed above with reference to Figure 27. In devices that employ a vibration-type table, such as the vibration-type table discussed with reference to Figure 30, the vibration-type table is also updated following update of the resonant-frequency table.

A generate-vibration event is raised by control logic in order to vibrate the generic device for a variety of different reasons. As one example, the device may be vibrated in response to user input. As another example, the device may be vibrated when the control logic determines that any of various alert conditions have arisen. As yet another example, generate-vibration events may be raised in order to communicate information to a device user.

Figure 32 provides a control-flow diagram for the characterize-vibration event handler, called in step 3106 of Figurer 31. In step 3202, the routine calls a subroutine *sweep* in order to generate a sampling of a vibration-response curve, surface, or hyper-dimensional surface. In step 3204, the routine calls a store-vibration-maxima subroutine in order to identify the resonant frequencies from the curve or surface sampled in step 3202. Finally, in step 3206, the routine calls a compute-and-store-vibration-type-controls subroutine in order to update the vibration-type table based on the new resonant-frequency determination made in steps 3202 and 3204.

Figure 33 provides a control-flow diagram for the subroutine *sweep*, called in step 3202 of Figurer 32. In step 3302, the subroutine *sweep* initializes a data structure for storing a vibration response. As discussed above, the vibration response may be a sampled curve, sampled surface, or sampled hyper-dimensional surface. In the *for*-loop of steps 3304-3306, a frequency sweep of each ORM is initiated. A frequency sweep is a control pattern that continuously sweeps each ORM over a wide range of driving frequencies. Each ORM repeats a single frequency sweep over a different time interval, so that following a number of iterations, the multi-dimensional ORM-driving-frequency space can be sampled. Then, in the *for*-loop of steps 3308-3312, the *sweep* routine continuously samples the vibration amplitude or vibrational energy produced in the device, using sensor output, while the driving-frequency sweeps take place. There are, of course, many alternative methods for sampling the multi-dimensional driving-frequency space in order to generate a sampled vibration-response curve, surface, or hyper-surface.

Figure 34 provides a control-flow diagram for the store-variation-maxima subroutine called in step 3204 of Figure 32. In step 3402, the routine identifies local maxima in the vibration-response curve or surface produced by the *sweep* routine. There are many well-known mathematical techniques for identifying local maxima within a curve, surface, or hyper-surface. Then, in the *for*-loop of steps 3404-3406, data that characterizes each of the local maxima are tabulated in the resonant-frequency table.

Figure 35 provides a control-flow diagram for the compute-and-store-vibration-type-control subroutine called in step 3206 of Figure 32. In a *for*-loop of

steps 3503-3509, each possible set of ORM/control-pattern/resonant-frequency triples is considered. The currently considered triple is used to estimate the vibration mode and intensity of the resulting device vibration, in step 3504. In step 3505, the nearest vibration-type to the estimated vibration mode is identified, if there is one. If a nearest vibration type is found, as determined in step 3506, and when the current ORM/control-pattern/resonant-frequency triple provides a device response closer to the vibration type than the control parameters currently associated with the vibration-type, as determined in step 3507, then, in step 3508, the vibration-type table entry for the found vibration type is updated with the current control parameters represented by the currently considered ORM/control-pattern/resonant-frequency triple. Of course, in certain cases, there may be too many possible ORM/control-pattern/resonant-frequency triples to consider in a reasonable amount of time, in which case the resonant-frequency data may be used in other ways to find the best control parameters for the vibration types in the vibration-type table.

Figure 36 provides a control-flow diagram for the generate-vibration handler called in step 3110 of Figure 31. In step 3602, the handler receives a vibration type, duration, and amplitude associated with the generate-vibration event that is being handled. In step 3604, the appropriate ORM control parameters and patterns are selected from the vibration-type table. In step 3606, the ORM control parameters are scaled according to the received duration and amplitude. In step 3608, a stop time at which the vibration will finish is determined from the received duration. Then, in the *for*-loop of steps 3610-3613, the generate-vibration handler continuously adjusts inputs to each ORM according to the scaled ORM control parameters produced in step 3606.

Precise and Accurate Control of ORMs

The current document is directed to various approaches used within the control logic of an ORM-containing device, appliance, or system, to accurately and precisely control the ORMs to produce time-dependent driving oscillations in conformance with desired control patterns. As discussed above, the combination of controlling ORMs in accordance with control patterns and the accurate characterization

of the resonant frequencies of the device, appliance, or system together allow for reproducible generation of many different types of vibration responses of the device, appliance, or system to the driving oscillations of control-pattern-controlled ORMs.

As further discussed below, many current control regimes fail to accurately reproduce the desired driving time-dependent oscillations in each ORM within a device, appliance, or system. As a result, the vibration response of the device, appliance, or system may vary significantly from a desired vibration response and, perhaps more importantly, may not be accurately reproduced at different points in time, due to the inability to accurately and deterministically control the ORMs to produce driving oscillations in conformance with desired control patterns.

A first approach to more accurately controlling ORMs is to use pulse-width modulation control signals rather than conventional constant-duration control pulses. Figures 37A-D illustrate pulse-width modulation control of an ORM. Figure 37A shows a desired vibration response for an ORM that represents a desired time-dependent driving oscillation for inducing at least a portion of the vibration response of a device, appliance, or system in which the ORM is included. The desired vibration response of the ORM is a sine-wave-like 3702 oscillation that is plotted, in Figure 37A, on an amplitude versus time coordinate system 3704. Figure 37B illustrate a hypothetical control regime that attempts to produce the desired driving oscillation discussed above with reference to Figure 37A in a hypothetical ORM. Constant-width voltage pulses, such as voltage pulse 3706, are input to the ORM to drive the weight or mass in forward and backward directions along the oscillation path. These pulses are plotted in Figure 37B in a voltage versus time coordinate system 3708. Because the constant-width pulses are a rather crude approximation of the desired sine-wave-like vibration response, the control regime shown in Figure 37B comprises a series of positive-voltage, 0-voltage, and negative-voltage constant-width pulses 3706 and 3710-3713 that produce a vibration response, superimposed in Figure 37B over the control pulses, as curve 3716. In general, the pulse widths are controlled by an oscillating clock or clock-based timing signal. The vibration-response curve 3716 differs significantly from the desired driving oscillation shown in Figure 37A. Figure 37C shows the desired vibration response 3702 plotted together with the vibration

response produced by the constant-width voltage-pulse control 3716. In fact, this is actually a relatively favorable case, because the sequence of positive, 0-voltage, and negative voltage pulses shown in Figure 37B has a period close to the period of the desired sine-wave-like vibration response. Otherwise, the actual vibration response would differ even more greatly from the desired vibration response, often having irregularly shaped wave forms.

Figure 37D illustrates pulse-width-modulation control of the ORM. In pulse-width-modulation control, rather than using constant-width voltage pulses to control the ORM, the controller instead uses variable-width pulses. Moreover, much shorter pulses can be used to more precisely control the vibration response of the ORM. In essence, pulse-width modulation allows a variable-frequency control signal to be used, rather than a constant-frequency control signal. Because a variable-frequency control signal can contain a much greater amount of information than a constant-frequency control signal, the pulse-width-modulation control signals can be used to much more precisely steer the vibration response of the ORM towards a desired wave form. As shown in Figure 37D, many more voltage pulses are used in order to achieve the sine-wave-like vibration response of the ORM. For example, in the constant-width-pulse control shown in Figure 37B, a positive-voltage pulse 3706, a 0-voltage pulse, and a negative-voltage pulse 3710 are used to attempt to approximate the first period of the desired vibration response. By contrast, as shown in Figure 37D, four positive-voltage pulses 3720-3722 and 3726 and three negative-voltage pulses 3723-3725 are employed to produce the first period of the desired vibration response. Moreover, these seven pulses have varying pulse widths and are irregularly spaced along the time axis.

Another problem associated with conventional control of ORMs is that the vibration response produced by a control pattern is often very different from the vibration response that might be predicted from the control pattern or desired. For example, in Figure 38A, a control pattern is shown that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806. Of course, this control pattern may correspond to a large number of positive-voltage pulses in the time interval t_i to t_f. The vibration response of the ORM is shown in Figure 38B. In this figure, the horizontal time axis 3808 has been rescaled to show more detail. The control

pattern 3802 shown in Figure 38A might be initially assumed to produce a pulse of constant-amplitude vibrations over the time interval t_i to t_f. However, as shown in Figure 38B, the actual vibration response of the ORM, shown as curve 3810, includes an initial ramp-up interval 3812 in which the amplitude of the vibration response steadily increases to the desired amplitude, a middle period 3814 in which the ORM is oscillating at the desired amplitude, a short period 3816 at the end of the time interval t_i to t_f during which, in anticipation of the sharp control-pattern edge at time t_f, the control voltage is dropped to 0 so that the vibration will fall to a low level at time t_f, and a fourth undesired ramp-down interval 3818, extending well past the time t_f, during which vibration of the ORM continues at increasingly smaller amplitudes.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f. In a first plot 3902, the naïve control pattern is shown. In a second plot 3904, the naïve control pattern is modified in order to produce the constant-amplitude oscillation that is desired. First, a large-voltage input 3906 occurs prior to time t_i in order to quickly force the ORM to begin vibrating. From time t_i to a time prior to time t_f, a lower-voltage input 3908 is provided in order to control the ORM to oscillate at the desired amplitude. Prior to time t_f, a negative-voltage control signal 3910 is input to the ORM in order to sharply drive the ORM towards oscillation out of phase with the desired driving oscillation during the time interval t_i to t_f. This negative-voltage control signal is then relaxed linearly 3912 in order to stop ORM vibration in a relatively short period of time. As shown in plot 3914 in Figure 39, the vibration response of the ORM much more closely approximates a desired constant-amplitude vibration between time intervals t_i and t_f.

Many different types of control inputs can be used to shape the vibration response of an ORM. For example, short control pulses can push the vibration to a different phase, resulting in cancellation of the previously established oscillation. The various types of inputs depend on the type and form of control signals that can be transmitted to the ORM, which, in turn, depends on the type of ROM, the driving force used to induce oscillation of the moving mass within the ORM, and the type of logic circuitry that receives input signals and translates them into oscillations.

Thus, in addition to pulse-width modulation, a wide variety of different types of complex control signals may be devised in order to achieve the vibration response desired from the simple control patterns discussed above, including control pattern 3802 shown in Figure 38A. Many different control-signal parameters may be varied in order to control an ORM to provide a desired vibration response, including varying the voltage of the control signal, using pulse-width modulation to finely tailor the control signal to produce a desired vibration response, and adjusting the control signal to include pre-response and post-response signals to remove undesired ramp-up and ramp-down periods in the vibration response.

In addition to varying the input control to an ORM, an ORM may be designed to include a variety of different mechanical controls to further increase the range of vibration responses of the ORM. Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs. Equivalent electromagnetic features may be included in other types of ORMs. Figure 40A illustrates a first type of ORM. In a first diagram 4002, the ORM is shown in an equilibrium, non-vibrating position. The ORM includes a moveable weight or mass 4002 that is connected to two ends of the ORM 4004 and 4006 by springs 4008 and 4010. Diagram 4012 shows the ORM when the movable mass 4002 has been moved, by application of a translational force, such as an electromagnetic force, to the furthest position in the leftward direction along the oscillation path. In this position, spring 4010 is compressed and spring 4008 is extended. In both cases, the springs have potential energy that produces forces that force the movable mass 4002 back in the rightward direction towards stop 4012. Diagram 4014 shows the ORM with the movable mass in the furthest rightward direction.

Figure 40B shows the equilibrium and largest-amplitude positions of a movable mass in a different type of ORM. In a first diagram 4016, the ORM is shown in an equilibrium position. The ORM features an arc-like oscillation path 4018 along which the moving mass 4020, attached to a rotor 4022, oscillates. The moving mass 4020 is attached to the rotor 4022 by a flexible support 4024. Diagram 4026 shows the ORM with the movable mass in the furthest leftward position and diagram 4028 shows

the ORM with the movable mass in the furthest rightward direction, similar to the positions shown for the ORM of Figure 40A in diagrams 4012 and 4014.

Figure 40C illustrates movable mechanical stops included in the ORM discussed above with reference to Figure 40A. The movable stops are depicted by features 4030 and 4032 in a first diagram 4034. Of course, the depictions do not necessarily reflect the shape, size, and structure of mechanical stops needed to stop motion of the moveable mass in the various different types of ORMs, but are instead used to illustrate positioning of the moveable stops and their deployment. In a second diagram 4036, the movable stops have been repositioned 4038 and 4040 in order to limit the length of travel of the moving mass 4002. The second diagram 4036 shows the leftward extent of motion of the moving mass 4002 with the movable stops deployed and diagram 4042 shows the rightward extent of travel of the moving mass when the movable stops are deployed. Similar illustration conventions are used, in Figure 40D, to illustrate deployment of movable stops in the ORM discussed above with reference to Figure 40B. Use of movable stops can significantly alter the vibration response of the ORM to a given control input. This may include changing the amplitude of the vibration response, the frequency of the vibration response, and changing the force imparted by the moving mass to the ORM when the moving mass strikes the stops versus the original end stops 4002 and 4004. In general, the vibration-response alterations are complex functions of the geometry, material composition, and driving forces used in the ORM.

Figures 40E-F illustrate use of the movable stops, discussed above with reference to Figures 40C and 40D, as latches. As shown in a first diagram 4048 in Figure 40E, the movable stops have been repositioned 4050 and 4052 closer to the center of the oscillation path. As shown in diagram 4054, the left-hand movable stop 4056 has been deployed when the moving mass 4002 has just reached its leftward, stopped position. As a result, motion of the moving mass is stopped, resulting in an immediate cessation of the driving oscillation produced by the ORM and a higher force exerted in the last oscillation on the left-end stop 4004 of the ORM. Diagram 4058 shows the right-hand movable stop 4052 deployed to latch the moving mass 4002 at its furthest right-hand position. Figure 40F shows similar deployment of the movable

stops, in the ORM discussed above with reference to Figure 40B, to latch the moving mass at its leftward and rightward extents. Latching of the moveable mass may trap the moveable mass in a high-potential-energy state, so that immediate, rapid oscillation may ensue when the latch is released. Latching may also significantly alter the relaxation of the oscillation at the end of control-pattern execution.

The current document is directed to employing the various different types of alternative control of ORMs to more accurately generate desired vibration responses. This involves use of a much greater amount of information about the ORM than used in the vibration response table discussed above. Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document. The information is stored in five different tables. An ORM table 4102 stores control information for each different ORM in a device, appliance, or system. This information includes an identifier for the ORM 4104, an indication of the ORM type 4105, an indication of the minimum pulse width that can be input in a control signal 4106, an indication of the minimum amplitude 4107 and maximum amplitude 4108 of an input control signal, indications of whether or not mechanical or electromagnetic latches are available in the ORM 4110 and 4112, the oscillation path length within the ORM 4114, the number of movable stops, or path blocks included in the ORM 4115, and the positioning range for each moveable stop 4116-4117. An event-types table 4120 includes various different types of control events. These may include deployment of latches, movement of movable stops, and output of control pulses of various different widths and amplitudes. An events table 4122 includes ordered pairs of event types and relative times that each represents one of the many different types of control events that can be input to ORMs. Each control event includes an event ID 4123, an event type 4124, and a relative time that specifies a time point within a control pattern 4126 at which the event occurs. Table 4128 includes the actual control actions that a logic controller employs to initiate each type of event in each type of ORM. For each type of control, the table includes an indication of the event type 4130, the ORM type 4131, a control ID 4132, a signal type 4133, a signal strength 4134, and any of many different other characterizations of the type of control 4135 executed by the control logic in order

to control an ORM to produce a particular type of event. Finally, table 4140 lists all of the different types of control patterns that can be used to control ORMs. These are equivalent to the previously discussed control patterns. Each control pattern includes a control-pattern identifier 4142, an indication of the number of events in the control pattern 4144, and the event identifiers for those events 4146-4149.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36. The alternative information incorporates more accurate control of ORMs using the information and techniques discussed above with reference to Figures 37A-41. In step 4202, the routine receives a vibration type, duration, amplitude, and start time for a desired device, appliance, or system vibration response. Then, in the *for*-loop of steps 4204-4212, the routine prepares for controlling each of the ORMs in the device, appliance, or system. In step 4205, a control-pattern ID is selected from the vibration-type table for the ORM, modified with respect to the previously described vibration-type table to include the identifiers of control patterns that are tabulated in the control-patterns table 4149. In step 4206, the identified control pattern is selected from the control-patterns table. In the inner *for*-loop of steps 4207-4212, each event is selected from the control pattern selected in step 4206. For each event, a corresponding event control entry is selected from the event-control table, in step 4208. The controls are scaled, in step 4209, according to the desired duration and amplitude for the vibration response. In step 4210, the time associated with the event, selected from the events table, is also scaled. In step 4211, the scaled controls and times are added to a list of time-ordered events, the controls for which are issued to the ORM during generation of the desired vibration response. In step 4214, the routine waits until the desired start time for the vibration response. Note that the desired start time takes into consideration any pre-vibration-response controls needed to produce the desired vibration response. Then, in the *while*-loop of steps 4216-4222, the routine carries out ORM control over a set of time points spanning the desired vibration-response duration. In the inner *for*-loop of steps 4217-4220, the routine initiates a control sequence for each of the time-ordered events for each of the ORMs at the points in time in which the control sequence is specified for issuance. Then, in step 4221, the routine waits for a next update-control time point.

The above-discussed methods for more accurate and reliable control of ORMs provide increased opportunities for generating increasingly complex vibration responses in devices, appliances, and systems that contain ORMs. However, with increasing complexity, attention is needed to simplifying and increasing the efficiency of driving-oscillation sensing in order to provide feedback-based control to ORMs. In addition, with more accurate control, it is possible to increase the complexity of ORM time-dependent driving oscillations, significantly increasing the types of time-dependent driving oscillations that can be encoded in control patterns and thus increasing the device, appliance, and system vibration responses to controlled ORM driving oscillations.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control. Figure 43 provides a simplified ORM-containing device architecture similar to that provided by Figure 25, discussed above. However, as shown in Figure 43, each of the ORMs, such as ORM 2504, is coupled to an additional passive oscillator, such as passive oscillator 4302. In various different implementations, a given ORM may be coupled to one, two, or more passive oscillators. When an ORM is mechanically coupled to one or more additional passive oscillators, the passive oscillators greatly increase the number of degrees of freedom for vibration of the combined ORM and one or more passive oscillators. The mathematical models for the vibration modes and resonant frequencies become far more complex, involving eigenvalue problems arising from coupled differential equations. As discussed above, the number of resonant frequencies for a system is generally proportional to the number of vibrational degrees of freedom. Furthermore, coupling passive oscillators to ORMs may provide new, complex vibrational modes with different frequencies and amplitudes. Thus, vibration components comprising an ORM and one or more passive oscillators can significantly increase the complexity of the time-dependent driving oscillations produced by these vibration components, and therefore greatly expand the types, frequencies, and modes of vibration responses produced in a device, appliance, or system containing the complex vibration components.

In the simpler system shown in Figure 25, two vibration sensors 2510 and 2511 were included. These vibration sensors detected vibration in one, two, or three orthogonal directions of the device, appliance, or system 2502 in which multiple ORMs are included. However, as shown in Figure 43, sensors that provide information regarding the driving oscillations produced by ORMs and passive oscillators, such as sensors 4304 and 4305 in ORM 2504 and passive oscillator 4302, respectively, may also provide information to local control logic, such as control logic 4306, within ORMs as well as the controller 2516 that controls one or more ORMs within the device, appliance, or system 2502. The sensors local to ORMs and passive oscillators may be designed to sense driving-oscillation characteristics while vibration sensors 2510 and 2511 are designed to sense the vibration response of the entire device, appliance, or system 2502.

By including a variety of different types of sensors within different positions and components of an ORM-containing device, appliance, or system, an opportunity is provided for hierarchical sensing and corresponding feedback control within a device, appliance, or system. In many cases, the output from a vibration sensor may be difficult to translate into accurate feedback information and corresponding control signals. For example, the vibration sensed by the vibration sensors 2510-2511 may be indirectly related to the individual driving oscillations produced by the ORM-based vibration components, such as the vibration component comprising ORM 2504 and mechanically coupled passive oscillator 4302. In such cases, significant inference is necessary to logically infer the driving oscillations of the vibration components producing the vibration-sensor signals and to compute corresponding adjustments to ORM control. Furthermore, there may be significant temporal lags between sensor vibration and the driving oscillations that produce the sensor vibration. Many of the common techniques for sensing ORM driving oscillations in order to provide local feedback to ORMs may suffer similar problems. Furthermore, there may be many different types of interferences and couplings between electromechanical driving forces, electromagnetic sensors, and other device components that mask or entirely prevent accurate inference of the real-time characteristics of ORMs and the vibration-response of the entire device, appliance, or system. For this reason, simpler and direct

types of sensing and control can provide enormous benefits in achieving desired vibration responses of the entire device, appliance, or system, particularly in devices, appliances, and systems that include multiple vibration components, each consisting of an ORM and one or more passive oscillators as well as various types of vibration sensors external to ORMs and passive oscillators as well as sensors within, or coupled to, ORMs and passive oscillators.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control. In Figure 44, a linear ORM 4402, used in previous examples, is again shown as an example ORM. The linear ORM includes a mass or weight 4404 that is driven electromagnetically by a drive coil 4406 to oscillate along a linear tube 4408. In this ORM, two sensor coils 4410 and 4412 are additionally included in order to detect motion of the weight or mass 4404 within the ORM as it is driven to oscillate. The sensor information may be provided to an internal ORM control logic 4414 or to the controller 2516 within the device, appliance, or system that includes the ORM. In certain cases, both the internal ORM control logic as well as the device controller may receive sensor information, for various different types of feedback-based control purposes. In the lower portion 4420 of Figure 44, a small control-flow diagram is provided to indicate how the sensor information is used. When a controller receives a target frequency ω_t at which the ORM is to oscillate, in step 4422, the control logic or controller initiates oscillation of the weight or mass, in step 4424, and then, in the *while*-loop of steps 4426-4430, continues to monitor the sensor output and modify control input to the ORM in order that the ORM oscillates at the target frequency ω_t. This involves reading the sensor data to determine the actual frequency of oscillation ω_a, in step 4427, then determining a difference between the target and actual frequencies in step 4428, using the determined difference to compute modifications to the current control of the ORM and modify the control in a way estimated to result in the ORM achieving the target frequency ω_t, in step 4429, and executing the modified control in step 4430. In many cases, the computations are sufficiently complex that the feedback-based control needs to be implemented by control routines running on a processor. Furthermore, because the sensors 4410 and 4412 are essentially external to the actual oscillating mass or

weight and oscillation path, the data that they output does not directly correspond to position and velocity data for the moving mass or weight, but is instead a signal proportional to the current induced in the sensor coils by the moving mass. A fair amount of interpretation is required to convert the sensor information into velocity and position information, or even into information related to the actual frequency ω_a of oscillation. Moreover, there may be significant electromagnetic interference between the drive coil 4406 and the sensor coils 4410 and 4412, limiting the accuracy at which the actual frequency ω_a or mass position and velocity can be determined. Sensor-coil-based inferences may also suffer from significant lag times between passing of the moving weight through the sensor coil and generation of a corresponding signal. In a complex system in which many different sensors are being monitored for many different ORMs, as well as sensors that detect the vibration response for a device, appliance, or system containing the ORMs, use of inferential feedback information, such as that provided by the sensor coils shown in Figure 44, may be problematic, at best.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the data provided one or more direct sensors. When a target frequency ω_t is received in step 4512, the control initiates oscillation of the mass in step 4514. In addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the one or more direct sensors and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the difference and position with time over several

readings, but because of the direct nature of the position sensing, is not inferential and is less computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

To clarify, direct sensors directly sense, in real time, the location of the moving mass of an ORM. Optical sensors, such as that shown in Figure 46, use light sources to directly identify the location of the moving mass, and the rate of change of

the accurately identified positions is straightforwardly converted into a very good approximation to the instantaneous velocity of the moving mass by simple arithmetic operations. A direct sensor provides position and velocity data in real time, constrained principally by the time needed for propagation of light, the time needed for propagation of electrical-current propagation, sensor response times, and the time needed for carrying out a small number of computer-instruction executions. These times are all far faster than the time needed for an ORM moving mass to move far enough for the motion to produce a different sensor reading, so that, in essence, a direct sensor easily produces an accurate, real-time position and velocity for the moving mass. Indirect sensors, by contrast, do not directly detect the position and velocity of an ORM moving mass. For example, as discussed with reference to Figure 44, above, the sensor-coil sensors may exhibit signal changes prior to and following the moving mass being located adjacent to them and as a result of current changes in the driving coil. Therefore, only by retrospective computational analysis can an approximate location of the moving mass be indirectly inferred. Furthermore, the sensor-coils may respond differently to the moving mass depending on a variety of external factors and even depending on the velocity of the moving mass. Indirect sensors cannot produce real-time position and velocity values for an ORM moving mass, and the accuracy of the approximations of the position and velocity may significantly deteriorate when the oscillation frequency is changing. Vibration detectors are even less accurate, since the directions and amplitudes of the vibrations of an entire device may not align with the direction of moving-mass vibration, may vary due to many different external factors, including the orientation of the device with respect the gravitational field, the local mechanical environment of the device, the model of the moving-mass trajectory they use for inferring moving-mass position, and other such factors. In these cases, inferring the position and velocity of the ORM moving mass is generally associated with large errors and computational time lags. Direct moving-mass position-and-velocity sensors therefore provide accurate and real-time, nearly instantaneous moving-mass position and velocity data. Indirect moving-mass position-and-velocity sensors do not provide real-time, nearly instantaneous moving-mass position and velocity data, and do not

achieve the accuracy, in the non-real-time position and velocity values they produce that is achieved by direct sensors.

Although the present invention has been described in terms of particular embodiments, it is not intended that the invention be limited to these embodiments. Modifications will be apparent to those skilled in the art. For example, any of many different design and implementation parameters may be varied in order to provide different implementations of the ORM control logic discussed above, including choice of type of logic control, programming language, in the case of a processor-controlled controller, modular organization, data structures, control structures, logic circuitry, processor type, and many other such design and implementation parameters. Many different types of direct sensors that directly determine the velocity and position of the oscillating mass within an ORM can be used in different types of ORMs. Various types of electromagnetic sensors that sense position, precious-metal brush-contact sensors, and Reed switches are examples of the many types of direct sensors that can be used to directly determine oscillating-mass position and velocity and induce direct, corresponding control of the ORM.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. The foregoing descriptions of specific embodiments of the present invention are presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments are shown and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents:

CLAIMS

1. An oscillating resonant module comprising:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

2. The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more:

mechanical sensors;

electromagnetic sensors; and

optical sensors.

3. The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass from the positions of the mass at two or more points in time.

4. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

5. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

6. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

7. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

8. The oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

9. The oscillating resonant module of claim 8 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

10. A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

the one or more oscillating resonant modules, each of which responds to control inputs to produce driving oscillations and includes a sensor that provides sensor data to a control component within the oscillating resonant module;

one or more vibration sensors;

a stored characterization of the natural vibration frequencies of the physical device; and

a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.

11. The physical device of claim 10 wherein each of the one or more oscillating resonant modules comprises:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

12. The physical device of claim 10 wherein the characterization of the natural vibration frequencies of the physical device is determined by simultaneously sweeping the driving oscillations of the one or more oscillating resonant modules over driving-oscillation ranges and monitoring the physical device vibration response using output from the one or more vibration sensors to identify the maximum-amplitude frequencies.

13. The physical device of claim 12 wherein the characterization of the natural vibration frequencies of the physical device is determined periodically by the controller.

14. The physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device.

15. The physical device of claim 10 wherein at least one of the each of the one or more oscillating resonant modules is mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

16. The physical device of claim 15 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

17. An oscillating resonant module comprising:

a first mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along a first oscillation path that represents a segment of a space curve;

a second mass that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve; and

a control component that

receives control signals input to the oscillating resonant module, and

controls oscillation of the first mass to produce a predetermined vibration response according to the received control signals by generating a control output to an actuator that drives the first mass to oscillate.

18. The oscillating resonant module of claim 17 further comprising:

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

19. The oscillating resonant module of claim 17 further comprising:

one or more sensors that output indications directly correlated with the position of the second mass within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

20. The oscillating resonant module of claim 17 included within a physical device to drive a vibration response in the physical device.

ABSTRACT OF THE DISCLOSURE

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

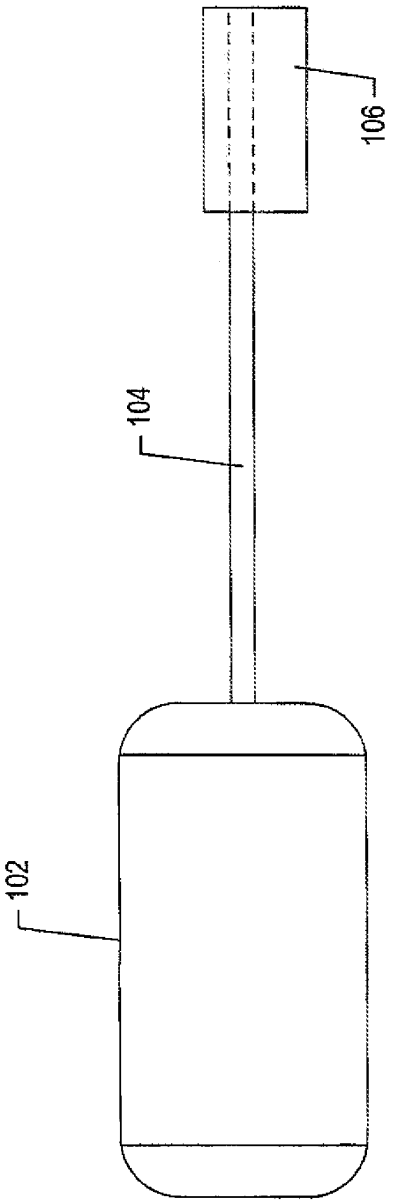


FIG. 1A
--Prior Art--

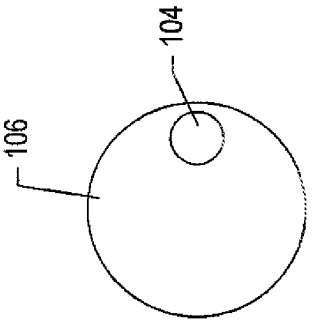


FIG. 1B
--Prior Art--

Electronic Patent Application Fee Transmittal

Application Number:	16806925
Filing Date:	02-Mar-2020
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER
First Named Inventor/Applicant Name:	Robin Elenga
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
Attorney Docket Number:	35099.008C1

Filed as Small Entity

Filing Fees for Utility under 35 USC 111(a)

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Basic Filing:				
UTILITY FILING FEE (ELECTRONIC FILING)	4011	1	75	75
UTILITY SEARCH FEE	2111	1	330	330
UTILITY EXAMINATION FEE	2311	1	380	380
Pages:				
Claims:				
Miscellaneous-Filing:				
LATE FILING FEE FOR OATH OR DECLARATION	2051	1	80	80
Petition:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				
Miscellaneous:				
		Total in USD ($)		865

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First Named Inventor/Applicant Name:	Robin Elenga
Customer Number:	34395
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
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1		35099-008C1-E-MP-1.pdf	8422785 31c51cfbabea89983195c96595b21eb26fab b5b5	yes	179

Multipart Description/PDF files in .zip description

Document Description	Start	End
Transmittal Letter	1	1
Miscellaneous Incoming Letter	2	3
Authorization for Extension of Time all replies	4	4
Oath or Declaration filed	5	5
Oath or Declaration filed	6	6
Oath or Declaration filed	7	7
Application Data Sheet	8	15
Drawings-only black and white line drawings	16	68
Specification	69	118
Claims	119	122
Abstract	123	123
Drawings-only black and white line drawings	124	124
Specification	125	174
Claims	175	178
Abstract	179	179

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MARKED UP SPEC

OSCILLATING-RES[illegible] JLE CONTROLLER

CROSS-REFERENCE TO RELAT[illegible] IONS

This application i[illegible] ion-in-part of Application No. 15/043,584, filed February 14, 201[illegible] the benefit of Provisional Patent Application No. 62/116,144, filed F[illegible] 5.

TECHNICAL FIELD

The current docume[illegible] ibration-generating devices and, in particular, to vibration modules that[illegible] ated into a wide variety of different types of electromechanical devices[illegible] produce predetermined vibration responses.

BACKGROUND

Vibration-inducing [illegible] hanisms have been used for many years in a wide variety of different[illegible] ances, toys, and other devices and systems. Examples include vibra[illegible] erated by pagers, smart phones, vibration-driven appliances, such a[illegible] appliances, electric toothbrushes, electric toy football games, and man[illegible] s, devices, and systems. The most common electromechanical system[illegible] ting vibrations is an intentionally unbalanced electric motor.

Figures 1A-B illustra[illegible] d electric motor typically used for generating vibrations in a wide vari[illegible] devices. As shown in Figure 1A, a small, relatively low-power electri[illegible] tates a cylindrical shaft 104 onto which a weight 106 is asymmetri[illegible] d. Figure 1B shows the weight asymmetrically mounted to the sh[illegible] vn at the weight and shaft in the direction of the axis of the shaft. A[illegible] re 1B, the weight 106 is mounted off-center on the electric-motor sh[illegible] es 2A-B illustrate the vibrational motion produced by the unbalanced[illegible] hown in Figures 1A-B. As shown in Figures 2A-B, the asymmetrical[illegible] ght creates an elliptical oscillation of the end of the shaft, normal to th[illegible] en the shaft is rotated at relatively high speed by the electric motor.[illegible] s displacement of the weight and

shaft from the stationary shaft axis
and shaft along the shaft axis, as i
provided at the periphery of the disk
rotation of the shaft. When the sha
the weight traces an ellipsoid 206 a
smaller ellipsoid 210. Were the sha
a position 212 in the center of the
asymmetrically-mounted weight att
weight-distribution characteristics
together create forces that move the
the shaft is rotated at relatively hig
shown in Figure 2B, by a major a
direction of the major axis of vibra
ellipsoids, shown in Figure 2A, an
amplitude of vibration in this directi
and forth along a defined path is
amplitude/minor-axis-amplitude rat
path, but, because the vibration is
possible to achieve oscillation back
path traced by the shaft center may
the unbalanced electric motor is equ
shaft, and is therefore constrained
At low rotational speeds, little vibra

While effective in
associated with the unbalanced-elec
shown in Figure 1A, commonly use
discussed above. Unbalancing the
vibrations that can be harnessed for
unbalanced forces within the motor
Enormous care and effort is undert
vehicles, and other types of machir

tated, looking down on the weight
n Figure 2A, a small mark 202 is
of electric-motor shaft to illustrate
speed, a point 204 on the edge of
the shaft 208 traces a narrower and
center of the shaft would remain at
rotation, but the presence of the
aft, as well as other geometric and
otor, shaft, and unbalanced weight
along the elliptical path 210 when
ovement can be characterized, as
or axis 222 of vibration, with the
direction of the major axis of the
e major axis corresponding to the
lications, in which oscillation back
ers seek to force the major-axis-
as possible, to approach a linear
otational force, it is generally not
a defined path. In many cases, the
lar. The frequency of vibration of
nal frequency of the electric-motor
ich the motor can rotate the shaft.

ations, there are many problems
tion-generating units, such as that
devices, systems, and applications
ric motor not only produces useful
ions, but also produces destructive,
rapid deterioration of motor parts.
y balance rotating parts of motors,
nsequences of unbalanced rotating

parts are well known to anyone fa
such devices and systems. The
particularly hand-held devices and
for generating vibrations may rang
hours of use, after which the vibra
precipitously as the electric motor
motors are relatively inefficient at p
of power is consumed by an unbala
force than the theoretical minimun
force. As a result, many hand-held
generating vibrations quickly con
motors, as discussed above, oscill
or space curve, cannot generally
Unbalanced electric motors genera
total vibrational-force/frequency sp
with respect to frequency for vario
is shown as a continuous hypothetic
discrete. As shown in Figure 3, for
held appliances, only a fairly narro
in Figure 3) generate a significant v
relatively modest. The bulk of ene
used to spin the shaft and unbalanc
forces within the motor. Only a r
translated into desired vibrational f

Because of the abo
employed unbalanced-electric-m
manufacturers, and, ultimately, us
devices, appliances, and systems co
generating units for incorporatior
systems.

mobiles, machine tools, and other
of many devices and appliances,
employ unbalanced electric motors
ns of hours to a few thousands of
produced by the devices declines
deteriorate. Unbalanced electric
onal motion. A far greater amount
otor to produce a given vibrational
d to produce the given vibrational
loy unbalanced electric motors for
during use. Unbalanced electric
and forth along a predefined path,
by unbalanced electric motors.
only a very limited portion of the
hows a graph of vibrational force
lanced electric motors. The graph
gh, of course, actual data would be
ower electric motors used in hand-
encies centered about 80 Hz (302
Moreover, the vibrational force is
by an unbalanced electric motor is
to overcome frictional and inertial
portion of the consumed energy is

isadvantages with the commonly
n-generation units, designers,
ariety of different vibration-based
ore efficient and capable vibration-
nsumer appliances, devices, and

SUMMARY

The current docume arious types of oscillating resonant modules ("ORMs"), including l vibration modules, that can be incorporated in a wide variety devices, and systems to provide vibrational forces. The vibrational uced by back-and-forth oscillation of a weight or member along a path. nent of a space curve. A controller controls each of one or more ORI driving oscillations according to a control curve or control pattern for t ecifies the frequency of the driving oscillations with respect to time. cillations, in turn, elicit a desired vibration response in the device, ap m in which the one or more ORMs are included. The desired vibrati ieved by selecting and scaling control patterns in view of known encies of the device, appliance, or system.

BRIEF DESCRIPTION OF THE D

Figures 1A-B illustr d electric motor typically used for generating vibrations in a wide vari devices.

Figures 2A-B illus tional motion produced by the unbalanced electric motor shown in

Figure 3 shows a gr al force with respect to frequency for various types of unbalanced ele

Figures 4A-D illustr is meant by the phrase "oscillating resonant module" in the current doc

Figures 5A-G illustr r type of ORM.

Figures 6A-B illustr switch that can be used, in various ORMs, to change the direction of o a coil that drives back-and-forth oscillation within the ORM.

Figure 7 provides a of the ORM illustrated in Figures 5A-G.

Figures 8A-C provi diagrams that illustrate the control program, executed by the CPU, tha ion of an ORM.

Figure 9 represents t uencies and vibrational forces that can be achieved by different impler RM and ORM control programs.

Figure 10 shows a pl ıde/frequency space and regions in that space that can be operationally balanced electrical motors and by ORMs.

Figures 11-18 show ferent alternative implementations of ORMs.

Figure 19 illustrates of an implementation of the ORM shown in Figure 17.

Figure 20 illustrates

Figure 21 illustrates ver.

Figure 22A illustrate of a stator having two coil layers.

Figure 22B illustrate of a stator having four coil layers.

Figure 22C illustrate of a stator having two coil layers.

Figure 23A illustrate driving force that is perpendicular to the surface of a substrate.

Figure 23B illustrate a magnetic armature in an upward position.

Figure 23C illustra with a magnetic armature in a downward position.

Figures 24A-D p ons of various physical and mathematical concepts related to os

Figure 25 shows a of a generic device, appliance, or system that employs ORMs to gene

Figures 26A-B illust sonant frequencies within a device or system.

Figure 27 provides a ant-frequency table for the generic ORM-containing device discussed ence to Figure 25.

Figures 28A-C illust M control scheme combines with a resonant frequency to produce a vit

Figure 29 shows a fe ontrol patterns that may be applied to ORMs by the control logic withi /ice.

Figure 30 shows an on-type table that may be prepared for the generic device shown in Fig

Figures 31-36 provi diagrams to illustrate control logic used in the generic device, discuss eference to Figure 25, to produce well-defined vibration modes or vit ; in the physical device or system.

Figures 37A-D illust modulation control of an ORM.

Figure 38A illustrate rn that involves a constant-voltage signal 3802 from an initial time t_i 3 d time t_f 3806.

Figure 38B illustrate ation response of the ORM.

Figure 39 illustrates the naïve control pattern, shown in Figure 38A, in order to achieve imation of the desired constant-amplitude oscillation in the time int

Figures 40A-40F ill mechanical stops and mechanical latches, two types of mechanical co it may be included in various types of ORMs.

Figure 41 shows exa on that may be stored in order to more accurately control ORMs acc hods and considerations disclosed in the current document.

Figure 42 provides implementation of the routine "generate vibration," discussed abo e to Figure 36.

Figure 43 illustrates for increasing the complexity of ORM time-dependent driving osc ll as increasing and simplifying feedback control.

Figure 44 illustrates RM driving-oscillation sensor that can be employed to provide feedbac or ORM control.

Figure 45 illustrates approach to sensing the driving oscillations produced by an ORM.

Figures 46A-B illust ible direct-sensing approaches.

DETAILED DESCRIPTION

The current docum to various oscillating resonant modules ("ORMs"), including var near oscillating resonant modules ("linear ORMs"), that can be used w ety of different types of appliances, devices, and systems, to generate vi ORMs produce vibrational forces by oscillation of a weight or comp ORM along a segment of a space curve, rather than as a by-produ nced rotation, as in the case of unbalanced electric motors. The e of the ORM vibration-inducing motion effectively addresses man ociated with unbalanced electric motors. Combining an ORM witl ol, so that the driving frequency produced by the ORM falls close t requency of a device in which the ORM is included, results in optima tion with respect to the amplitude and frequency of vibration produce s well as maximal vibration energy of the device. Oscillation within a late into highly directional driving forces produced by the ORM to dr esponse in an appliance or device that incorporates the ORM. The su ncludes a first subsection, in which various types of ORMs are describe ection on which an ORM controller is discussed, and a third subsectio rate methods for ORM control, to which the current document is direc d in detail.

Figures 4A-D illustr is meant by the phrase "oscillating resonant module" in the current contrast to the above-discussed unbalanced electric motors often te vibrations in vibration-driven appliances, an oscillating resonant a weight, or mass, that oscillates back and forth along a path. The pa ar path, or line segment, but, in the general case, can be potentially an nent of a space curve. Figure 4A illustrates operation of a linear osc module. In a first diagram 402, labeled with the time "0," the linear l at time 0 (40 in Figure 4A), with the mass or weight 406 centered w th 408 bounded by two stops 410 and 412. When the linear ORM is eight begins moving to the left, as shown in diagram 414. The small n the disk-like mass 406 indicates

the direction of movement. The m
until the mass strikes the left-hand
the mass reverses and the mass begi
in diagram 418. In diagrams 419 an
of travel during time intervals 4 an
strikes the right-hand stop 404 and
direction, as shown in diagram 422
indefinitely during operation of the
along the linear path. The perio
oscillation can generally be control

Figure 4B illustrate
the weight along a circle to the actu
as discussed above with reference
weight is plotted along a circle 430
position is vertically mapped, as in
line 436 within the circle 430, to a
the circle. The position of the weig
direction, as long as the linear ORM
442. At time 1, indicated by point 4
by vertical dashed line 446, to poin
point 450, the position of the mas
represented by point 454 along the
Thus, as the position of the mass pl
point 454, the direction of movem
continuing in the opposite directio
Small horizontal arrows, such as arr
the linear motion of the mass of th
points. Thus, the back-and-forth
described by a logical revolution of
1, then the position x at time t of
expressed as:

move, as shown in diagram 416,
ich point the direction of travel of
in the opposite direction, as shown
continues in its rightward direction
is shown in diagram 421, the mass
ion, traveling back in the leftward
ndicate that this process continues
e mass oscillates back and forward
and the maximum amplitude of
gnals input to an ORM.

continuous logical movement of
of the weight within a linear ORM,
In Figure 4B, the position of the
presented by point 432, the weight
d line 434 as well as by the solid
on the linear path 440 shown below
the circle, in a counter-clockwise
icated by the dashed circular arrow
he position of the mass is mapped,
ath 440. At time 2, represented by
ath 440 is point 452. At time 3,
on of the mass is again point 448.
circle has moved from point 444 to
has reversed and the mass is now
tion in which it originally moved.
below the linear path 440, illustrate
etween each pair of adjacent time
ne mass in a linear ORM can be
circle. If the circle has a radius of
the actual path of travel can be

$x($ $)$.

where ω is the angular velocity at w presenting the mass moves around the circle.

Figure 4C illustrates curve segment path. In Figure 4C, a short space-curve segment 460 i in a three-dimensional Cartesian coordinate system 462. The weight illating resonant module ("ORM") may oscillate back and forth along rve-segment path. In the first plot in Figure 4C 458, the weight or m left to right along the path, as indicated by the small curved arro ved arrow 460. As shown in the second plot 462 in Figure 4C, once reaches the left-hand end of the space-curve segment, it reverses dir e to the left. As shown in the third plot 464 in Figure 4C, once the wei hes the left-hand end of the space-curve segment, it again reverses dir s to the right. Ellipses 466 indicate that this back-and-forth oscillation e the ORM operates. The space-curve-segment path of the weight in ied by the physical implementation and operation of the ORM.

Figure 4D illustrate l example paths along which the weight or mass of an ORM may as t path is a circular arc 470 and the second path is a partially elliptica 472. As mentioned above, many additional different types of space-c aths for ORMs are possible.

Figures 5A-G illustr r type of ORM. Figures 5A-G all use the same illustration convention l with reference to Figure 5A. The ORM includes a cylindrical housing ch a solid, cylindrical mass 504, or weight, can move linearly along th cylindrically shaped chamber 506 within the cylindrical housing or tu eight is a magnet, in the described an implementation, with polarity ir +" sign 510 on the right-hand end and the "-" sign 512 on the left-han ight 504. The cylindrical chamber 506 is capped by two magnetic disl vith polarities indicated by the "+" sign 518 and the "-" sign 519. Th iets 514 and 518 are magnetically oriented opposite from the magnet the weight 504, so that when the

weight moves to either the extre
chamber, the weight is repelled by
of the cylindrical chamber. In other
to facilitate deceleration and reve
minimize or prevent mechanical-im
off the cylindrical chamber. Fin
cylindrical housing, or tube 502
housing.

Figures 5B-G illust
When an electric current is appl
corresponding magnetic force 524
cylindrical chamber, which accele
force 524. When the weight reache
magnet 514, as shown in Figure 5C
like magnet 514 and the weight
decelerating the weight and revers
as shown in Figure 5D. current is a
producing a magnetic force 582
magnetic force shown in Figure 5E
opposite to the direction in which th
Figure 5E, the weight then moves ri
decelerated, stopped, and then acce
disk-like magnet 516. An electrica
direction 534 as in Figure 5B, again
direction as in Figure 5B. Thus,
reversing polarity, generated by alt
and by the repulsive forces betwee
each end of the hollow, cylindrica
forth within the cylindrical housing
cylindrical chamber with each reve

me right sides of the cylindrical
ke magnets at the left or right ends
like magnets act much like springs,
of motion of the weight and to
weight and the end caps that close
conductive wire 520 girdles the
the mid-point of the cylindrical

f the ORM shown in Figure 5A.
520 in a first direction 522, a
direction parallel to the axis of the
04 in the direction of the magnetic
lose to the corresponding disk-like
ce due to the repulsion of the disk-
nerated in the opposite direction,
As the weight reverses direction,
osite direction 530 to the coil 520,
irection from the direction of the
ates the weight 504 in a direction
lerated in Figure 5B. As shown in
s shown in Figure 5F, the weight is
posite direction by repulsion of the
applied to the coil 520 in the same
solid cylindrical mass in the same
n of a magnetic field with rapidly
ction of current applied to the coil,
agnet and the disk-like magnets at
veight linearly oscillates back and
directional force at the ends of the

Clearly, the amplitu
vibrational forces produced within
chamber in which the weight oscill
weight, the acceleration of the weig
ORM. All of these parameters are e
the ORM can be designed to produ

The frequency of t
determined by the frequency at whi
changed. Figures 6A-B illustrate
ORMs, to change the direction of
oscillation within the ORM. Figure
described next with respect to Fig
directional signal *d* 602 and direct-
signal *d* 602 controls four switches
the input control signal *d* 602 is hig
609 are closed and switches 606 a
indicated by curved arrows, such
604 to ground 612 in a leftward dire
signal *d* is low, or "0," as shown in
coil is reversed. The H-bridge swit
various different types of electrical
rapidly alternate the direction of cu

Figure 7 provides a
5A-G. The ORM, in addition to the
shown in Figure 5A, includes a po
electromechanical buttons or swit
reference to Figures 7A-B, a centra
powered microprocessor, and one
components are packaged together
device, or system.

on and other characteristics of the
elated to the length of the hollow
applied to the coil, the mass of the
the coil, and the mass of the entire
parameters for the ORM, and thus
of different amplitudes.

of the solid, cylindrical mass is
of the current applied to the coil is
itch that can be used, in various
a coil that drives back-and-forth
the same illustration conventions,
bridge switch receives, as input, a
power 604. The direction-control
as transistors in Figure 6A. When
wn in Figure 6A, switches 608 and
n, and therefore current flows, as
610, from the power-source input
e coil 614. When the input-control
rection of the current through the
gures 6A-B, is but one example of
anical switches that can be used to
coil of an ORM.

of the ORM, illustrated in Figures
sing, coil, and internal components
er interface, generally comprising
ige switch, discussed above with
t ("CPU"), generally a small, low-
mechanical sensors. All of these
ithin a vibration-based appliance,

As shown in Figure is controlled by a control program
executed by the CPU microprocesse roprocessor may contain sufficient
on-board memory to store the c and other values needed during
execution of the control program, c may be coupled to a low-powered
memory chip 704 or flash memory ntrol program. The CPU receives
inputs from the user controls 706 omprise a user interface. These
controls may include any of v ush buttons, switches, or other
electromechanical-control devices. the user controls may include a
dial to select a strength of vibratio onds to the current applied to the
coil, a switch to select one of variou itional modes, and a power button.
The user controls generate signals U 708-710. A power supply 712
provides power, as needed, to us , to the CPU 716 and optional,
associated memory, to the H-bridg nd, when needed, to one or more
sensors 732. The voltage and cur the power supply to the various
components may vary, depending al characteristics and requirements
of the components. The H-bridge sv s a control-signal input *d* 722 from
the CPU. The power supply 712 re input 724 from the CPU to control
the current supplied to the H-bridge transfer to the coil 726. The CPU
receives input 730 from one or mo anical sensors 732 that generate a
signal corresponding to the streng currently being produced by the
linearly oscillating mass 734. Sen one or more of accelerometers,
piezoelectric devices, pressure-sen other types of sensors that can
generate signals corresponding to th sired vibrational forces.

Figures 8A-C provic diagrams that illustrate the control
program, executed by the CPU, that n of an ORM. Figure 8A provides
a control-flow diagram for the hi program. The program begins
execution in step 802, upon a pov voked by a user through a power
button or other user control. In st local variables are set to default
values, including the variables: (1) icates the current operational mode
of the device; (2) *strength*, a numeri onding to the current user-selected
strength of operation, correspondir al current applied to the coil; (3)

lvl0, a previously sensed vibrationa
strength; (6) *freq*, the current frequ
in the coil; (6) *d*, the control output t
that indicates that the frequency is
control program waits for a next ev
executing loop, or event handler,
handled by the control program. I
events may be initiated by interrupt
in more primitive implementations,
or dropped. In the implementation
one for controlling the change in
currently established frequency, an
which the control program monitor
than using a formal timer mechani
counted loops or other simple proc
tasks. When an event occurs, the c
which is represented by the conditic
and appropriately handle that eve
determined in step 806, the value
output to the H-bridge switch, with
frequency-related event. The frequ
value of the variable *freq*. Otherw
event, as determined in step 810,
Otherwise, when the event corresp
interface, as determined in step 8
Otherwise, when the event is a pow
from deactivation of a power button
powers down the device, in step 82
Any other of various types of ever
handler 824. These events may i
operation of the device.

vl1, a currently sensed vibrational
e direction of current is alternated
witch; and (7) *inc*, a Boolean value
increased. Next, in step 804, the
ing steps represent a continuously
event that occurs is appropriately
ientations of the control program,
s and stacked for execution while,
hat overlap in time may be ignored
igures 8A-C, two timers are used,
current applied to the coil, at a
ontrolling a monitoring interval at
force currently produced. Rather
lementations may simply employ
ques for periodically carrying out
egins a series of tasks, the first of
determine what event has occurred
frequency timer has expired, as
gnal *d* is flipped, in step 808, and
timer being reset to trigger a next
rval is determined by the current
ent is a monitor timer expiration
"monitor" is called in step 812.
in the user input through the user
"control" is called in step 816.
s determined in step 818, resulting
the control program appropriately
ol program terminates in step 822.
ur are handled by a default event
error conditions that arise during

Figure 8B provides liagram for the routine "monitor," called in step 812 of Figure 8A. In itine "monitor" converts the sensor input to an integer representing the al force produced by the ORM and stores the integer value in the varia in step 832, the routine "monitor" determines whether or not the ORM erating in the default mode. In the default mode, the ORM uses contii control to optimize the vibrational force produced by the ORM by eking to operate the ORM at a frequency as close as possible to tl uency for the ORM. Other, more complex operational modes may various more complex routines, represented by step 834 in Figu complex vibrational modes may systematically and/or periodically ncy or produce various complex, multi-component vibrational modes applications, appliances, devices, and systems. These more compl plication dependent, and are not further described in the control-flo the case that the operational mode is the default mode, in which the seeks to optimize the vibrational force generated by the device, in st ine "monitor" determines whether the local variable *inc* is set to TR the control program is currently increasing the frequency at which t es in order to obtain the resonance frequency. When *lvl1* is greater letermined in step 838, then the vibrational force has been recently creasing the frequency, and so the routine "monitor" increases the fr in step 840, and correspondingly resets the frequency timer. Otherwi ess than *lvl0*, as determined in step 842, then the control program h ie frequency past the resonance frequency, and therefore, in step 84 gram decreases the frequency, sets the variable *inc* to FALSE, and con ets the frequency timer. In similar fashion, when the variable *inc* is ini determined in step 836, and when *lvl1* is greater than *lvl0*, as determin he routine "monitor" decreases the value stored in the variable *freq*, in s ts the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as det 860, then the routine "monitor" increases the value stored in the var ie variable *inc* to TRUE, and resets

the frequency timer in step 862. Fi
monitor timer is reset, in step 864.

Figure 8C provides
called in step 816 in Figure 8A.
controls has occurred. In step 86
currently selected mode and vibrat
control features in the user interface
an output value *p* corresponding to t
strength, and outputs the value *p* to
an appropriate current to the coil.
a new monitor timer interval and re

The control program
example of many different implem
out, depending on requirements
inherent in a particular ORM, the ty
interface, the nature of the power
implemented for the ORM.

Figure 9 represents
can be achieved by different imple
Figure 9 has the same axes as the gr
Figure 9 includes many different
vibrational forces and frequencie
implementation. Again, an ORMs
characteristic of the geometry and
each ORM is naturally operated at a
to achieve maximum vibrational f
possible implementations, to a rela
forces, as in the case of unbalanc
implemented to produce desired v
frequencies, and desired vibratio
vibrational forces. The contrast is

in *lvl1* is transferred to *lvl0* and the

diagram for the routine "control."
invoked when a change in the user
mode and *strength* are set to the
epresented by the current states of
362, the routine "control" computes
cted strength, stored in the variable
y so that the power supply outputs
364, the routine "control" computes
timer accordingly.

reference to Figures 8A-C is one
control program that can be carried
ne parameters and characteristics
puts received from a particular user
ypes of operational modes that are

uencies and vibrational forces that
ORM and ORM control programs.
gure 3. However, unlike Figure 3,
curve 902, each representing the
btained from a particular ORM
least one resonant frequency that is
ous components of the ORM, and
to this resonant frequency in order
her than being restricted, over all
nge of frequencies and vibrational
tors, ORMs can be designed and
over a wide range of vibrational
over a wide range of desired
n in Figure 10. Figure 10 shows a

plot of the amplitude/frequency ions in that space that can be
operationally achieved by unbal motors and by linear ORMs.
Unbalanced electric motors can l to produce amplitude/frequency
combinations roughly within tl d square region 1002 within
amplitude/frequency space. By r ORMs can be designed and
implemented to produce amplitud binations underlying curve 1004.
Thus, linear ORMs can achieve mu tional frequencies and much lower
operational frequencies than can be ned by unbalanced electric motors,
and can produce much higher ampl tional forces than can be achieved
by relatively low-powered unbalan otors used in hand-held appliances
and other commonly encountered stems. Furthermore, when larger
vibrational forces are needed, balai notors are generally impractical or
infeasible, due to the destructive within the electrical motors. In
general, a single implemented lir access a much larger region of
amplitude/frequency space than cu vibration modules, which generally
operate at fixed amplitudes and/or f s, as further discussed below.

Figures 11-18 show ferent alternative implementations
of ORMs. Figure 11 provides a ration of an ORM similar to that
discussed above with reference to F e that, in place of the end magnets
1102 and 1104, mechanical sprin itively be used. These may be
traditional helical springs made fro igs made from a compressible and
durable material or mechanical de to restore its initial shape when
depressed or compressed. Note th l chamber may be cylindrical, in
cross section, as discussed above to Figure 5A, or may have other
shapes, including rectangular or hex ctions.

Figure 12 shows a si ation in which the control unit and
power supply are incorporated into s 1202. In this implementation, the
relative masses of the moving mas aining components of the ORM is
maximized, thus maximizing the vi produced at a given level of power
consumption.

Figure 13 shows ive ORM. In this alternative implementation, additional coils 13 incorporated in the moving mass, and a centering magnet or coil 130(a fixed location on the housing so that, when the direction of the curre coils 1302 and 130[illegible] is alternated, an oscillating rotational force is gen ne movable weight to oscillate both in a plane perpendicular to the axis as well as linearly oscillating the direction of the chamber.

Figure 14 illustrates ich multiple electromagnetic coils are employed. In Figure 14, two 1404 are placed in two different positions on the housing. The first e used to drive linear oscillation of the moving mass 1406, while the se activated in order to shorten the length of the chamber within which nass linearly oscillates, essentially serving as a second repelling magn nentation of the ORM, the moving mass may linearly oscillate with fferent amplitudes. depending on whether or not the second coil 1404 pel the moving mass. Additionally more complex patterns of current re coils can be employed to produce complex multi-component vibratio moving mass.

When the housing dampen oscillation of the moving , air within the chamber serves to providing channels, on the sides of ampening may be minimized by of the moving mass to the other, by , to allow air to pass from one side openings in the housing to allow ai the moving mass, or by providing housing. Additionally, different flu the housing and drawn into the to change the dampening effect pro employed within the chamber the moving mass linearly oscillates cement of the fluids and gasses as

Figure 15 illustrate ORM an implementation of the linear-resonant vibration module t document is directed in which a plunger linearly oscillates to prod . The plunger 1502 is slideably contained within a moveable-comp ogonal to a long axis of the main housing 1504 of the ORM that incl supply, microcontroller, and other control components. The plunger is ncludes, a driving magnet 1506 that

is attracted to, and seeks to be posi ent with, a centering magnet 1508 mounted within the housing. Appl one of two driving coils 1512 and 1514 forces the driving magnet aw ilibrium position shown in Figure 15. By rapidly switching the dire applied to the driving coils, the microcontroller can control the plun scillate in an up-and-down fashion, as indicated by arrow 1520.

Figure 16 shows ye an implementation of the linear- resonant vibration module to wh cument is directed. In this an implementation of the linear-resona dule to which current document is directed, a spring-like member 16 at one end 1604 to the housing. Driving magnets 1606 and 1608 ar ring-like member 1602, and when current is rapidly reversed in a coil g-like member 1602 is induced to vibrate at a relatively high freque

Figure 17 shows ano ar to the ORM shown in Figure 16. in this ORM, the spring member 17 provide an external massage arm 1704 that extends out from the hou linearly oscillating massage-foot member 1706 for massaging huma other substrate, depending on the application.

Figure 18 shows a m ion adjustment feature that can be added to either of the ORMs showr nd 17. An adjustment screw 1802 can be manipulated to alter the posi e spring clamp 1804 that acts as a movable clamping point for the spri 806. Moving the movable spring clamp 1804 leftward, in Figure 18, gth of the spring-like member and thus tends to increase the resonant f rticular power-consumption level. Conversely, moving the movable sp tward, in Figure 18, lengthens the spring-like member and decreases t equency.

Figure 19 illustrates of an implementation of the ORM shown in Figure 17. In this implen assage foot is enhanced to include elastomer bristles 1902-1906 to tra oscillation of the massage foot to human skin or another substrate. Th ristles, or pad or brush comprising numerous elastomeric bristles, allow f vibration to a surface even at low

operational powers, when a rigid or pliant massage foot would instead simply stop moving for inability to nal forces.

Figure 20-23C illustr pe of ORM. This ORM comprises a motor incorporated within a pri rd ("PCB"). The motor includes moving and non-moving compon ct via electromagnetic forces to produce motion. The non-movin include a stator that generates a magnetic field. A stator can be g one or more coils. In certain implementations, a stator adapted ith a planar substrate is produced using combinations of one or more nductive traces.

Figure 20 illustrates The first coil layer 2000 includes a substrate 2002 and a spiral-shape is wound in a clockwise direction from the outside of the spiral to the iral. The spiral-shaped trace 2004 surrounds a central core and overla 2002. In some implementations, the substrate 2002 is a printed cir width and thickness of the trace influence the conductivity of the t general, thicker and wider traces have lower electrical resistance an with lower resistance and higher current carrying capacity. Spirals ore diameter and spirals having a larger number of turns produce co ondingly higher inductance. The inductance of the spiral-shaped trac ir core at the center of the spiral is expressed as:

$$L($$

where:

r is the core radius in inche

N is the number of turns; a

W is the total width of the v s.

The inductance of the resulting coil by altering the above parameters, as well as through the selection of c

A first connection a second connection pad 2008 terminate the ends of the spiral-shap certain implementations, the first

connection pad 2006 and/or the sec
ormore conductive vias connecting
circuits constructed on the substrat
and 201 can provide connection p
multiple layers of traces.

Figure 20 additional
elements in a particular motor imple
2004 is a circular opening 2018. Th
2020. The armature 2020 can be ma
moves in a direction substantially p
response to a drive current applied
the armature 2020 in the circular ope
movement perpendicular to the sub

In certain implemen
from conductive material, such as n
traces and connection pads on the f
circuit-board manufacturing techn
created and laminated onto the subs
achieved using a number of techn
laminated foil decals separated by i
some implementations, the traces ar
2002.

Figure 21 illustrates
constructed using techniques alrea
layer 2000. A spiral-shaped trace 2
connection pad 2104 to the ending
positioned over the coil layer of F
another so that the second connec
connection pad 2104 in Figure 21,
with the ending connection pad
connections between the second c

pad 2008 are incorporated into one
r to other coil layers or to electrical
onnection pads 2010, 2012, 2014,
ncorporated into vias that connect

placement of a number of motor
he center of the spiral-shaped trace
ig provides a space for an armature
is metal or a magnetic material and
he surface of the substrate 2002 in
. A centering spring 2022 retains
substrate 2002, and allows limited

es and connection pads are made
minum, or conductive alloys. The
00 can be fabricated using printed-
implementations, foil decals are
construction of multi-layer coils is
g: multi-layer PCB construction;
and 2-sided PCB construction. In
ds are embedded into the substrate

yer. The second coil layer 2100 is
r the construction of the first coil
ockwise direction from the starting
2106. The coil layer of Figure 20 is
e two layers are aligned with one
n Figure 20 overlays the starting
tion pad 2010 in Figure 20 aligns
21. PCB vias form electrical
2008 in Figure 1 and the starting

connection pad 2104. When the fir
layer 2100 in Figure 21 are connect
layers is additive. In one mode of o
20 starting at the first connection p
connection pad 2008, through a via
to the ending connection pad 2106
inductance of the resulting coil. A
2114 provide connection points an
layers. In certain implementations,
similar methods to those described
insulating layers or placed on opp
implementations, the multi-layer co

Figure 22A illustrate
A first coil layer 2202 and a secon
planar substrate 2206, such as a PC
are separated by an insulating layer
2208. The stator is driven by a first
2212. In certain implementations,
front surface of the PCB using a via
moves perpendicularly to the surfa
stator. The first and second coil
illustrated in Figures 20 and 21, or
layers produce a single direction
implementations illustrated in Figu
layers laminated to both sides of a p

Figure 22B illustrate
A first-front coil layer 2250 and a
front surface of an insulating plana
layer 2256 and a second-back coil l
insulating planar substrate 2254. A
first-front coil layer 2250 to the be

0 in Figure 20 and the second coil
id energized, the inductance of the
t flows into the coil layer of Figure
vise around the coil to the second
onnection pad 2104, and clockwise
onal coil layers increases the total
ction pads 2108, 2110, 2112, and
ias that connect to additional coil
yers can be added to the coil using
itional coil layers are separated by
n insulating substrate. In certain
ator in a motor.

of a stator having two coil layers.
4 are laminated onto an insulating
second coil layers 2202 and 2204
connected to each other with a via
2210 and a second connection pad
nection pad 2212 is routed to the
14 is provided for an armature that
ate in response to energizing the
onstructed using the coil layers
ce patters arranged so that the coil
round the opening 2214. The
xtended to include additional coil

of a stator having four coil layers.
il layer 2252 are laminated onto a
, such as a PCB. A first-back coil
minated onto a back surface of the
lectrically connects the end of the
d-front coil layer 2252. A second

via 2262 electrically connects the end of the first-back coil layer 2256 to the beginning of second-back coil layer 2258. Cross-substrate via 2264 connects the end of first-front coil layer 2250 to the end of first-back coil layer 2256. When current enters at an entry connection pad 2266 and passes through the four coil layers, the current travels with a single direction of rotation until the current exits at an exit connection pad 2268. The inductance of the stator in Figure 22B is approximately double that of the stator shown in Figure 22A.

Figure 22C illustrates a cross-section of a stator having two coil layers. A front coil layer 2280 and a back coil layer 2282 are laminated onto opposing sides of an insulating planar substrate 2284, such as a PCB. A via 2288 electrically connects the front coil layer 2280 to the back coil layer 2282 forming a coil wound in a single direction around the opening 2290. Connection pads 2292 and 2294 provide electrical contacts for connecting the coil to a drive current.

In some implementations, the coil layers that make up the stator are not interconnected to form a single coil. For example, cross-substrate via 2264 may be omitted, and the two front coil layers 2250 and 2252 are electrically driven independently from the two back coil layers 2256 and 2258. In other implementations, the two front coil layers 2250 and 2252 are counter-wound with respect to the two back coil layers 2256 and 2258. In this configuration, the magnetic fields generated in the opening 2270 by the two front coil layers oppose the magnetic field generated by the two back coil layers.

PCBs are suitable substrates for making the coils and motors described in the current document. A PCB can be constructed using a PCB process where layers of printed copper are separated by a hard laminate core, for example, using FR-4 glass-reinforced epoxy. A PCB made from polyimide can support a greater density of coils and increased mechanical flexibility. A PCB made from a ceramic, such as aluminum oxide, provides increased heat resistance. The stators described above can be constructed with any of these PCB materials.

In certain implementations, the coil layers described above are arranged to form one or more coils that overlay the front and/or back surfaces of a PCB. The coils form a stator that drives the armature of a motor.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate. The motor 2300 is constructed on a substrate 2302 , such as a PCB. A first front coil layer 2304 and a second front coil layer 2306 overlay the front surface of the substrate 2302. A first back coil layer 2308 and a second back coil layer 2310 overlay the back surface of the substrate. A first via 2312 electrically connects the first front coil layer 2304 to the second front coil layer 2306 to form a front coil, and a second via 2314 electrically connects the first back coil layer 2308 to the second back coil layer 2310 to form a back coil. Front coil connections 2316 and 2318 provide electrical connectivity for driving the front coil, and back coil connections 2320 and 2322 provide electrical connectivity for driving the back coil.

A magnetic armature 2324 having a north pole 2326 and a south pole 2328 is positioned in an opening in the substrate 2302 through the center of the front and back coils. In order to drive the magnetic armature 2324 into vibration, a first oscillating current is applied to the front coil connections 2316 and 2318, and a second oscillating current is applied to the back coil connections 2320 and 2322. When the motor is operated, the current that flows through the front coil and the current that flows through the back coil flow with opposite directions of rotation. In certain implementations, this is accomplished by applying the same oscillating current to both front and back coils provided the coils are counter-wound. In an alternative implementation, where the coils are not counter-wound, the second oscillating current is 180 degrees out of phase with the first oscillating current. The resulting oscillating magnetic field provides a magneto-motive force to the north pole 2326 and the south pole 2328 in synchrony, driving the magnetic armature 2324 into vibration at a frequency proportional to the frequency at which the oscillating current is applied. In an alternative implementation, the second front coil layer 2306 is connected to the first back coil layer 2308 with a third conductive via to form a single-drive counter-wound stator that is driven with a single oscillating current to produce vibratory motion of the armature.

The magnetic armature is constructed from an axially polarized magnet. In one implementation, the magnet is a neodymium grade N-42 disk magnet. The size

and shape of the magnet is adapted based, in part, on the desired vibration profile of the motor.

Figure 23B illustrates the motor with the magnetic armature in an upward position. When a first driving current is applied to a front coil 2330, the front coil 2330 generates a downward magnetic flux 2332. In response to the downward magnetic flux 2332, an upward vertical force is exerted on the north pole 2336. As the first driving current is applied, a second driving current is applied to a back coil 2338 and an upward magnetic flux 2340 is generated. In response to the upward magnetic flux 2340, an upward vertical force is exerted on the south pole 2342 of the magnet. In response to the upward forces, the magnetic armature 2334 moves upwards as illustrated in Figure 23B.

Figure 23C illustrates the motor with the magnetic armature in a downward position. When the direction of the first and second driving currents is reversed, the forces on the north pole 2360 and south pole 2362 are reversed. When the first reversed current is applied to a front coil 2364, the front coil 2364 generates an upward magnetic flux 2366, and a downward vertical force is exerted on the north pole 2360. When the second reversed current is applied to a back coil 2368 a downward magnetic flux 2370 is generated. A downward vertical force is exerted on the south pole 2362 of the magnetic armature 2372. In response to these two forces, the magnetic armature 2372 moves downwards as illustrated in Figure 23C.

The drive currents are alternated to cause the magnetic armature to vibrate perpendicularly to the surface of the substrate at a chosen frequency. In one implementation, the front coil and back coil are counter-wound with respect to each other. The front and back coils are connected with a conductive via or wire and driven with one drive current. This arrangement causes the front and back coils to generate simultaneous magnetic flux signals in opposing directions, which, in turn, acts on the north and south poles of the magnetic armature to drive the magnetic armature into vibration.

In alternative implementations, additional coil layers are employed. For example, an 8-layer PCB can have four front coil layers and four back coil layers. The four front coil layers are connected to form a front coil, and the four back coil layers

are connected to form a back coil. In certain implementations, the front coil and back coil are counter wound, and driven with a single drive current as explained above.

Next, a slightly more mathematically descriptive explanation of oscillation, resonance, and the Q factor is provided. Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation. Great insight into harmonic oscillators can be provided by considering a simple, one-dimensional spring. Figure 24A illustrates a spring that can be extended in the x direction. In a first diagram 2402, the spring is shown in an equilibrium, resting state with a point or mass 2404 at the end of the spring located at the position $x = 0$. In a second diagram 2406, the spring has been pulled rightward, along the x direction, with the mass 2404 now located at a position x. As is well known, the extended spring has potential energy that results in a force F_x 2408 that points in the opposite direction. In other words, were the spring released, the mass would travel leftward, oscillate back and forth, and eventually settle back to the 0 position shown in diagram 2402. Were the spring frictionless, however, the mass would continue to oscillate back and forth, in a manner similar to the linear ORM described in Figures 4A-B, indefinitely.

The frictionless spring can be mathematically modeled as follows:

$$F_x(x) = -kx.$$

where $F_x(x)$ is the force exerted by the spring;
x is the position of the spring end; and
k is the force constant.

The force constant k is a property of the spring, including all of the parameters that contribute to its elasticity, compressibility, and other physical characteristics of the spring. In more complex, realistic situations, many different factors may contribute to the force constants associated with harmonic oscillators, including interaction with other harmonic-oscillation modes within a physical device or module.

The potential energy of the spring system illustrated in Figure 24A can be modeled as:

$$U(x) = \frac{1}{2}kx^2,$$

where $U(x)$ is the potential energy of the spring system.

Using Newton's second law, the equation that models the force exerted by the spring when it is extended or compressed can be modeled as a simple, second-order differential equation:

$$m\ddot{x} = Fx = -kx,$$

where m = mass of oscillator; and

$$\ddot{x} = \frac{d^2x}{dt^2}.$$

This differential equation can be simplified as:

$$\ddot{x} = \frac{-k}{m}x = -\omega^2 x,$$

where $\omega = \sqrt{\frac{k}{m}}$.

The general solution for this simple, second-order differential equation is, in one form:

$$x(t) = C_1 e^{i\omega t} + C_2 e^{-i\omega t}.$$

In this equation, C_1 and C_2 are arbitrary constants that are determined by the initial conditions of a particular spring system. This solution can be recast as:

$$x(t) = B_1 \cos(\omega t) + B_2 \sin(\omega t),$$

where $B_1 = C_1 + C_2$; and

$$B_2 = i(C_1 - C_2).$$

A final, perhaps most elegant form of the solution is:

$$x(t) = \mathrm{Re}[Ae^{i(\omega t - \delta)}],$$

where $Ae^{-i\delta} = B_1 - iB_2 = C$.

In this equation, A is the amplitude of the oscillation, ω is an angular velocity of the oscillation, as discussed above with reference to Figure 24B, and δ is an initial phase offset. This final expression describes the mapping of a rotation to linear harmonic oscillation, as discussed above with reference to Figure 4B, shown again, in Figure 24B, with annotations taken from final expression for the solution to the differential equation.

As mentioned above, a frictionless spring would continue to oscillate indefinitely after being released from an extended position. However, in actual systems, there are always resistive forces, such as friction, that dampen the oscillation so that, over time, the amplitude of the oscillation decreases and the oscillation finally stops. This more complex and more realistic scenario can be modeled by including a resistive-force term in the second-order differential equation:

$$m\ddot{x} + b\dot{x} + kx = 0$$

where $-b\dot{x}$ is a resistive force; and

$$\dot{x} = \frac{dx}{dt}.$$

Defining several new constants as follows:

$$\beta = \frac{b}{2m} \Rightarrow \text{damping constant, and}$$

$$\omega_0 = \sqrt{\frac{k}{m}} \Rightarrow \text{natural frequency}$$

and solving the above modified second-order ordinary differential equation, the following result is obtained:

$$x(t) = Ae^{-\beta t}\cos(\omega_1 t - \delta)$$

where $\omega_1 = \sqrt{\omega_0^2 - \beta^2}$; and

$$\beta < \omega_0$$

when, as indicated above, the damping constant β has a value less than the value of the natural frequency ω_0, the system in under-damped and the amplitude of the oscillations decrease non-linearly, as shown in Figure 24C. When β is greater than ω_0, the system is over-damped, in which case only a single oscillation may occur, as shown in Figure 24D.

Most physical systems have one or more natural frequencies at which they oscillate, when mechanically perturbed from their equilibrium states. In ORMs, a motor is used to continuously perturb the system in order to drive the ORM to oscillate and generate vibration. A device in which an ORM is incorporated vibrates in response to a driving vibration generated by the ORM. In this case, an external

driving force $F(t)$ is applied by the ORM to drive continuous oscillation of the device in which it is included. An external-force-driven linear oscillator can be modeled by the following expression:

$$m\ddot{x} + b\dot{x} + kx = F(t),$$

where $F(t)$ is an external driving force.

With the definition:

$$f(t) = \frac{F(t)}{m},$$

the mathematical model becomes:

$$\ddot{x} + 2\beta\dot{x} + \omega_0^2 x = f(t).$$

A solution for this expression is:

$$x(t) = A\cos(\omega t - \delta)$$

where $f(t) = f_0\cos(\omega t)$;

$$A^2 = \frac{f_0^2}{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2}; \text{ and}$$

$$\delta = \arctan\left(\frac{2\beta\omega}{\omega_0^2 - \omega^2}\right).$$

In this expression, the constant ω is the driving frequency of the driving force, which is somewhat less than the natural frequency ω_0. As can be seen in the expression for the square of the amplitude, which is proportional to the energy of the vibration, the amplitude is maximized when the denominator of this expression is a value approaching 0. Maximizing the expression can be carried out either by varying the physical device in order to vary the natural frequency ω_0, while the external-driving-force frequency remains fixed ω, or by varying the driving frequency ω when the natural frequency ω_0 is fixed. When ω_0 varies and ω is fixed, A is maximum when $\omega_0 = \omega$; and when ω varies and ω_0, A is maximum when $\omega = \sqrt{\omega_0^2 - 2\beta^2}$. This is where the term "resonance" arises. The resonant frequency is the frequency at which the amplitude A is maximized. As can be seen, this occurs, in general, when the driving frequency of the motor or other mechanical-force-input mechanism has a frequency

close to or equal to the natural frequency ω_0 of the physical system. A quality factor Q can be expressed, in terms of the natural frequency and damping factor, as:

$$Q = \frac{\omega_0}{2\beta}.$$

This is the reciprocal of the ratio of the width of the amplitude peak at half its maximum value to the natural frequency ω_0.

An ORM Controller

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration. The vibration may be generated for application to people, animals, or objects for various purposes, including therapeutic purposes, or may instead be generated to provide haptic feedback, such as vibration in mobile phones, vibration-based notification, or vibration-based communications. Thus, the current document is directed to particular features of a generic ORM-containing device or system that may be used in a wide variety of different types of applications or included in larger devices and systems. In Figure 25, the device, appliance, or system is represented by an outer rectangle 2502. The device includes four ORMs 2504-2507. The ORMs may be of any of many different types, including the types of ORM discussed above. In general, the ORMs convert input energy, such as an electrical current, to mechanical vibration. The device also includes several vibration sensor 2510-2511. There are a variety of different types of vibration sensors, including piezoelectric accelerometers that measure acceleration in one, two, or three different orthogonal directions. Other types of sensors may include membranes attached to moving coils that generate electronic signals when the membrane vibrates, similar to a reverse audio speaker. In addition, the device or system contains a controller 2516. The controller includes ORM control logic 2518 that transmits control signals, in certain cases electrical signals that also serve to power the ORMs. The ORM control logic may be implemented as a sequence of processor instructions, when the controller 2516 is a processor or processor-controlled controller subsystem. In many of the ORM devices and systems, the controller accesses some type of electronic memory 2520, which stores processor instructions and other types of data for

implementing ORM control logic 2518. Not shown in Figure 25 are various standard components and signal lines, including a power supply and power-transmitting circuitry, display screens, push buttons, other user-interface-related components, and other types of logic and logic-controlled subcomponents particular to particular types of devices, such as transceivers and communications subsystems within mobile phones. A set of double-headed arrows, such as double-headed arrow 2522, represent the fact that the controller may control many other subcomponents and features of the device or system in addition to the ORMs.

In the previous discussion of oscillation, vibration, and resonance, simple mathematical models for one-dimensional harmonic oscillation were developed. However, in the generic ORM-containing device or system, there may be multiple ORMs, activation of which produce very complex three-dimensional spatial vibration. Vibration modes of individual ORMs may couple to produce a large number of complex spatial-vibration modes. The physical characteristics of these vibration modes may be highly dependent on the exact geometry, weight and balance, and the material type of the housing and internal components of a particular device or system. As a result, there may be numerous different natural resonant frequencies for the device or system.

Figures 26A-B illustrate multiple resonant frequencies within a device or system. In Figure 26A, the vibrational energy, or square of the amplitude of the vibration, is plotted with respect to frequency. The vertical axis represents the energy and vibration 2602 and the horizontal axis represents the frequency of vibration 2604. The plotted curve 2606 shows numerous different vibration-energy peaks 2610-2615. The heights and positions of these peaks along the frequency axis 2604 may vary considerably with slight changes to the physical characteristics of a device or system that is vibrated by ORM components.

Figure 26B shows a more complex type of vibration-response plot. The vibration response is represented by a surface 2620 in the plot shown in Figure 26B. Measured amplitudes or vibration energies produce a surface 2620 in a three-dimensional Cartesian coordinate system that includes an x-direction vibration frequency axis 2522, a y-direction frequency axis 2624, and a vibration-energy axis

2626. The device or system for which the vibration-response surface 2620 is obtained includes two ORMs, one of which generates vibrations in the x direction and one of which generates vibrations in the y direction. The two ORMs can be independently controlled to generate vibrations in their respective directions at different frequencies. The x, y plane 2628 below the plotted vibration-energy surface 2620 represents all possible x-direction vibration frequencies and y-direction vibration frequencies that can be generated by the two ORMs within the device or system. As shown in Figure 26B, the surface includes three local vibration-energy maxima 2630-2632. These three local maxima are each associated with x-direction frequency and y-direction frequency components 2634. Thus, in the case shown in Figure 26B, two ORMs which generate vibrations in two different directions within the device or system may generate a complex vibration-response surface with respect to the frequencies at which the two ORMs are operated. Depending on the types and numbers of ORMs, the vibration response may be a hyper-dimensional surface in a much higher dimensional frequency space. In all cases, however, the device or system generally has some number of characteristic resonant frequencies that represent maximal vibration energy or amplitude with respect to the frequencies at which individual ORMs are driven with the device or system. In general, the number of resonant frequencies is equal to the number of vibrational degrees of freedom in the device, appliance, or system.

A vibration-response obtained for a device or system by measuring sensor output can be used to identify and tabulate the natural resonant frequencies for the device or system. Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25. Each row in the resonant-frequency table 2702, such as row 2704, represents a local maxima, or peak, in the vibration response for the generic device. In the example table shown in Figure 27, each peak is characterized by an amplitude in the x 2706, y 2707, and z 2708 directions as well as by the frequency of vibration represented by the peak ω 2710 and by the frequency at which each of the four ORMs are driven by the ORM control logic 2712-2715. Thus, to achieve maximum vibration energy of the vibration of the generic device at any of the resonant frequencies for the device, the ORMs are driven at the control frequencies for that resonant frequency.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response. Figure 28A shows the vibration-response for a simple device, vibration of which is stimulated by a single ORM. There is a single natural frequency ω_1 2802 corresponding to the vibration-energy peak 2804 in the vibration-response plot of vibration energy with response to frequency. Figure 28B shows a plot of the frequency of vibration generated by an ORM with respect to time over a time interval that represents an ORM control scheme. In Figure 28B, the vertical axis 2810 represents the frequency at which the ORM is driven by ORM-control input and the horizontal axis 2812 represents time. The control curve 2814 indicates that the ORM is non-linearly driven over an initial time period 2816 to the natural frequency ω_1 2818 for the device in which the ORM is included. At a final point in time t_f 2820, input to the ORM is discontinued. Figure 28C shows a vibration-response curve for the device containing the ORM when the ORM is operated according to the control curve 2814 discussed above with reference to Figure 28B. As shown in the vibration-response curve 2822, there is an initial lag time 2824 following initiation of the control scheme before a perceptible device vibration occurs, at time t_i 2826. The vibrational energy, or amplitude of vibration, very steeply increases from this point on as the ORM is controlled to approach and equal the natural frequency ω_1 for the device. At time t_f 2820, the vibrational energy of the device relatively steeply falls, since the ORM is no longer being driven. However, the vibrational energy does not immediately fall to 0, as in the control curve, but over a short period of time 2828 after the ORM ceases to be driven.

The generic device, as discussed above, contains a memory that may store various types of control schemes, or control patterns, for the ORMs that are controlled by the ORM control logic. Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device. The example patterns include a linear ramp-up and ramp-down pattern 2902, a constant control over a specified duration of time 2904, and an oscillating control 2906. The patterns may be parameterized by the duration of the pattern 2908 and the maximum input to the ORM 2910. The input may be specified as the current or voltage, for certain types of ORMs. Other ORMs may be controlled by digital control signals in

which numerically encoded commands are transmitted to the ORM. The control patterns can be scaled in both time and frequency in order to generate a variety of equivalent vibration responses for the ORM with similar forms, but different maximum amplitudes and over different periods of time.

A set of scalable control patterns, such as those shown in Figure 29, and a table of resonant frequencies, such as that shown in Figure 27, can be used to generate a table of different types of vibration that can be generated in the generic device by controlling the ORMs within the device according to scaled control patterns. Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25. Each row in the table, such as row 3004, represents a different vibration type that can be produced in the generic device by controlling the ORMs within the device. For example, a cell phone may use a variety of different haptic vibration signals to alert the cell phone user of many different types of events. Each different vibration signal corresponds to a different vibration- type. Each vibration type is characterized by a vibration-type identifier 3006, an amplitude range for the vibration 3008, a reference duration for the vibration 3010, and the control pattern and scaling parameters for the pattern for each of the ORMs 3012-3015. Each vibration type can be scaled within the amplitude range and may also be scaled for a desired duration.

By using either external or internal sensors to characterize the natural resonant frequencies for a physical device or system that contains ORMs, a large number of different vibration responses for the physical device or system can be compiled based on the resonant frequencies as well as a set of ORM control patterns. In alternative vibration-control approaches, the different types of vibration responses may be computed, on the fly, rather than tabulated based on a set of control patterns. However, in all cases, characterization of the resonant frequencies of the device or system that is vibrated by the ORMs contained within the device or system is a necessary step in producing predictable vibration responses via ORM control.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figure 31 illustrates the inner control loop of the control logic within the physical device shown in Figure 25. The inner control loop waits, in step 3102, for a next event and then handles the event that occurs. When the event is a characterize-vibration event, as determined in step 3104, the routine *characterize vibration* is called to handle the event in step 3106. When the event is a generate-vibration event, as determined in step 3108, a generate-vibration routine is called in step 3110 to generate a vibration in response to the generate-vibration event. When the next event is a user-input event, as determined in step 3112, a process-input routine is called, in step 3114, to handle the input from the user. Ellipses 3116 are used in Figure 31 to indicate that many other types of events are handled by the inner event loop of the control logic. When, after handling the most recently occurring event, there are other events that are queued for handling which arose while handling the most recently handled event, as determined in step 3118, then a next event is dequeued in step 3120 with control flowing back to step 3104. Otherwise, control flows back to step 3102 where the inner event loop waits for a next event to occur.

The characterize-vibration event 3104 is an event that is raised by control-logic routines, timer-expiration handlers, and by other control logic in order to control the ORMs and sensors within the generic device to carry out a re-characterization of the vibration-response for the physical device, as discussed above with reference to Figures 26A-B, in order to update the resonant-frequency table, such as the resonant-frequency table discussed above with reference to Figure 27. In devices that employ a vibration-type table, such as the vibration-type table discussed with reference to Figure 30, the vibration-type table is also updated following update of the resonant-frequency table.

A generate-vibration event is raised by control logic in order to vibrate the generic device for a variety of different reasons. As one example, the device may be vibrated in response to user input. As another example, the device may be vibrated when the control logic determines that any of various alert conditions have arisen. As yet another example, generate-vibration events may be raised in order to communicate information to a device user.

Figure 32 provides a control-flow diagram for the characterize-vibration event handler, called in step 3106 of Figurer 31. In step 3202, the routine calls a subroutine *sweep* in order to generate a sampling of a vibration-response curve, surface, or hyper-dimensional surface. In step 3204, the routine calls a store-vibration-maxima subroutine in order to identify the resonant frequencies from the curve or surface sampled in step 3202. Finally, in step 3206, the routine calls a compute-and-store-vibration-type-controls subroutine in order to update the vibration-type table based on the new resonant-frequency determination made in steps 3202 and 3204.

Figure 33 provides a control-flow diagram for the subroutine *sweep*, called in step 3202 of Figurer 32. In step 3302, the subroutine *sweep* initializes a data structure for storing a vibration response. As discussed above, the vibration response may be a sampled curve, sampled surface, or sampled hyper-dimensional surface. In the *for*-loop of steps 3304-3306, a frequency sweep of each ORM is initiated. A frequency sweep is a control pattern that continuously sweeps each ORM over a wide range of driving frequencies. Each ORM repeats a single frequency sweep over a different time interval, so that following a number of iterations, the multi-dimensional ORM-driving-frequency space can be sampled. Then, in the *for*-loop of steps 3308-3312, the *sweep* routine continuously samples the vibration amplitude or vibrational energy produced in the device using sensor output, while the driving-frequency sweeps take place. There are, of course, many alternative methods for sampling the multi-dimensional driving-frequency space in order to generate a sampled vibration-response curve, surface, or hyper-surface.

Figure 34 provides a control-flow diagram for the store-variation-maxima subroutine called in step 3204 of Figure 32. In step 3402, the routine identifies local maxima in the vibration-response curve or surface produced by the *sweep* routine. There are many well-known mathematical techniques for identifying local maxima within a curve, surface, or hyper-surface. Then, in the *for*-loop of steps 3404-3406, data that characterizes each of the local maxima are tabulated in the resonant-frequency table.

Figure 35 provides a control-flow diagram for the compute-and-store-vibration-type-control subroutine called in step 3206 of Figure 32. In a *for*-loop of

steps 3503-3509, each possible set of ORM/control-pattern/resonant-frequency triples is considered. The currently considered triple is used to estimate the vibration mode and intensity of the resulting device vibration, in step 3504. In step 3505, the nearest vibration-type to the estimated vibration mode is identified, if there is one. If a nearest vibration type is found, as determined in step 3506, and when the current ORM/control-pattern/resonant-frequency triple provides a device response closer to the vibration type than the control parameters currently associated with the vibration-type, as determined in step 3507, then, in step 3508, the vibration-type table entry for the found vibration type is updated with the current control parameters represented by the currently considered ORM/control-pattern/resonant-frequency triple. Of course, in certain cases, there may be too many possible ORM/control-pattern/resonant-frequency triples to consider in a reasonable amount of time, in which case the resonant-frequency data may be used in other ways to find the best control parameters for the vibration types in the vibration-type table.

Figure 36 provides a control-flow diagram for the generate-vibration handler called in step 3110 of Figure 31. In step 3602, the handler receives a vibration type, duration, and amplitude associated with the generate-vibration event that is being handled. In step 3604, the appropriate ORM control parameters and patterns are selected from the vibration-type table. In step 3606, the ORM control parameters are scaled according to the received duration and amplitude. In step 3608, a stop time at which the vibration will finish is determined from the received duration. Then, in the *for*-loop of steps 3610-3613, the generate-vibration handler continuously adjusts inputs to each ORM according to the scaled ORM control parameters produced in step 3606.

Precise and Accurate Control of ORMs

The current document is directed to various approaches used within the control logic of an ORM-containing device, appliance, or system, to accurately and precisely control the ORMs to produce time-dependent driving oscillations in conformance with desired control patterns. As discussed above, the combination of controlling ORMs in accordance with control patterns and the accurate characterization

of the resonant frequencies of the device, appliance, or system together allow for reproducible generation of many different types of vibration responses of the device, appliance, or system to the driving oscillations of control-pattern-controlled ORMs.

As further discussed below, many current control regimes fail to accurately reproduce the desired driving time-dependent oscillations in each ORM within a device, appliance, or system. As a result, the vibration response of the device, appliance, or system may vary significantly from a desired vibration response and, perhaps more importantly, may not be accurately reproduced at different points in time, due to the inability to accurately and deterministically control the ORMs to produce driving oscillations in conformance with desired control patterns.

A first approach to more accurately controlling ORMs is to use pulse-width modulation control signals rather than conventional constant-duration control pulses. Figures 37A-D illustrate pulse-width modulation control of an ORM. Figure 37A shows a desired vibration response for an ORM that represents a desired time-dependent driving oscillation for inducing at least a portion of the vibration response of a device, appliance, or system in which the ORM is included. The desired vibration response of the ORM is a sine-wave-like 3702 oscillation that is plotted, in Figure 37A, on an amplitude versus time coordinate system 3704. Figure 37B illustrate a hypothetical control regime that attempts to produce the desired driving oscillation discussed above with reference to Figure 37A in a hypothetical ORM. Constant-width voltage pulses, such as voltage pulse 3706, are input to the ORM to drive the weight or mass in forward and backward directions along the oscillation path. These pulses are plotted in Figure 37B in a voltage versus time coordinate system 3708. Because the constant-width pulses are a rather crude approximation of the desired sine-wave-like vibration response, the control regime shown in Figure 37B comprises a series of positive-voltage, 0-voltage, and negative-voltage constant-width pulses 3706 and 3710-3713 that produce a vibration response, superimposed in Figure 37B over the control pulses, as curve 3716. In general, the pulse widths are controlled by an oscillating clock or clock-based timing signal. The vibration-response curve 3716 differs significantly from the desired driving oscillation shown in Figure 37A. Figure 37C shows the desired vibration response 3702 plotted together with the vibration

response produced by the constant-width voltage-pulse control 3716. In fact, this is actually a relatively favorable case, because the sequence of positive, 0-voltage, and negative voltage pulses shown in Figure 37B has a period close to the period of the desired sine-wave-like vibration response. Otherwise, the actual vibration response would differ even more greatly from the desired vibration response, often having irregularly shaped wave forms.

Figure 37D illustrates pulse-width-modulation control of the ORM. In pulse-width-modulation control, rather than using constant-width voltage pulses to control the ORM, the controller instead uses variable-width pulses. Moreover, much shorter pulses can be used to more precisely control the vibration response of the ORM. In essence, pulse-width modulation allows a variable-frequency control signal to be used, rather than a constant-frequency control signal. Because a variable-frequency control signal can contain a much greater amount of information than a constant-frequency control signal, the pulse-width-modulation control signals can be used to much more precisely steer the vibration response of the ORM towards a desired wave form. As shown in Figure 37D, many more voltage pulses are used in order to achieve the sine-wave-like vibration response of the ORM. For example, in the constant-width-pulse control shown in Figure 37B, a positive-voltage pulse 3706, a 0-voltage pulse, and a negative-voltage pulse 3710 are used to attempt to approximate the first period of the desired vibration response. By contrast, as shown in Figure 37D, four positive-voltage pulses 3720-3722 and 3726 and three negative-voltage pulses 3723-3725 are employed to produce the first period of the desired vibration response. Moreover, these seven pulses have varying pulse widths and are irregularly spaced along the time axis.

Another problem associated with conventional control of ORMs is that the vibration response produced by a control pattern is often very different from the vibration response that might be predicted from the control pattern or desired. For example, in Figure 38A, a control pattern is shown that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806. Of course, this control pattern may correspond to a large number of positive-voltage pulses in the time interval t_i to t_f. The vibration response of the ORM is shown in Figure 38B. In this figure, the horizontal time axis 3808 has been rescaled to show more detail. The control

pattern 3802 shown in Figure 38A might be initially assumed to produce a pulse of constant-amplitude vibrations over the time interval t_i to t_f. However, as shown in Figure 38B, the actual vibration response of the ORM, shown as curve 3810, includes an initial ramp-up interval 3812 in which the amplitude of the vibration response steadily increases to the desired amplitude, a middle period 3814 in which the ORM is oscillating at the desired amplitude, a short period 3816 at the end of the time interval t_i to t_f during which, in anticipation of the sharp control-pattern edge at time t_f, the control voltage is dropped to 0 so that the vibration will fall to a low level at time t_f, and a fourth undesired ramp-down interval 3818, extending well past the time t_f, during which vibration of the ORM continues at increasingly smaller amplitudes.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f. In a first plot 3902, the naïve control pattern is shown. In a second plot 3904, the naïve control pattern is modified in order to produce the constant-amplitude oscillation that is desired. First, a large-voltage input 3906 occurs prior to time t_i in order to quickly force the ORM to begin vibrating. From time t_i to a time prior to time t_f, a lower-voltage input 3908 is provided in order to control the ORM to oscillate at the desired amplitude. Prior to time t_f, a negative-voltage control signal 3910 is input to the ORM in order to sharply drive the ORM towards oscillation out of phase with the desired driving oscillation during the time interval t_i to t_f. This negative-voltage control signal is then relaxed linearly 3912 in order to stop ORM vibration in a relatively short period of time. As shown in plot 3914 in Figure 39, the vibration response of the ORM much more closely approximates a desired constant-amplitude vibration between time intervals t_i and t_f.

Many different types of control inputs can be used to shape the vibration response of an ORM. For example, short control pulses can push the vibration to a different phase, resulting in cancellation of the previously established oscillation. The various types of inputs depend on the type and form of control signals that can be transmitted to the ORM, which, in turn, depends on the type of ROM, the driving force used to induce oscillation of the moving mass within the ORM, and the type of logic circuitry that receives input signals and translates them into oscillations.

Thus, in addition to pulse-width modulation, a wide variety of different types of complex control signals may be devised in order to achieve the vibration response desired from the simple control patterns discussed above, including control pattern 3802 shown in Figure 38A. Many different control-signal parameters may be varied in order to control an ORM to provide a desired vibration response, including varying the voltage of the control signal, using pulse-width modulation to finely tailor the control signal to produce a desired vibration response, and adjusting the control signal to include pre-response and post-response signals to remove undesired ramp-up and ramp-down periods in the vibration response.

In addition to varying the input control to an ORM, an ORM may be designed to include a variety of different mechanical controls to further increase the range of vibration responses of the ORM. Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs. Equivalent electromagnetic features may be included in other types of ORMs. Figure 40A illustrates a first type of ORM. In a first diagram 4002, the ORM is shown in an equilibrium, non-vibrating position. The ORM includes a moveable weight or mass 4002 that is connected to two ends of the ORM 4004 and 4006 by springs 4008 and 4010. Diagram 4012 shows the ORM when the movable mass 4002 has been moved, by application of a translational force, such as an electromagnetic force, to the furthest position in the leftward direction along the oscillation path. In this position, spring 4010 is compressed and spring 4008 is extended. In both cases, the springs have potential energy that produces forces that force the movable mass 4002 back in the rightward direction towards stop 4012. Diagram 4014 shows the ORM with the movable mass in the furthest rightward direction.

Figure 40B shows the equilibrium and largest-amplitude positions of a movable mass in a different type of ORM. In a first diagram 4016, the ORM is shown in an equilibrium position. The ORM features an arc-like oscillation path 4018 along which the moving mass 4020, attached to a rotor 4022, oscillates. The moving mass 4020 is attached to the rotor 4022 by a flexible support 4024. Diagram 4026 shows the ORM with the movable mass in the furthest leftward position and diagram 4028 shows

the ORM with the movable mass in the furthest rightward direction, similar to the positions shown for the ORM of Figure 40A in diagrams 4012 and 4014.

Figure 40C illustrates movable mechanical stops included in the ORM discussed above with reference to Figure 40A. The movable stops are depicted by features 4030 and 4032 in a first diagram 4034. Of course, the depictions do not necessarily reflect the shape, size, and structure of mechanical stops needed to stop motion of the moveable mass in the various different types of ORMs, but are instead used to illustrate positioning of the moveable stops and their deployment. In a second diagram 4036, the movable stops have been repositioned 4038 and 4040 in order to limit the length of travel of the moving mass 4002. The second diagram 4036 shows the leftward extent of motion of the moving mass 4002 with the movable stops deployed and diagram 4042 shows the rightward extent of travel of the moving mass when the movable stops are deployed. Similar illustration conventions are used, in Figure 40D, to illustrate deployment of movable stops in the ORM discussed above with reference to Figure 40B. Use of movable stops can significantly alter the vibration response of the ORM to a given control input. This may include changing the amplitude of the vibration response, the frequency of the vibration response, and changing the force imparted by the moving mass to the ORM when the moving mass strikes the stops versus the original end stops 4002 and 4004. In general, the vibration-response alterations are complex functions of the geometry, material composition, and driving forces used in the ORM.

Figures 40E-F illustrate use of the movable stops, discussed above with reference to Figures 40C and 40D, as latches. As shown in a first diagram 4048 in Figure 40E, the movable stops have been repositioned 4050 and 4052 closer to the center of the oscillation path. As shown in diagram 4054, the left-hand movable stop 4056 has been deployed when the moving mass 4002 has just reached its leftward, stopped position. As a result, motion of the moving mass is stopped, resulting in an immediate cessation of the driving oscillation produced by the ORM and a higher force exerted in the last oscillation on the left-end stop 4004 of the ORM. Diagram 4058 shows the right-hand movable stop 4052 deployed to latch the moving mass 4002 at its furthest right-hand position. Figure 40F shows similar deployment of the movable

stops, in the ORM discussed above with reference to Figure 40B, to latch the moving mass at its leftward and rightward extents. Latching of the moveable mass may trap the moveable mass in a high-potential-energy state, so that immediate, rapid oscillation may ensue when the latch is released. Latching may also significantly alter the relaxation of the oscillation at the end of control-pattern execution.

The current document is directed to employing the various different types of alternative control of ORMs to more accurately generate desired vibration responses. This involves use of a much greater amount of information about the ORM than used in the vibration response table discussed above. Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document. The information is stored in five different tables. An ORM table 4102 stores control information for each different ORM in a device, appliance, or system. This information includes an identifier for the ORM 4104, an indication of the ORM type 4105, an indication of the minimum pulse width that can be input in a control signal 4106, an indication of the minimum amplitude 4107 and maximum amplitude 4108 of an input control signal, indications of whether or not mechanical or electromagnetic latches are available in the ORM 4110 and 4112, the oscillation path length within the ORM 4114, the number of movable stops, or path blocks included in the ORM 4115, and the positioning range for each moveable stop 4116-4117. An event-types table 4120 includes various different types of control events. These may include deployment of latches, movement of movable stops, and output of control pulses of various different widths and amplitudes. An events table 4122 includes ordered pairs of event types and relative times that each represents one of the many different types of control events that can be input to ORMs. Each control event includes an event ID 4123, an event type 4124, and a relative time that specifies a time point within a control pattern 4126 at which the event occurs. Table 4128 includes the actual control actions that a logic controller employs to initiate each type of event in each type of ORM. For each type of control, the table includes an indication of the event type 4130, the ORM type 4131, a control ID 4132, a signal type 4133, a signal strength 4134, and any of many different other characterizations of the type of control 4135 executed by the control logic in order

to control an ORM to produce a particular type of event. Finally, table 4140 lists all of the different types of control patterns that can be used to control ORMs. These are equivalent to the previously discussed control patterns. Each control pattern includes a control-pattern identifier 4142, an indication of the number of events in the control pattern 4144, and the event identifiers for those events 4146-4149.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36. The alternative information incorporates more accurate control of ORMs using the information and techniques discussed above with reference to Figures 37A-41. In step 4202, the routine receives a vibration type, duration, amplitude, and start time for a desired device, appliance, or system vibration response. Then, in the *for*-loop of steps 4204-4212, the routine prepares for controlling each of the ORMs in the device, appliance, or system. In step 4205, a control-pattern ID is selected from the vibration-type table for the ORM, modified with respect to the previously described vibration-type table to include the identifiers of control patterns that are tabulated in the control-patterns table 4149. In step 4206, the identified control pattern is selected from the control-patterns table. In the inner *for*-loop of steps 4207-4212, each event is selected from the control pattern selected in step 4206. For each event, a corresponding event control entry is selected from the event-control table, in step 4208. The controls are scaled, in step 4209, according to the desired duration and amplitude for the vibration response. In step 4210, the time associated with the event, selected from the events table, is also scaled. In step 4211, the scaled controls and times are added to a list of time-ordered events, the controls for which are issued to the ORM during generation of the desired vibration response. In step 4214, the routine waits until the desired start time for the vibration response. Note that the desired start time takes into consideration any pre-vibration-response controls needed to produce the desired vibration response. Then, in the *while*-loop of steps 4216-4222, the routine carries out ORM control over a set of time points spanning the desired vibration-response duration. In the inner *for*-loop of steps 4217-4220, the routine initiates a control sequence for each of the time-ordered events for each of the ORMs at the points in time in which the control sequence is specified for issuance. Then, in step 4221, the routine waits for a next update-control time point.

The above-discussed methods for more accurate and reliable control of ORMs provide increased opportunities for generating increasingly complex vibration responses in devices, appliances, and systems that contain ORMs. However, with increasing complexity, attention is needed to simplifying and increasing the efficiency of driving-oscillation sensing in order to provide feedback-based control to ORMs. In addition, with more accurate control, it is possible to increase the complexity of ORM time-dependent driving oscillations, significantly increasing the types of time-dependent driving oscillations that can be encoded in control patterns and thus increasing the device, appliance, and system vibration responses to controlled ORM driving oscillations.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control. Figure 43 provides a simplified ORM-containing device architecture similar to that provided by Figure 25, discussed above. However, as shown in Figure 43, each of the ORMs, such as ORM 2504, is coupled to an additional passive oscillator, such as passive oscillator 4302. In various different implementations, a given ORM may be coupled to one, two, or more passive oscillators. When an ORM is mechanically coupled to one or more additional passive oscillators, the passive oscillators greatly increase the number of degrees of freedom for vibration of the combined ORM and one or more passive oscillators. The mathematical models for the vibration modes and resonant frequencies become far more complex, involving eigenvalue problems arising from coupled differential equations. As discussed above, the number of resonant frequencies for a system is generally proportional to the number of vibrational degrees of freedom. Furthermore, coupling passive oscillators to ORMs may provide new, complex vibrational modes with different frequencies and amplitudes. Thus, vibration components comprising an ORM and one or more passive oscillators can significantly increase the complexity of the time-dependent driving oscillations produced by these vibration components, and therefore greatly expand the types, frequencies, and modes of vibration responses produced in a device, appliance, or system containing the complex vibration components.

In the simpler system shown in Figure 25, two vibration sensors 2510 and 2511 were included. These vibration sensors detected vibration in one, two, or three orthogonal directions of the device, appliance, or system 2502 in which multiple ORMs are included. However, as shown in Figure 43, sensors that provide information regarding the driving oscillations produced by ORMs and passive oscillators, such as sensors 4304 and 4305 in ORM 2504 and passive oscillator 4302, respectively, may also provide information to local control logic, such as control logic 4306, within ORMs as well as the controller 2516 that controls one or more ORMs within the device, appliance, or system 2502. The sensors local to ORMs and passive oscillators may be designed to sense driving-oscillation characteristics while vibration sensors 2510 and 2511 are designed to sense the vibration response of the entire device, appliance, or system 2502.

By including a variety of different types of sensors within different positions and components of an ORM-containing device, appliance, or system, an opportunity is provided for hierarchical sensing and corresponding feedback control within a device, appliance, or system. In many cases, the output from a vibration sensor may be difficult to translate into accurate feedback information and corresponding control signals. For example, the vibration sensed by the vibration sensors 2510-2511 may be indirectly related to the individual driving oscillations produced by the ORM-based vibration components, such as the vibration component comprising ORM 2504 and mechanically coupled passive oscillator 4302. In such cases, significant inference is necessary to logically infer the driving oscillations of the vibration components producing the vibration-sensor signals and to compute corresponding adjustments to ORM control. Furthermore, there may be significant temporal lags between sensor vibration and the driving oscillations that produce the sensor vibration. Many of the common techniques for sensing ORM driving oscillations in order to provide local feedback to ORMs may suffer similar problems. Furthermore, there may be many different types of interferences and couplings between electromechanical driving forces, electromagnetic sensors, and other device components that mask or entirely prevent accurate inference of the real-time characteristics of ORMs and the vibration-response of the entire device, appliance, or system. For this reason, simpler and direct

types of sensing and control can provide enormous benefits in achieving desired vibration responses of the entire device, appliance, or system, particularly in devices, appliances, and systems that include multiple vibration components, each consisting of an ORM and one or more passive oscillators as well as various types of vibration sensors external to ORMs and passive oscillators as well as sensors within, or coupled to, ORMs and passive oscillators.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control. In Figure 44, a linear ORM 4402, used in previous examples, is again shown as an example ORM. The linear ORM includes a mass or weight 4404 that is driven electromagnetically by a drive coil 4406 to oscillate along a linear tube 4408. In this ORM, two sensor coils 4410 and 4412 are additionally included in order to detect motion of the weight or mass 4404 within the ORM as it is driven to oscillate. The sensor information may be provided to an internal ORM control logic 4414 or to the controller 2516 within the device, appliance, or system that includes the ORM. In certain cases, both the internal ORM control logic as well as the device controller may receive sensor information, for various different types of feedback-based control purposes. In the lower portion 4420 of Figure 44, a small control-flow diagram is provided to indicate how the sensor information is used. When a controller receives a target frequency ω_t at which the ORM is to oscillate, in step 4422, the control logic or controller initiates oscillation of the weight or mass, in step 4424, and then, in the *while*-loop of steps 4426-4430, continues to monitor the sensor output and modify control input to the ORM in order that the ORM oscillates at the target frequency ω_t. This involves reading the sensor data to determine the actual frequency of oscillation ω_a, in step 4427, then determining a difference between the target and actual frequencies in step 4428, using the determined difference to compute modifications to the current control of the ORM and modify the control in a way estimated to result in the ORM achieving the target frequency ω_t, in step 4429, and executing the modified control in step 4430. In many cases, the computations are sufficiently complex that the feedback-based control needs to be implemented by control routines running on a processor. Furthermore, because the sensors 4410 and 4412 are essentially external to the actual oscillating mass or

weight and oscillation path, the data that they output does not directly correspond to position and velocity data for the moving mass or weight, but is instead a signal proportional to the current induced in the sensor coils by the moving mass. A fair amount of interpretation is required to convert the sensor information into velocity and position information, or even into information related to the actual frequency ω_a of oscillation. Moreover, there may be significant electromagnetic interference between the drive coil 4406 and the sensor coils 4410 and 4412, limiting the accuracy at which the actual frequency ω_a or mass position and velocity can be determined. Sensor-coil-based inferences may also suffer from significant lag times between passing of the moving weight through the sensor coil and generation of a corresponding signal. In a complex system in which many different sensors are being monitored for many different ORMs, as well as sensors that detect the vibration response for a device, appliance, or system containing the ORMs, use of inferential feedback information, such as that provided by the sensor coils shown in Figure 44, may be problematic, at best.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the data provided one or more direct sensors. When a target frequency ω_t is received in step 4512, the control initiates oscillation of the mass in step 4514. In addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the one or more direct sensors and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the difference and position with time over several

readings, but because of the direct nature of the position sensing, is not inferential and is less computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

To clarify, direct sensors directly sense, in real time, the location of the moving mass of an ORM. Optical sensors, such as that shown in Figure 46, use light sources to directly identify the location of the moving mass, and the rate of change of

the accurately identified positions is straightforwardly converted into a very good approximation to the instantaneous velocity of the moving mass by simple arithmetic operations. A direct sensor provides position and velocity data in real time, constrained principally by the time needed for propagation of light, the time needed for propagation of electrical-current propagation, sensor response times, and the time needed for carrying out a small number of computer-instruction executions. These times are all far faster than the time needed for an ORM moving mass to move far enough for the motion to produce a different sensor reading, so that, in essence, a direct sensor easily produces an accurate, real-time position and velocity for the moving mass. Indirect sensors, by contrast, do not directly detect the position and velocity of an ORM moving mass. For example, as discussed with reference to Figure 44, above, the sensor-coil sensors may exhibit signal changes prior to and following the moving mass being located adjacent to them and as a result of current changes in the driving coil. Therefore, only by retrospective computational analysis can an approximate location of the moving mass be indirectly inferred. Furthermore, the sensor-coils may respond differently to the moving mass depending on a variety of external factors and even depending on the velocity of the moving mass. Indirect sensors cannot produce real-time position and velocity values for an ORM moving mass, and the accuracy of the approximations of the position and velocity may significantly deteriorate when the oscillation frequency is changing. Vibration detectors are even less accurate, since the directions and amplitudes of the vibrations of an entire device may not align with the direction of moving-mass vibration, may vary due to many different external factors, including the orientation of the device with respect the gravitational field, the local mechanical environment of the device, the model of the moving-mass trajectory they use for inferring moving-mass position, and other such factors. In these cases, inferring the position and velocity of the ORM moving mass is generally associated with large errors and computational time lags. Direct moving-mass position-and-velocity sensors therefore provide accurate and real-time, nearly instantaneous moving-mass position and velocity data. Indirect moving-mass position-and-velocity sensors do not provide real-time, nearly instantaneous moving-mass position and velocity data, and do not

achieve the accuracy, in the non-real-time position and velocity values they produce that is achieved by direct sensors.

Although the present invention has been described in terms of particular embodiments, it is not intended that the invention be limited to these embodiments. Modifications will be apparent to those skilled in the art. For example, any of many different design and implementation parameters may be varied in order to provide different implementations of the ORM control logic discussed above, including choice of type of logic control, programming language, in the case of a processor-controlled controller, modular organization, data structures, control structures, logic circuitry, processor type, and many other such design and implementation parameters. Many different types of direct sensors that directly determine the velocity and position of the oscillating mass within an ORM can be used in different types of ORMs. Various types of electromagnetic sensors that sense position, precious-metal brush-contact sensors, and Reed switches are examples of the many types of direct sensors that can be used to directly determine oscillating-mass position and velocity and induce direct, corresponding control of the ORM.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. The foregoing descriptions of specific embodiments of the present invention are presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments are shown and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents:

CLAIMS

1. An oscillating resonant module comprising:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

2. The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more:

mechanical sensors;

electromagnetic sensors; and

optical sensors.

3. The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass from the positions of the mass at two or more points in time.

4. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

5. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

6. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

7. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

8. The oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

9. The oscillating resonant module of claim 8 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

10. A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

the one or more oscillating resonant modules, each of which responds to control inputs to produce driving oscillations and includes a sensor that provides sensor data to a control component within the oscillating resonant module;

one or more vibration sensors;

a stored characterization of the natural vibration frequencies of the physical device; and

a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.

11. The physical device of claim 10 wherein each of the one or more oscillating resonant modules comprises:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

12. The physical device of claim 10 wherein the characterization of the natural vibration frequencies of the physical device is determined by simultaneously sweeping the driving oscillations of the one or more oscillating resonant modules over driving-oscillation ranges and monitoring the physical device vibration response using output from the one or more vibration sensors to identify the maximum-amplitude frequencies.

13. The physical device of claim 12 wherein the characterization of the natural vibration frequencies of the physical device is determined periodically by the controller.

14. The physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device.

15. The physical device of claim 10 wherein at least one of the each of the one or more oscillating resonant modules is mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

16. The physical device of claim 15 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

17. An oscillating resonant module comprising:

a first mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along a first oscillation path that represents a segment of a space curve;

a second mass that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve; and

a control component that

receives control signals input to the oscillating resonant module, and

controls oscillation of the first mass to produce a predetermined vibration response according to the received control signals by generating a control output to an actuator that drives the first mass to oscillate.

18. The oscillating resonant module of claim 17 further comprising:

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

19. The oscillating resonant module of claim 17 further comprising:

one or more sensors that output indications directly correlated with the position of the second mass within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

20. The oscillating resonant module of claim 17 included within a physical device to drive a vibration response in the physical device.

ABSTRACT OF THE DISCLOSURE

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

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RESPONSE TO REQUEST FOR CORRECTED FILING RECEIPT

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In response to your request for a corrected Filing Receipt, the Office is unable to comply with your request because:

- One or more of the benefit claims under 35 U.S.C. § 120 cannot be included on the Filing Receipt since applicant did not specify whether the application is a continuation, divisional or continuation-in-part of the prior application. Applicant must submit a new application data sheet (ADS) that sets forth the relationship, and the ADS must be accompanied by a petition under 37 CFR 1.78 if filed after the time period set forth in 37 CFR 1.78.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

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Receipt is acknowledged of this non-provisional utility patent application. The application will be taken up for examination in due course. Applicant will be notified as to the results of the examination. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF FIRST INVENTOR, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection.

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Domestic Applications for which benefit is claimed - None.
A proper domestic benefit claim must be provided in an Application Data Sheet in order to constitute a claim for domestic benefit. See 37 CFR 1.76 and 1.78.

Foreign Applications for which priority is claimed (You may be eligible to benefit from the **Patent Prosecution Highway** program at the USPTO. Please see http://www.uspto.gov for more information.) - None.
Foreign application information must be provided in an Application Data Sheet in order to constitute a claim to foreign priority. See 37 CFR 1.55 and 1.76.

Permission to Access Application via Priority Document Exchange: No

Permission to Access Search Results: No

Applicant may provide or rescind an authorization for access using Form PTO/SB/39 or Form PTO/SB/69 as appropriate.

If Required, Foreign Filing License Granted: 03/17/2020

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 16/806,925**

Projected Publication Date: To Be Determined - pending completion of Missing Parts

Non-Publication Request: No

Early Publication Request: No
**** SMALL ENTITY ****
Title

OSCILLATING-RESONANT-MODULE CONTROLLER

Preliminary Class

310

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at http://www.uspto.gov/web/offices/pac/doc/general/index.html.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, http://www.stopfakes.gov. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific

countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4258).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign AssetsControl, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

SelectUSA

The United States represents the largest, most dynamic marketplace in the world and is an unparalleled location for business investment, innovation, and commercialization of new technologies. The U.S. offers tremendous resources and advantages for those who invest and manufacture goods here. Through SelectUSA, our nation works to promote and facilitate business investment. SelectUSA provides information assistance to the international investor community; serves as an ombudsman for existing and potential investors; advocates on behalf of U.S. cities, states, and regions competing for global investment; and counsels U.S. economic development organizations on investment attraction best practices. To learn more about why the United States is the best country in the world to develop

technology, manufacture products, deliver services, and grow your business, visit http://www.SelectUSA.gov or call +1-202-482-6800.

PATENT APPLICATION FEE DETERMINATION RECORD

Substitute for Form PTO-875

Application or Docket Number: 16/806,925

APPLICATION AS FILED - PART I

FOR	(Column 1) NUMBER FILED	(Column 2) NUMBER EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY FEE($)
BASIC FEE (37 CFR 1.16(a), (b), or (c))	N/A	N/A	N/A	75		N/A	
SEARCH FEE (37 CFR 1.16(k), (i), or (m))	N/A	N/A	N/A	330		N/A	
EXAMINATION FEE (37 CFR 1.16(o), (p), or (q))	N/A	N/A	N/A	380		N/A	
TOTAL CLAIMS (37 CFR 1.16(i))	20 minus 20 =	*	x 50 =	0.00	OR		
INDEPENDENT CLAIMS (37 CFR 1.16(h))	3 minus 3 =	*	x 230 =	0.00			
APPLICATION SIZE FEE (37 CFR 1.16(s))	If the specification and drawings exceed 100 sheets of paper, the application size fee due is $310 ($155 for small entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).			0.00			
MULTIPLE DEPENDENT CLAIM PRESENT (37 CFR 1.16(j))				0.00			
* If the difference in column 1 is less than zero, enter "0" in column 2.			TOTAL	785		TOTAL	

APPLICATION AS AMENDED - PART II

AMENDMENT A

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	SMALL ENTITY RATE($)	SMALL ENTITY ADDITIONAL FEE($)	OR	OTHER THAN SMALL ENTITY RATE($)	OTHER THAN SMALL ENTITY ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

AMENDMENT B

	(Column 1) CLAIMS REMAINING AFTER AMENDMENT		(Column 2) HIGHEST NUMBER PREVIOUSLY PAID FOR	(Column 3) PRESENT EXTRA	RATE($)	ADDITIONAL FEE($)		RATE($)	ADDITIONAL FEE($)
Total (37 CFR 1.16(i))	*	Minus	**	=	x =		OR	x =	
Independent (37 CFR 1.16(h))	*	Minus	***	=	x =		OR	x =	
Application Size Fee (37 CFR 1.16(s))									
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM (37 CFR 1.16(j))							OR		
					TOTAL ADD'L FEE		OR	TOTAL ADD'L FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20".

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3".

The "Highest Number Previously Paid For" (Total or Independent) is the highest found in the appropriate box in column 1.

UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
16/806,925	03/02/2020	Robin Elenga	35099.008C1

CONFIRMATION NO. 7971

34395
OLYMPIC PATENT WORKS PLLC
P.O. BOX 4277
SEATTLE, WA 98104

FORMALITIES LETTER

OC000000115492558

Date Mailed: 03/18/2020

NOTICE TO FILE MISSING PARTS OF NONPROVISIONAL APPLICATION

FILED UNDER 37 CFR 1.53(b)

Filing Date Granted

Items Required To Avoid Abandonment:

An application number and filing date have been accorded to this application. The item(s) indicated below, however, are missing. Applicant is given **TWO MONTHS** from the date of this Notice within which to file all required items below to avoid abandonment. Extensions of time may be obtained by filing a petition accompanied by the extension fee under the provisions of 37 CFR 1.136(a).

- Complete residence information, either city and state or city and country for **Robin Elenga**, **Dan Knodle**, and **Brian Pepin** has not been provided. Residence information is required, separately from the mailing address, if the inventor lives at a location which is different from where the inventor customarily receives mail. Also, a valid state code or a valid country code must be provided. For lists of valid state and valid country codes, see the Instructions for Application Data Sheet available at https://www.uspto.gov/patent/forms/forms-patent-applications-filed-or-after-september-16-2012. There is an indication on either the ADS or the inventor's oath or declaration that the mailing address and residence information is not the same for this inventor.
  Applicant must provide the residence information on either:
  - An inventor's oath or declaration in compliance with 37 CFR 1.63, or
  - A properly marked up application data sheet (ADS) in compliance with 37 CFR 1.76.
- A complete mailing address that includes either the city and state or city and country, for each inventor has not been submitted. Applicant must provide the mailing address on either:
  - An inventor's oath or declaration in compliance with 37 CFR 1.63, or
  - A properly marked up application data sheet (ADS) in compliance with 37 CFR 1.76.

  Note that an inventor's mailing address is required even if a correspondence address has been submitted. An inventor's mailing address may not necessarily be the same as the correspondence address for the application and must be separately submitted in the manner set forth above. If the inventor lives at a location which is different from the inventor's mailing address, the inventor's residence (either city and state or city and country) must also be separately submitted in the manner set forth above. For lists of valid state and valid country codes, see the Instructions for Application Data Sheet available at https://www.uspto.gov/patent/forms/forms-patent-applications-filed-or-after-september-16-2012.
  Mailing address information is needed for the following inventor(s): **Robin Elenga**, **Dan Knodle**, and **Brian Pepin**

The application is informal since it does not comply with the regulations for the reason(s) indicated below.

The required item(s) identified below must be timely submitted to avoid abandonment:

- A substitute specification in compliance with 37 CFR 1.52, 1.121(b)(3), and 1.125, is required. The substitute specification must be submitted with markings and be accompanied by a clean version (without markings) as set forth in 37 CFR 1.125(c) and a statement that the substitute specification contains no new matter (see 37 CFR 1.125(b)). The specification, claims, and/or abstract page(s) submitted is not acceptable and cannot be scanned or properly stored because:
  - The application papers (including any electronically submitted papers) are not in compliance with 37 CFR 1.52 because pages 1-22 contain text that is unreadable or of insufficient clarity.
    Application papers (including any electronically submitted papers) must be presented in a form having sufficient clarity and contrast between the background of the paper and the writing thereon to permit the Office to electronically reproduce the papers by use of digital imaging and optical character recognition. See 37 CFR 1.52(a)(1)(v).
- Replacement drawings in compliance with 37 CFR 1.84 and 37 CFR 1.121(d) are required. The drawings submitted are not acceptable because:
  - The drawings must be reasonably free from erasures and must be free from alterations, overwriting, interlineations, folds, and copy marks. See Figure(s) 41.

Applicant is cautioned that correction of the above items may cause the specification and drawings page count to exceed 100 pages. If the specification and drawings exceed 100 pages, applicant will need to submit the required application size fee.

- The statutory basic filing fee is missing.
- The application search fee must be submitted.
- The application examination fee must be submitted.
- Surcharge as set forth in 37 CFR 1.16(f) must be submitted.
  The surcharge is due for any one of:
  - late submission of the basic filing fee, search fee, or examination fee,
  - late submission of inventor's oath or declaration,
  - filing an application that does not contain at least one claim on filing, or
  - submission of an application filed by reference to a previously filed application.

SUMMARY OF FEES DUE:

The fee(s) required within **TWO MONTHS** from the date of this Notice to avoid abandonment is/are itemized below. Small entity discount is in effect. If applicant is qualified for micro entity status, an acceptable Certification of Micro Entity Status must be submitted to establish micro entity status. (See 37 CFR 1.29 and forms PTO/SB/15A and 15B.)

- $ **75** basic filing fee.
- $ **80** surcharge.
- $ **330** search fee.
- $ **380** examination fee.
- $(**0**) previous unapplied payment amount.
- $ **865** TOTAL FEE BALANCE DUE.

Items Required To Avoid Processing Delays:

Applicant is notified that the above-identified application contains the deficiencies noted below. No period for reply is set forth in this notice for correction of these deficiencies. However, if a deficiency relates to the inventor's oath or declaration, the applicant must file an oath or declaration in compliance with 37 CFR 1.63, or a substitute statement in compliance with 37 CFR 1.64, executed by or with respect to each actual inventor no later than the expiration of the time period set in the "Notice of Allowability" to avoid abandonment. See 37 CFR 1.53(f).

- A properly executed inventor's oath or declaration has not been received for the following inventor(s):
  Robin Elenga
  Dan Knodle
  Brian Pepin

Replies must be received in the USPTO within the set time period or must include a proper Certificate of Mailing or Transmission under 37 CFR 1.8 with a mailing or transmission date within the set time period. For more information and a suggested format, see Form PTO/SB/92 and MPEP 512.

Replies should be mailed to:

Mail Stop Missing Parts
Commissioner for Patents
P.O. Box 1450
Alexandria VA 22313-1450

Registered users of EFS-Web may alternatively submit their reply to this notice via EFS-Web, including a copy of this Notice and selecting the document description "Applicant response to Pre-Exam Formalities Notice". https://sportal.uspto.gov/authenticate/AuthenticateUserLocalEPF.html

For more information about EFS-Web please call the USPTO Electronic Business Center at 1-866-217-9197 or visit our website at http://www.uspto.gov/ebc.

If you are not using EFS-Web to submit your reply, you must include a copy of this notice.

Questions about the contents of this notice and the requirements it sets forth should be directed to the Office of Data Management, Application Assistance Unit, at **(571) 272-4000** or **(571) 272-4200** or **1-888-786-0101**.

/mgabre/

PTO/AIA/15 (03-13)
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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket No.	35099.008C1
First Named Inventor	Robin Elenga
Title	Oscillating-Resonant-Module Controller
Express Mail Label No.	VIA EFS WEB

APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

1. ☐ **Fee Transmittal Form** (PTO/SB/17 or equivalent)
2. ☑ **Applicant asserts small entity status.** See 37 CFR 1.27
3. ☐ **Applicant certifies micro entity status.** See 37 CFR 1.29. Applicant must attach form PTO/SB/15A or B or equivalent.
4. ☑ **Specification** [*Total Pages* 55] Both the claims and abstract must start on a new page. *(See MPEP § 608.01(a) for information on the preferred arrangement)*
5. ☑ **Drawing(s)** (35 U.S.C. 113) [*Total Sheets* 53]
6. **Inventor's Oath or Declaration** [*Total Pages* ____] *(including substitute statements under 37 CFR 1.64 and assignments serving as an oath or declaration under 37 CFR 1.63(e))*
   a. ☐ Newly executed (original or copy)
   b. ☐ A copy from a prior application (37 CFR 1.63(d))
7. ☑ **Application Data Sheet** ** See note below.* See 37 CFR 1.76 (PTO/AIA/14 or equivalent)
8. **CD-ROM or CD-R** in duplicate, large table, or Computer Program (*Appendix*)
   ☐ Landscape Table on CD
9. **Nucleotide and/or Amino Acid Sequence Submission** (*if applicable, items a. – c. are required*)
   a. ☐ Computer Readable Form (CRF)
   b. ☐ Specification Sequence Listing on:
      i. ☐ CD-ROM or CD-R (2 copies); or
      ii. ☐ Paper
   c. ☐ Statements verifying identity of above copies

ADDRESS TO: **Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450**

ACCOMPANYING APPLICATION PAPERS

10. ☐ **Assignment Papers** (cover sheet & document(s)) Name of Assignee ____
11. ☐ **37 CFR 3.73(c) Statement** (*when there is an assignee*) ☐ **Power of Attorney**
12. ☐ **English Translation Document** (*if applicable*)
13. ☐ **Information Disclosure Statement** (PTO/SB/08 or PTO-1449)
    ☐ Copies of citations attached
14. ☐ **Preliminary Amendment**
15. ☐ **Return Receipt Postcard** (*MPEP § 503*) (*Should be specifically itemized*)
16. ☐ **Certified Copy of Priority Document(s)** (*if foreign priority is claimed*)
17. ☐ **Nonpublication Request** Under 35 U.S.C. 122(b)(2)(B)(i). Applicant must attach form PTO/SB/35 or equivalent.
18. ☐ **Other:** ____

*Note: (1) Benefit claims under 37 CFR 1.78 and foreign priority claims under 1.55 **must** be included in an Application Data Sheet (ADS).
(2) For applications filed under 35 U.S.C. 111, the application must contain an ADS specifying the applicant if the applicant is an assignee, person to whom the inventor is under an obligation to assign, or person who otherwise shows sufficient proprietary interest in the matter. See 37 CFR 1.46(b).

19. CORRESPONDENCE ADDRESS

☑ The address associated with Customer Number: 34395 **OR** ☐ Correspondence address below

Name					
Address					
City		State		Zip Code	
Country		Telephone		Email	

Signature	/Robert W. Bergstrom/	Date	March 2, 2020
Name (Print/Type)	Robert W. Bersgtom	Registration No. (Attorney/Agent)	39906

This collection of information is required by 37 CFR 1.53(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

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.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

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Application Data Sheet 37 CFR 1.76	Attc App
Title of Invention	OSCILLATING-RESONANT-MODU

The application data sheet is part of the provisional or nonprovisio
bibliographic data arranged in a format specified by the United Sta
This document may be completed electronically and submitted t
document may be printed and included in a paper filed application

ıber	35099.008C1

ich it is being submitted. The following form contains the
mark Office as outlined in 37 CFR 1.76.
onic format using the Electronic Filing System (EFS) or the

Secrecy Order 37 CFR 5.2:

☐ Portions or all of the application associated with this
37 CFR 5.2 (Paper filers only. Applications that

Sheet may fall under a Secrecy Order pursuant to
Order may not be filed electronically.)

Inventor Information:

Inventor 1

Remove

Legal Name

Prefix	Given Name	Middle	Family Name	Suffix
	Robin		Elenga	

Residence Information (Select One) ◉ US Resid — JS Residency ◯ Active US Military Service

City	Seattle	State/Provi	ountry of Residence	US

Mailing Address of Inventor:

Address 1	3420 - 10th Avenue West	/Province	WA
Address 2			US
City	Seattle		
Postal Code	98119		

Inventor 2

Remove

Legal Name

Prefix	Given Name	Middle	Family Name	Suffix
	Dan		Knodle	

Residence Information (Select One) ◉ US Resid — JS Residency ◯ Active US Military Service

City	Seattle	State/Provi	ountry of Residence	US

Mailing Address of Inventor:

Address 1	3420 - 10th Avenue West	/Province	WA
Address 2			US
City	Seattle		
Postal Code	98119		

Inventor 3

Remove

Legal Name

Prefix	Given Name	Middle	Family Name	Suffix
	Brian		Pepin	

Residence Information (Select One) ◉ US Resid — JS Residency ◯ Active US Military Service

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Application Data Sheet 37 CFR 1.76	Atto / App
Title of Invention	OSCILLATING-RESONANT-MODU

City	Oakland	**State/Provi**	

Mailing Address of Inventor:

Address 1	2355 Broadway
Address 2	
City	Oakland
Postal Code	94612

All Inventors Must Be Listed - Additional Inventc
generated within this form by selecting the **Add** butto

Correspondence Information:

Enter either Customer Number or complete the C
For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the corresp**

Customer Number	34395
Email Address	joanne@olympicpatentwork

Application Information:

Title of the Invention	OSCILLATING-RESONAN
Attorney Docket Number	35099.008C1
Application Type	Nonprovisional
Subject Matter	Utility
Total Number of Drawing Sheets (if any)	53

Filing By Reference:

Only complete this section when filing an application by referen
application papers including a specification and any drawings ar
provided in the appropriate section(s) below (i.e., "Domestic Ben

For the purposes of a filing date under 37 CFR 1.53(b), the descri
reference to the previously filed application, subject to conditior

Application number of the previously filed application	Filing date (YYY

Publication Information:

☐ Request Early Publication (Fee required at time

☐ **Request Not to Publish.** I hereby re
35 U.S.C. 122(b) and certify that the invention c
subject of an application filed in another country
publication at eighteen months after filing.

EFS Web 2.2.12

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e/Province | WA

US

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Add Email | Remove Email

ROLLER

ll Entity Status Claimed ☒

ggested Figure for Publication (if any) 45

1(c) and 37 CFR 1.57(a). Do not complete this section if
omestic benefit or foreign priority information must be
nformation" and "Foreign Priority Information").

ngs of the present application are replaced by this
of 37 CFR 1.57(a).

	Intellectual Property Authority or Country

FR 1.219)

ached application not be published under
tached application **has not and will not** be the
lateral international agreement, that requires

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a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76	Atto App
Title of Invention	OSCILLATING-RESONANT-MODU

iber	35099.008C1

Representative Information:

Representative information should be provided for all
this information in the Application Data Sheet does not con
Either enter Customer Number or complete the Represen
Number will be used for the Representative Information du

g a power of attorney in the application. Providing
ttorney in the application (see 37 CFR 1.32).
n below. If both sections are completed the customer

Please Select One:	◉ Customer Number
Customer Number	34395

ctitioner	○ Limited Recognition (37 CFR 11.9)

Domestic Benefit/National Stage Infc

This section allows for the applicant to either claim ber
National Stage entry from a PCT application. Providing
the specific reference required by 35 U.S.C. 119(e) or
When referring to the current application, please leave

.C. 119(e), 120, 121, 365(c), or 386(c) or indicate
ormation in the Application Data Sheet constitutes
1.78.
Number" field blank.

Prior Application Status	Pending
Application Number	Continuity Type
	Continuation in part of
Prior Application Status	Expired
Application Number	Continuity Type
15/043584	Claims benefit of provisiona

Additional Domestic Benefit/National Stage Data ma
by selecting the **Add** button.

Remove

plication Number	Filing or 371(c) Date (YYYY-MM-DD)
4	2016-02-14

Remove

plication Number	Filing or 371(c) Date (YYYY-MM-DD)
4	2015-02-13

ithin this form

Foreign Priority Information:

This section allows for the applicant to claim priority to a fore
constitutes the claim for priority as required by 35 U.S.C. 11
that is eligible for retrieval under the priority document excha
automatically attempt retrieval pursuant to 37 CFR 1.55(i)(1)
responsibility for ensuring that a copy of the foreign applicati
property office, or a certified copy of the foreign priority appli

oviding this information in the application data sheet
55. When priority is claimed to a foreign application
) the information will be used by the Office to
PDX program, applicant bears the ultimate
e Office from the participating foreign intellectual
the time period specified in 37 CFR 1.55(g)(1).

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Name of the Deceased or Legally Incapacitated Inven

If the Applicant is an Organization check here. ☐

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OSCILLATING-RES(JLE CONTROLLER

CROSS-REFERENCE TO RELAT IONS

This application i ion-in-part of Application No. 15/043,584, filed February 14, 201 s the benefit of Provisional Patent Application No. 62/116,144, filed F 5.

TECHNICAL FIELD

The current docume ibration-generating devices and, in particular, to vibration modules that ated into a wide variety of different types of electromechanical devices produce predetermined vibration responses.

BACKGROUND

Vibration-inducing hanisms have been used for many years in a wide variety of different ances, toys, and other devices and systems. Examples include vibra erated by pagers, smart phones, vibration-driven appliances, such a appliances, electric toothbrushes, electric toy football games, and man es, devices, and systems. The most common electromechanical system ating vibrations is an intentionally unbalanced electric motor.

Figures 1A-B illustr d electric motor typically used for generating vibrations in a wide vari levices. As shown in Figure 1A, a small, relatively low-power electri tates a cylindrical shaft 104 onto which a weight 106 is asymmetri d. Figure 1B shows the weight asymmetrically mounted to the sh vn at the weight and shaft in the direction of the axis of the shaft. A re 1B, the weight 106 is mounted off-center on the electric-motor sh es 2A-B illustrate the vibrational motion produced by the unbalanced hown in Figures 1A-B. As shown in Figures 2A-B, the asymmetrical ght creates an elliptical oscillation of the end of the shaft, normal to th en the shaft is rotated at relatively high speed by the electric motor. s displacement of the weight and

shaft from the stationary shaft axis
and shaft along the shaft axis, as i
provided at the periphery of the disk
rotation of the shaft. When the sha
the weight traces an ellipsoid 206 a
smaller ellipsoid 210. Were the sha
a position 212 in the center of the
asymmetrically-mounted weight at
weight-distribution characteristics
together create forces that move the
the shaft is rotated at relatively hig
shown in Figure 2B, by a major a
direction of the major axis of vibra
ellipsoids, shown in Figure 2A, and
amplitude of vibration in this directi
and forth along a defined path is
amplitude/minor-axis-amplitude ra
path, but, because the vibration is
possible to achieve oscillation back
path traced by the shaft center may
the unbalanced electric motor is equ
shaft, and is therefore constrained
At low rotational speeds, little vibra

While effective in
associated with the unbalanced-elec
shown in Figure 1A, commonly use
discussed above. Unbalancing the
vibrations that can be harnessed for
unbalanced forces within the motor
Enormous care and effort is undert
vehicles, and other types of machir

tated, looking down on the weight
n Figure 2A, a small mark 202 is
of electric-motor shaft to illustrate
speed, a point 204 on the edge of
the shaft 208 traces a narrower and
center of the shaft would remain at
rotation, but the presence of the
aft, as well as other geometric and
otor, shaft, and unbalanced weight
along the elliptical path 210 when
ovement can be characterized, as
or axis 222 of vibration, with the
direction of the major axis of the
e major axis corresponding to the
lications, in which oscillation back
ers seek to force the major-axis-
as possible, to approach a linear
otational force, it is generally not
a defined path. In many cases, the
lar. The frequency of vibration of
nal frequency of the electric-motor
ich the motor can rotate the shaft.
l.

ations, there are many problems
tion-generating units, such as that
devices, systems, and applications
ric motor not only produces useful
ions, but also produces destructive,
rapid deterioration of motor parts.
y balance rotating parts of motors,
sequences of unbalanced rotating

parts are well known to anyone fa
such devices and systems. The u
particularly hand-held devices and a
for generating vibrations may rang
hours of use, after which the vibra
precipitously as the electric motor
motors are relatively inefficient at p
of power is consumed by an unbala
force than the theoretical minimun
force. As a result, many hand-held
generating vibrations quickly con
motors, as discussed above, oscillat
or space curve, cannot generally
Unbalanced electric motors genera
total vibrational-force/frequency sp
with respect to frequency for vario
is shown as a continuous hypothetic
discrete. As shown in Figure 3, for
held appliances, only a fairly narro
in Figure 3) generate a significant v
relatively modest. The bulk of ene
used to spin the shaft and unbalanc
forces within the motor. Only a r
translated into desired vibrational f

Because of the abo
employed unbalanced-electric-m
manufacturers, and, ultimately, us
devices, appliances, and systems co
generating units for incorporatior
systems.

mobiles, machine tools, and other
of many devices and appliances,
employ unbalanced electric motors
ns of hours to a few thousands of
produced by the devices declines
deteriorate. Unbalanced electric
onal motion. A far greater amount
otor to produce a given vibrational
d to produce the given vibrational
oloy unbalanced electric motors for
during use. Unbalanced electric
and forth along a predefined path,
by unbalanced electric motors.
only a very limited portion of the
shows a graph of vibrational force
lanced electric motors. The graph
gh, of course, actual data would be
ower electric motors used in hand-
iencies centered about 80 Hz (302
Moreover, the vibrational force is
oy an unbalanced electric motor is
to overcome frictional and inertial
portion of the consumed energy is

isadvantages with the commonly
n-generation units, designers,
ariety of different vibration-based
ore efficient and capable vibration-
nsumer appliances, devices, and

SUMMARY

The current documer arious types of oscillating resonant modules ("ORMs"), including l vibration modules, that can be incorporated in a wide variety c devices, and systems to provide vibrational forces. The vibrational uced by back-and-forth oscillation of a weight or member along a path, nent of a space curve. A controller controls each of one or more ORI lriving oscillations according to a control curve or control pattern for t ecifies the frequency of the driving oscillations with respect to time. cillations, in turn, elicit a desired vibration response in the device, ap m in which the one or more ORMs are included. The desired vibrati achieved by selecting and scaling control patterns in view of known encies of the device, appliance, or system.

BRIEF DESCRIPTION OF THE D

Figures 1A-B illustr d electric motor typically used for generating vibrations in a wide vari devices.

Figures 2A-B illus tional motion produced by the unbalanced electric motor shown in

Figure 3 shows a gr al force with respect to frequency for various types of unbalanced ele

Figures 4A-D illustr is meant by the phrase "oscillating resonant module" in the current doc

Figures 5A-G illustr r type of ORM.

Figures 6A-B illustr switch that can be used, in various ORMs, to change the direction of c o a coil that drives back-and-forth oscillation within the ORM.

Figure 7 provides a of the ORM, illustrated in Figures 5A-G.

Figures 8A-C provi diagrams that illustrate the control program, executed by the CPU, tha ion of an ORM.

Figure 9 represents t uencies and vibrational forces that can be achieved by different impler RM and ORM control programs.

Figure 10 shows a pl ıde/frequency space and regions in that space that can be operationally ıbalanced electrical motors and by ORMs.

Figures 11-18 show ferent alternative implementations of ORMs.

Figure 19 illustrates of an implementation of the ORM shown in Figure 17.

Figure 20 illustrates .

Figure 21 illustrates ver.

Figure 22A illustrate ı of a stator having two coil layers.

Figure 22B illustrate ı of a stator having four coil layers.

Figure 22C illustrate ı of a stator having two coil layers.

Figure 23A illustrate driving force that is perpendicular to the surface of a substrate.

Figure 23B illustrate a magnetic armature in an upward position.

Figure 23C illustra with a magnetic armature in a downward position.

Figures 24A-D p: ions of various physical and mathematical concepts related to os

Figure 25 shows a of a generic device, appliance, or system that employs ORMs to gene

Figures 26A-B illust sonant frequencies within a device or system.

Figure 27 provides a ant-frequency table for the generic ORM-containing device discussed ence to Figure 25.

Figures 28A-C illust M control scheme combines with a resonant frequency to produce a vib

Figure 29 shows a fe ontrol patterns that may be applied to ORMs by the control logic withi /ice.

Figure 30 shows an on-type table that may be prepared for the generic device shown in Fig

Figures 31-36 provi diagrams to illustrate control logic used in the generic device, discuss eference to Figure 25, to produce well-defined vibration modes or vi in the physical device or system.

Figures 37A-D illust modulation control of an ORM.

Figure 38A illustrate rn that involves a constant-voltage signal 3802 from an initial time t_i 3 id time t_f 3806.

Figure 38B illustrate ation response of the ORM.

Figure 39 illustrates the naïve control pattern, shown in Figure 38A, in order to achieve imation of the desired constant-amplitude oscillation in the time int

Figures 40A-40F illi mechanical stops and mechanical latches, two types of mechanical co it may be included in various types of ORMs.

Figure 41 shows ex on that may be stored in order to more accurately control ORMs acc hods and considerations disclosed in the current document.

Figure 42 provides implementation of the routine "generate vibration," discussed abo to Figure 36.

Figure 43 illustrates for increasing the complexity of ORM time-dependent driving osc ll as increasing and simplifying feedback control.

Figure 44 illustrates M driving-oscillation sensor that can be employed to provide feedbac or ORM control.

Figure 45 illustrates approach to sensing the driving oscillations produced by an ORM.

Figures 46A-B illust ible direct-sensing approaches.

DETAILED DESCRIPTION

The current docum to various oscillating resonant modules ("ORMs"), including var near oscillating resonant modules ("linear ORMs"), that can be used w ety of different types of appliances, devices, and systems, to generate vi ORMs produce vibrational forces by oscillation of a weight or comp ORM along a segment of a space curve, rather than as a by-produ nced rotation, as in the case of unbalanced electric motors. The e of the ORM vibration-inducing motion effectively addresses man ociated with unbalanced electric motors. Combining an ORM witl rol, so that the driving frequency produced by the ORM falls close t requency of a device in which the ORM is included, results in optima otion with respect to the amplitude and frequency of vibration produce s well as maximal vibration energy of the device. Oscillation within a late into highly directional driving forces produced by the ORM to dr esponse in an appliance or device that incorporates the ORM. The cu ncludes a first subsection, in which various types of ORMs are describe ection on which an ORM controller is discussed, and a third subsectio rate methods for ORM control, to which the current document is direc ed in detail.

Figures 4A-D illustr is meant by the phrase "oscillating resonant module" in the current contrast to the above-discussed unbalanced electric motors often ate vibrations in vibration-driven appliances, an oscillating resonant a weight, or mass, that oscillates back and forth along a path. The pa ar path, or line segment, but, in the general case, can be potentially an nent of a space curve. Figure 4A illustrates operation of a linear osc module. In a first diagram 402, labeled with the time "0," the linear l at time 0 (404 in Figure 4A), with the mass or weight 406 centered w th 408 bounded by two stops 410 and 412. When the linear ORM is eight begins moving to the left, as shown in diagram 414. The small n the disk-like mass 406 indicates

the direction of movement. The m
until the mass strikes the left-hand
the mass reverses and the mass begi
in diagram 418. In diagrams 419 an
of travel during time intervals 4 an
strikes the right-hand stop 404 and
direction, as shown in diagram 422
indefinitely during operation of the
along the linear path. The perio
oscillation can generally be control

Figure 4B illustrates
the weight along a circle to the actu
as discussed above with reference
weight is plotted along a circle 43(
position is vertically mapped, as in
line 436 within the circle 430, to a c
the circle. The position of the wei
direction, as long as the linear ORM
442. At time 1, indicated by point 4
by vertical dashed line 446, to poin
point 450, the position of the mas
represented by point 454 along the
Thus, as the position of the mass pl
point 454, the direction of movem
continuing in the opposite directio
Small horizontal arrows, such as arr
the linear motion of the mass of th
points. Thus, the back-and-forth
described by a logical revolution of
1, then the position x at time t of
expressed as:

) move, as shown in diagram 416,
ich point the direction of travel of
in the opposite direction, as shown
continues in its rightward direction
as shown in diagram 421, the mass
ion, traveling back in the leftward
ndicate that this process continues
e mass oscillates back and forward
and the maximum amplitude of
gnals input to an ORM.

a continuous logical movement of
of the weight within a linear ORM,
In Figure 4B, the position of the
presented by point 432, the weight
ed line 434 as well as by the solid
on the linear path 440 shown below
the circle, in a counter-clockwise
icated by the dashed circular arrow
the position of the mass is mapped,
ath 440. At time 2, represented by
path 440 is point 452. At time 3,
ion of the mass is again point 448.
circle has moved from point 444 to
has reversed and the mass is now
tion in which it originally moved.
below the linear path 440, illustrate
etween each pair of adjacent time
ne mass in a linear ORM can be
circle. If the circle has a radius of
the actual path of travel can be

$x($ $)$,

where ω is the angular velocity at w :presenting the mass moves around the circle.

Figure 4C illustrates ·curve segment path. In Figure 4C, a short space-curve segment 460 i l in a three-dimensional Cartesian coordinate system 462. The weight :illating resonant module ("ORM") may oscillate back and forth along rve-segment path. In the first plot in Figure 4C 458, the weight or ı m left to right along the path, as indicated by the small curved arro ved arrow 460. As shown in the second plot 462 in Figure 4C, once ass reaches the left-hand end of the space-curve segment, it reverses dir 'e to the left. As shown in the third plot 464 in Figure 4C, once the wei :hes the left-hand end of the space-curve segment, it again reverses dir s to the right. Ellipses 466 indicate that this back-and-forth oscillation e the ORM operates. The space-curve-segment path of the weight in ıed by the physical implementation and operation of the ORM.

Figure 4D illustrate l example paths along which the weight or mass of an ORM may os t path is a circular arc 470 and the second path is a partially elliptica 472. As mentioned above, many additional different types of space-(aths for ORMs are possible.

Figures 5A-G illustr r type of ORM. Figures 5A-G all use the same illustration convention l with reference to Figure 5A. The ORM includes a cylindrical housing ch a solid, cylindrical mass 504, or weight, can move linearly along th cylindrically shaped chamber 506 within the cylindrical housing or tu eight is a magnet, in the described an implementation, with polarity ir +" sign 510 on the right-hand end and the "-" sign 512 on the left-han ight 504. The cylindrical chamber 506 is capped by two magnetic disl vith polarities indicated by the "+" sign 518 and the "-" sign 519. Th ıets 514 and 518 are magnetically oriented opposite from the magnet the weight 504, so that when the

weight moves to either the extrei
chamber, the weight is repelled by (
of the cylindrical chamber. In other
to facilitate deceleration and reve
minimize or prevent mechanical-im
off the cylindrical chamber. Fin
cylindrical housing, or tube 502 a
housing.

Figures 5B-G illust
When an electric current is appl
corresponding magnetic force 524 i
cylindrical chamber, which acceler
force 524. When the weight reache
magnet 514, as shown in Figure 5C
like magnet 514 and the weight
decelerating the weight and reversi
as shown in Figure 5D, current is a
producing a magnetic force 532 i
magnetic force shown in Figure 5E
opposite to the direction in which th
Figure 5E, the weight then moves ri
decelerated, stopped, and then acce
disk-like magnet 516. An electrica
direction 534 as in Figure 5B, again
direction as in Figure 5B. Thus, b
reversing polarity, generated by alt
and by the repulsive forces betwee
each end of the hollow, cylindrical
forth within the cylindrical housing
cylindrical chamber with each revei

me right sides of the cylindrical
ke magnets at the left or right ends
like magnets act much like springs,
of motion of the weight and to
e weight and the end caps that close
conductive wire 520 girdles the
the mid-point of the cylindrical

f the ORM shown in Figure 5A.
520 in a first direction 522, a
direction parallel to the axis of the
04 in the direction of the magnetic
lose to the corresponding disk-like
ce due to the repulsion of the disk-
nerated in the opposite direction,
As the weight reverses direction,
osite direction 530 to the coil 520,
irection from the direction of the
ates the weight 504 in a direction
lerated in Figure 5B. As shown in
s shown in Figure 5F, the weight is
posite direction by repulsion of the
applied to the coil 520 in the same
solid cylindrical mass in the same
n of a magnetic field with rapidly
ction of current applied to the coil,
agnet and the disk-like magnets at
veight linearly oscillates back and
directional force at the ends of the

Clearly, the amplitu
on and other characteristics of the
vibrational forces produced within
elated to the length of the hollow
chamber in which the weight oscill
applied to the coil, the mass of the
weight, the acceleration of the weig
the coil, and the mass of the entire
ORM. All of these parameters are e
parameters for the ORM, and thus
the ORM can be designed to produ
of different amplitudes.

The frequency of
of the solid, cylindrical mass is
determined by the frequency at whi
of the current applied to the coil is
changed. Figures 6A-B illustrate
itch that can be used, in various
ORMs, to change the direction of
o a coil that drives back-and-forth
oscillation within the ORM. Figure
the same illustration conventions,
described next with respect to Figu
bridge switch receives, as input, a
directional signal *d* 602 and direct-
power 604. The direction-control
signal *d* 602 controls four switches
as transistors in Figure 6A. When
the input control signal *d* 602 is hig
wn in Figure 6A, switches 608 and
609 are closed and switches 606
n, and therefore current flows, as
indicated by curved arrows, such a
610, from the power-source input
604 to ground 612 in a leftward dire
e coil 614. When the input-control
signal *d* is low, or "0," as shown in
irection of the current through the
coil is reversed. The H-bridge swit
gures 6A-B, is but one example of
various different types of electrical
anical switches that can be used to
rapidly alternate the direction of cu
oil of an ORM.

Figure 7 provides a
of the ORM, illustrated in Figures
5A-G. The ORM, in addition to the
sing, coil, and internal components
shown in Figure 5A, includes a po
er interface, generally comprising
electromechanical buttons or swit
lge switch, discussed above with
reference to Figures 7A-B, a centra
t ("CPU"), generally a small, low-
powered microprocessor, and one
mechanical sensors. All of these
components are packaged together
ithin a vibration-based appliance,
device, or system.

As shown in Figure is controlled by a control program executed by the CPU microprocesso roprocessor may contain sufficient on-board memory to store the co and other values needed during execution of the control program, c may be coupled to a low-powered memory chip 704 or flash memory ontrol program. The CPU receives inputs from the user controls 706 omprise a user interface. These controls may include any of v ushbuttons, switches, or other electromechanical-control devices. e, the user controls may include a dial to select a strength of vibratio onds to the current applied to the coil, a switch to select one of variou itional modes, and a power button. The user controls generate signals U 708-710. A power supply 712 provides power, as needed, to us , to the CPU 716 and optional, associated memory, to the H-bridg nd, when needed, to one or more sensors 732. The voltage and cur the power supply to the various components may vary, depending c l characteristics and requirements of the components. The H-bridge sv s a control-signal input *d* 722 from the CPU. The power supply 712 re input 724 from the CPU to control the current supplied to the H-bridge transfer to the coil 726. The CPU receives input 730 from one or mo nical sensors 732 that generate a signal corresponding to the streng currently being produced by the linearly oscillating mass 734. Sen le one or more of accelerometers, piezoelectric devices, pressure-sen other types of sensors that can generate signals corresponding to th sired vibrational forces.

Figures 8A-C provic diagrams that illustrate the control program, executed by the CPU, that on of an ORM. Figure 8A provides a control-flow diagram for the hi l program. The program begins execution, in step 802, upon a pov voked by a user through a power button or other user control. In st local variables are set to default values, including the variables: (1) i icates the current operational mode of the device; (2) *strength*, a numeri onding to the current user-selected strength of operation, correspondir al current applied to the coil; (3)

lvl0, a previously sensed vibration
strength; (6) *freq*, the current frequ
in the coil; (6) *d*, the control output t
that indicates that the frequency is
control program waits for a next ev
executing loop, or event handler,
handled by the control program. I
events may be initiated by interrupt
in more primitive implementations,
or dropped. In the implementation
one for controlling the change in
currently established frequency, an
which the control program monitor
than using a formal timer mechani
counted loops or other simple prog
tasks. When an event occurs, the c
which is represented by the conditic
and appropriately handle that eve
determined in step 806, the value
output to the H-bridge switch, with
frequency-related event. The frequ
value of the variable *freq*. Otherw
event, as determined in step 810,
Otherwise, when the event corresp
interface, as determined in step 8
Otherwise, when the event is a pow
from deactivation of a power button
powers down the device, in step 82
Any other of various types of ever
handler 824. These events may i
operation of the device.

vl1, a currently sensed vibrational
e direction of current is alternated
witch; and (7) *inc*, a Boolean value
increased. Next, in step 804, the
ing steps represent a continuously
event that occurs is appropriately
mentations of the control program,
s and stacked for execution while,
nat overlap in time may be ignored
igures 8A-C, two timers are used,
current applied to the coil, at a
ontrolling a monitoring interval at
force currently produced. Rather
lementations may simply employ
ques for periodically carrying out
begins a series of tasks, the first of
determine what event has occurred
frequency timer has expired, as
gnal *d* is flipped, in step 808, and
timer being reset to trigger a next
rval is determined by the current
ent is a monitor timer expiration
"monitor" is called in step 812.
in the user input through the user
"control" is called in step 816.
s determined in step 818, resulting
the control program appropriately
ol program terminates in step 822.
ur are handled by a default event
error conditions that arise during

Figure 8B provides liagram for the routine "monitor," called in step 812 of Figure 8A. In itine "monitor" converts the sensor input to an integer representing the al force produced by the ORM and stores the integer value in the vari in step 832, the routine "monitor" determines whether or not the ORM erating in the default mode. In the default mode, the ORM uses conti control to optimize the vibrational force produced by the ORM by eking to operate the ORM at a frequency as close as possible to t uency for the ORM. Other, more complex operational modes may various more complex routines, represented by step 834 in Figu complex vibrational modes may systematically and/or periodically ncy or produce various complex, multi-component vibrational mode applications, appliances, devices, and systems. These more compl plication dependent, and are not further described in the control-flo the case that the operational mode is the default mode, in which the seeks to optimize the vibrational force generated by the device, in st ine "monitor" determines whether the local variable *inc* is set to TR the control program is currently increasing the frequency at which t es in order to obtain the resonance frequency. When *lvl1* is greater letermined in step 838, then the vibrational force has been recently creasing the frequency, and so the routine "monitor" increases the fr in step 840, and correspondingly resets the frequency timer. Otherwi ess than *lvl0*, as determined in step 842, then the control program h ie frequency past the resonance frequency, and therefore, in step 84 gram decreases the frequency, sets the variable *inc* to FALSE, and cor ets the frequency timer. In similar fashion, when the variable *inc* is ini determined in step 836, and when *lvl1* is greater than *lvl0*, as determin he routine "monitor" decreases the value stored in the variable *freq*, in s ts the frequency timer. Otherwise, when *lvl1* is less than *lvl0*, as det 860, then the routine "monitor" increases the value stored in the var ie variable *inc* to TRUE, and resets

the frequency timer in step 862. Fi
monitor timer is reset, in step 864.

Figure 8C provides
called in step 816 in Figure 8A. T
controls has occurred. In step 86
currently selected mode and vibrat
control features in the user interface
an output value *p* corresponding to t
strength, and outputs the value *p* to
an appropriate current to the coil. I
a new monitor timer interval and re

The control program
example of many different implem
out, depending on requirements
inherent in a particular ORM, the ty
interface, the nature of the power s
implemented for the ORM.

Figure 9 represents t
can be achieved by different imple
Figure 9 has the same axes as the gr
Figure 9 includes many different
vibrational forces and frequencie
implementation. Again, an ORMs
characteristic of the geometry and
each ORM is naturally operated at a
to achieve maximum vibrational f
possible implementations, to a rela
forces, as in the case of unbalanc
implemented to produce desired v
frequencies, and desired vibratio
vibrational forces. The contrast is

in *lvl1* is transferred to *lvl0* and the

diagram for the routine "control,"
ıvoked when a change in the user
mode and *strength* are set to the
epresented by the current states of
362, the routine "control" computes
cted strength, stored in the variable
ly so that the power supply outputs
64, the routine "control" computes
timer accordingly.

reference to Figures 8A-C is one
control program that can be carried
ıe parameters and characteristics
puts received from a particular user
ypes of operational modes that are

uencies and vibrational forces that
ORM and ORM control programs.
gure 3. However, unlike Figure 3,
curve 902, each representing the
obtained from a particular ORM
least one resonant frequency that is
ous components of the ORM, and
to this resonant frequency in order
her than being restricted, over all
nge of frequencies and vibrational
tors, ORMs can be designed and
over a wide range of vibrational
over a wide range of desired
n in Figure 10. Figure 10 shows a

plot of the amplitude/frequency ions in that space that can be
operationally achieved by unbal motors and by linear ORMs.
Unbalanced electric motors can l to produce amplitude/frequency
combinations roughly within tl d square region 1002 within
amplitude/frequency space. By r ORMs can be designed and
implemented to produce amplitud ıbinations underlying curve 1004.
Thus, linear ORMs can achieve mu tional frequencies and much lower
operational frequencies than can be ned by unbalanced electric motors,
and can produce much higher ampl tional forces than can be achieved
by relatively low-powered unbalan otors used in hand-held appliances
and other commonly encountered stems. Furthermore, when larger
vibrational forces are needed, bala notors are generally impractical or
infeasible, due to the destructive within the electrical motors. In
general, a single implemented lir access a much larger region of
amplitude/frequency space than cur vibration modules, which generally
operate at fixed amplitudes and/or f s, as further discussed below.

Figures 11-18 show ferent alternative implementations
of ORMs. Figure 11 provides a ration of an ORM similar to that
discussed above with reference to 1 e that, in place of the end magnets
1102 and 1104, mechanical sprir ıtively be used. These may be
traditional helical springs made fro ıgs made from a compressible and
durable material or mechanical de to restore its initial shape when
depressed or compressed. Note th ıd chamber may be cylindrical, in
cross section, as discussed above to Figure 5A, or may have other
shapes, including rectangular or he ctions.

Figure 12 shows a si :ation in which the control unit and
power supply are incorporated into s 1202. In this implementation, the
relative masses of the moving mas aining components of the ORM is
maximized, thus maximizing the vi produced at a given level of power
consumption.

Figure 13 shows ive ORM. In this alternative
implementation, additional coils 13 incorporated in the moving mass,
and a centering magnet or coil 130(a fixed location on the housing so
that, when the direction of the curre coils 1302 and 1304 is alternated,
an oscillating rotational force is gen ıe movable weight to oscillate both
in a plane perpendicular to the axi as well as linearly oscillating the
direction of the chamber.

Figure 14 illustrates ich multiple electromagnetic coils
are employed. In Figure 14, two 1404 are placed in two different
positions on the housing. The first e used to drive linear oscillation of
the moving mass 1406, while the s ɔe activated in order to shorten the
length of the chamber within whic ıass linearly oscillates, essentially
serving as a second repelling magn nentation of the ORM, the moving
mass may linearly oscillate with fferent amplitudes, depending on
whether or not the second coil 1404 pel the moving mass. Additionally
more complex patterns of current re ɔ coils can be employed to produce
complex multi-component vibratio moving mass.

When the housing i , air within the chamber serves to
dampen oscillation of the moving ampening may be minimized by
providing channels, on the sides of ɔ, to allow air to pass from one side
of the moving mass to the other, by ı the moving mass, or by providing
openings in the housing to allow ai ɔm the housing and drawn into the
housing. Additionally, different flu ıy be employed within the chamber
to change the dampening effect pr cement of the fluids and gasses as
the moving mass linearly oscillates

Figure 15 illustrate ORM an implementation of the
linear-resonant vibration module t document is directed in which a
plunger linearly oscillates to prod . The plunger 1502 is slideably
contained within a moveable-comp ıogonal to a long axis of the main
housing 1504 of the ORM that incl supply, microcontroller, and other
control components. The plunger is ıcludes, a driving magnet 1506 that

is attracted to, and seeks to be posi
mounted within the housing. Appl
1514 forces the driving magnet aw
15. By rapidly switching the dire
microcontroller can control the plun
as indicated by arrow 1520.

Figure 16 shows ye
resonant vibration module to wh
implementation of the linear-resona
directed, a spring-like member 16
Driving magnets 1606 and 1608 ar
current is rapidly reversed in a coil
vibrate at a relatively high frequenc

Figure 17 shows ano
In this ORM, the spring member 17
1704 that extends out from the hou
member 1706 for massaging huma
application.

Figure 18 shows a m
added to either of the ORMs shown
can be manipulated to alter the posi
movable clamping point for the spri
clamp 1804 leftward, in Figure 18,
thus tends to increase the resonant f
Conversely, moving the movable sp
spring-like member and decreases th

Figure 19 illustrates
shown in Figure 17. In this implen
elastomer bristles 1902-1906 to tra
human skin or another substrate. Th
numerous elastomeric bristles, allov

ent with, a centering magnet 1508
one of two driving coils 1512 and
ilibrium position shown in Figure
applied to the driving coils, the
scillate in an up-and-down fashion,

an implementation of the linear-
cument is directed. In this an
dule to which current document is
at one end 1604 to the housing.
ring-like member 1602, and when
g-like member 1602 is induced to

ar to the ORM shown in Figure 16.
provide an external massage arm
a linearly oscillating massage-foot
other substrate, depending on the

ion adjustment feature that can be
nd 17. An adjustment screw 1802
le spring clamp 1804 that acts as a
1806. Moving the movable spring
gth of the spring-like member and
rticular power-consumption level.
tward, in Figure 18, lengthens the
equency.

of an implementation of the ORM
assage foot is enhanced to include
oscillation of the massage foot to
ristles, or pad or brush comprising
f vibration to a surface even at low

operational powers, when a rigid or pliant massage foot would instead simply stop moving for inability to ›nal forces.

Figure 20-23C illustr 'pe of ORM. This ORM comprises a motor incorporated within a pri rd ("PCB"). The motor includes moving and non-moving compon ct via electromagnetic forces to produce motion. The non-movin include a stator that generates a magnetic field. A stator can be g one or more coils. In certain implementations, a stator adapted ith a planar substrate is produced using combinations of one or more nductive traces.

Figure 20 illustrates The first coil layer 2000 includes a substrate 2002 and a spiral-shape is wound in a clockwise direction from the outside of the spiral to the iral. The spiral-shaped trace 2004 surrounds a central core and overla 2002. In some implementations, the substrate 2002 is a printed circ width and thickness of the trace influence the conductivity of the re general, thicker and wider traces have lower electrical resistance an with lower resistance and higher current carrying capacity. Spirals ›re diameter and spirals having a larger number of turns produce co ondingly higher inductance. The inductance of the spiral-shaped trac .ir core at the center of the spiral is expressed as:

$$L($$

where:

r is the core radius in inche

N is the number of turns; a

W is the total width of the v

:s.

The inductance of the resulting coil by altering the above parameters, as well as through the selection of c

A first connection a second connection pad 2008 terminate the ends of the spiral-shap ı certain implementations, the first

connection pad 2006 and/or the sec pad 2008 are incorporated into one or more conductive vias connecting r to other coil layers or to electrical circuits constructed on the substrat onnection pads 2010, 2012, 2014, and 2016 can provide connection p ncorporated into vias that connect multiple layers of traces.

Figure 20 additional placement of a number of motor elements in a particular motor impl he center of the spiral-shaped trace 2004 is a circular opening 2018. Th ıg provides a space for an armature 2020. The armature 2020 can be ma ıs metal or a magnetic material and moves in a direction substantially p he surface of the substrate 2002 in response to a drive current applied . A centering spring 2022 retains the armature 2020 in the circular op substrate 2002, and allows limited movement perpendicular to the sub

In certain implemen es and connection pads are made from conductive material, such as n ıminum, or conductive alloys. The traces and connection pads on the fi 00 can be fabricated using printed-circuit-board manufacturing techni implementations, foil decals are created and laminated onto the subs construction of multi-layer coils is achieved using a number of tech g: multi-layer PCB construction; laminated foil decals separated by i and 2-sided PCB construction. In some implementations, the traces ar ıds are embedded into the substrate 2002.

Figure 21 illustrates yer. The second coil layer 2100 is constructed using techniques alrea r the construction of the first coil layer 2000. A spiral-shaped trace 2 ockwise direction from the starting connection pad 2104 to the ending 2106. The coil layer of Figure 20 is positioned over the coil layer of F e two layers are aligned with one another so that the second connec n Figure 20 overlays the starting connection pad 2104 in Figure 21, tion pad 2010 in Figure 20 aligns with the ending connection pad 21. PCB vias form electrical connections between the second c 2008 in Figure 1 and the starting

connection pad 2104. When the fir
layer 2100 in Figure 21 are connect
layers is additive. In one mode of o
20 starting at the first connection p
connection pad 2008, through a via
to the ending connection pad 2106.
inductance of the resulting coil. A
2114 provide connection points an
layers. In certain implementations,
similar methods to those described
insulating layers or placed on opp
implementations, the multi-layer co

Figure 22A illustrate

A first coil layer 2202 and a secon
planar substrate 2206, such as a PC
are separated by an insulating layer
2208. The stator is driven by a first
2212. In certain implementations,
front surface of the PCB using a via
moves perpendicularly to the surfa
stator. The first and second coil
illustrated in Figures 20 and 21, or
layers produce a single directio
implementations illustrated in Figu
layers laminated to both sides of a p

Figure 22B illustrate

A first-front coil layer 2250 and a
front surface of an insulating plana
layer 2256 and a second-back coil l
insulating planar substrate 2254. A
first-front coil layer 2250 to the be

0 in Figure 20 and the second coil
ıd energized, the inductance of the
t flows into the coil layer of Figure
vise around the coil to the second
ɔnnection pad 2104, and clockwise
onal coil layers increases the total
ction pads 2108, 2110, 2112, and
ias that connect to additional coil
ıyers can be added to the coil using
itional coil layers are separated by
n insulating substrate. In certain
ıtor in a motor.

ı of a stator having two coil layers.
4 are laminated onto an insulating
second coil layers 2202 and 2204
connected to each other with a via
2210 and a second connection pad
nection pad 2212 is routed to the
14 is provided for an armature that
ate in response to energizing the
constructed using the coil layers
ɔe patters arranged so that the coil
round the opening 2214. The
xtended to include additional coil

of a stator having four coil layers.
il layer 2252 are laminated onto a
, such as a PCB. A first-back coil
minated onto a back surface of the
lectrically connects the end of the
d-front coil layer 2252. A second

via 2262 electrically connects the end of the first-back coil layer 2256 to the beginning of second-back coil layer 2258. Cross-substrate via 2264 connects the end of first-front coil layer 2250 to the end of first-back coil layer 2256. When current enters at an entry connection pad 2266 and passes through the four coil layers, the current travels with a single direction of rotation until the current exits at an exit connection pad 2268. The inductance of the stator in Figure 22B is approximately double that of the stator shown in Figure 22A.

Figure 22C illustrates a cross-section of a stator having two coil layers. A front coil layer 2280 and a back coil layer 2282 are laminated onto opposing sides of an insulating planar substrate 2284, such as a PCB. A via 2288 electrically connects the front coil layer 2280 to the back coil layer 2282 forming a coil wound in a single direction around the opening 2290. Connection pads 2292 and 2294 provide electrical contacts for connecting the coil to a drive current.

In some implementations, the coil layers that make up the stator are not interconnected to form a single coil. For example, cross-substrate via 2264 may be omitted, and the two front coil layers 2250 and 2252 are electrically driven independently from the two back coil layers 2256 and 2258. In other implementations, the two front coil layers 2250 and 2252 are counter-wound with respect to the two back coil layers 2256 and 2258. In this configuration, the magnetic fields generated in the opening 2270 by the two front coil layers oppose the magnetic field generated by the two back coil layers.

PCBs are suitable substrates for making the coils and motors described in the current document. A PCB can be constructed using a PCB process where layers of printed copper are separated by a hard laminate core, for example, using FR-4 glass-reinforced epoxy. A PCB made from polyimide can support a greater density of coils and increased mechanical flexibility. A PCB made from a ceramic, such as aluminum oxide, provides increased heat resistance. The stators described above can be constructed with any of these PCB materials.

In certain implementations, the coil layers described above are arranged to form one or more coils that overlay the front and/or back surfaces of a PCB. The coils form a stator that drives the armature of a motor.

Figure 23A illustrates a motor with a driving force that is perpendicular to the surface of a substrate. The motor 2300 is constructed on a substrate 2302 , such as a PCB. A first front coil layer 2304 and a second front coil layer 2306 overlay the front surface of the substrate 2302. A first back coil layer 2308 and a second back coil layer 2310 overlay the back surface of the substrate. A first via 2312 electrically connects the first front coil layer 2304 to the second front coil layer 2306 to form a front coil, and a second via 2314 electrically connects the first back coil layer 2308 to the second back coil layer 2310 to form a back coil. Front coil connections 2316 and 2318 provide electrical connectivity for driving the front coil, and back coil connections 2320 and 2322 provide electrical connectivity for driving the back coil.

A magnetic armature 2324 having a north pole 2326 and a south pole 2328 is positioned in an opening in the substrate 2302 through the center of the front and back coils. In order to drive the magnetic armature 2324 into vibration, a first oscillating current is applied to the front coil connections 2316 and 2318, and a second oscillating current is applied to the back coil connections 2320 and 2322. When the motor is operated, the current that flows through the front coil and the current that flows through the back coil flow with opposite directions of rotation. In certain implementations, this is accomplished by applying the same oscillating current to both front and back coils provided the coils are counter-wound. In an alternative implementation, where the coils are not counter-wound, the second oscillating current is 180 degrees out of phase with the first oscillating current. The resulting oscillating magnetic field provides a magneto-motive force to the north pole 2326 and the south pole 2328 in synchrony, driving the magnetic armature 2324 into vibration at a frequency proportional to the frequency at which the oscillating current is applied. In an alternative implementation, the second front coil layer 2306 is connected to the first back coil layer 2308 with a third conductive via to form a single-drive counter-wound stator that is driven with a single oscillating current to produce vibratory motion of the armature.

The magnetic armature is constructed from an axially polarized magnet. In one implementation, the magnet is a neodymium grade N-42 disk magnet. The size

and shape of the magnet is adapted based, in part, on the desired vibration profile of the motor.

Figure 23B illustrates the motor with the magnetic armature in an upward position. When a first driving current is applied to a front coil 2330, the front coil 2330 generates a downward magnetic flux 2332. In response to the downward magnetic flux 2332, an upward vertical force is exerted on the north pole 2336. As the first driving current is applied, a second driving current is applied to a back coil 2338 and an upward magnetic flux 2340 is generated. In response to the upward magnetic flux 2340, an upward vertical force is exerted on the south pole 2342 of the magnet. In response to the upward forces, the magnetic armature 2334 moves upwards as illustrated in Figure 23B.

Figure 23C illustrates the motor with the magnetic armature in a downward position. When the direction of the first and second driving currents is reversed, the forces on the north pole 2360 and south pole 2362 are reversed. When the first reversed current is applied to a front coil 2364, the front coil 2364 generates an upward magnetic flux 2366, and a downward vertical force is exerted on the north pole 2360. When the second reversed current is applied to a back coil 2368 a downward magnetic flux 2370 is generated. A downward vertical force is exerted on the south pole 2362 of the magnetic armature 2372. In response to these two forces, the magnetic armature 2372 moves downwards as illustrated in Figure 23C.

The drive currents are alternated to cause the magnetic armature to vibrate perpendicularly to the surface of the substrate at a chosen frequency. In one implementation, the front coil and back coil are counter-wound with respect to each other. The front and back coils are connected with a conductive via or wire and driven with one drive current. This arrangement causes the front and back coils to generate simultaneous magnetic flux signals in opposing directions, which, in turn, acts on the north and south poles of the magnetic armature to drive the magnetic armature into vibration.

In alternative implementations, additional coil layers are employed. For example, an 8-layer PCB can have four front coil layers and four back coil layers. The four front coil layers are connected to form a front coil, and the four back coil layers

are connected to form a back coil. In certain implementations, the front coil and back coil are counter wound, and driven with a single drive current as explained above.

Next, a slightly more mathematically descriptive explanation of oscillation, resonance, and the Q factor is provided. Figures 24A-D provide illustrations of various physical and mathematical concepts related to oscillation. Great insight into harmonic oscillators can be provided by considering a simple, one-dimensional spring. Figure 24A illustrates a spring that can be extended in the x direction. In a first diagram 2402, the spring is shown in an equilibrium, resting state with a point or mass 2404 at the end of the spring located at the position $x = 0$. In a second diagram 2406, the spring has been pulled rightward, along the x direction, with the mass 2404 now located at a position x. As is well known, the extended spring has potential energy that results in a force F_x 2408 that points in the opposite direction. In other words, were the spring released, the mass would travel leftward, oscillate back and forth, and eventually settle back to the 0 position shown in diagram 2402. Were the spring frictionless, however, the mass would continue to oscillate back and forth, in a manner similar to the linear ORM described in Figures 4A-B, indefinitely.

The frictionless spring can be mathematically modeled as follows:

$$F_x(x) = -kx,$$

where $F_x(x)$ is the force exerted by the spring;
x is the position of the spring end; and
k is the force constant.

The force constant k is a property of the spring, including all of the parameters that contribute to its elasticity, compressibility, and other physical characteristics of the spring. In more complex, realistic situations, many different factors may contribute to the force constants associated with harmonic oscillators, including interaction with other harmonic-oscillation modes within a physical device or module.

The potential energy of the spring system illustrated in Figure 24A can be modeled as:

$$U(x) = \frac{1}{2}kx^2,$$

where $U(x)$ is the potential energy of the spring system.

Using Newton's second law, the equation that models the force exerted by the spring when it is extended or compressed can be modeled as a simple, second-order differential equation:

$$m\ddot{x} = Fx = -kx,$$

where m = mass of oscillator; and

$$\ddot{x} = \frac{d^2x}{dt^2}.$$

This differential equation can be simplified as:

$$\ddot{x} = \frac{-k}{m}x = -\omega^2 x,$$

where $\omega = \sqrt{\frac{k}{m}}$.

The general solution for this simple, second-order differential equation is, in one form:

$$x(t) = C_1 e^{i\omega t} + C_2 e^{-i\omega t}.$$

In this equation, C_1 and C_2 are arbitrary constants that are determined by the initial conditions of a particular spring system. This solution can be recast as:

$$x(t) = B_1 \cos(\omega t) + B_2 \sin(\omega t),$$

where $B_1 = C_1 + C_2$; and

$$B_2 = i(C_1 - C_2).$$

A final, perhaps most elegant form of the solution is:

$$x(t) = \mathrm{Re}[Ae^{i(\omega t - \delta)}],$$

where $Ae^{-i\delta} = B_1 - iB_2 = C$.

In this equation, A is the amplitude of the oscillation, ω is an angular velocity of the oscillation, as discussed above with reference to Figure 24B, and δ is an initial phase offset. This final expression describes the mapping of a rotation to linear harmonic oscillation, as discussed above with reference to Figure 4B, shown again, in Figure 24B, with annotations taken from final expression for the solution to the differential equation.

As mentioned above, a frictionless spring would continue to oscillate indefinitely after being released from an extended position. However, in actual systems, there are always resistive forces, such as friction, that dampen the oscillation so that, over time, the amplitude of the oscillation decreases and the oscillation finally stops. This more complex and more realistic scenario can be modeled by including a resistive-force term in the second-order differential equation:

$$m\ddot{x} + b\dot{x} + kx = 0,$$

where $-b\dot{x}$ is a resistive force; and

$$\dot{x} = \frac{dx}{dt}.$$

Defining several new constants as follows:

$$\beta = \frac{b}{2m} = \text{ damping constant, and}$$

$$\omega_0 = \sqrt{\frac{k}{m}} = \text{ natural frequency}$$

and solving the above modified second-order ordinary differential equation, the following result is obtained:

$$x(t) = Ae^{-\beta t}\cos(\omega_1 t - \delta)$$

where $\omega_1 = \sqrt{\omega_0^2 - \beta^2}$; and

$\beta < \omega_0$.

when, as indicated above, the damping constant β has a value less than the value of the natural frequency ω_0, the system in under-damped and the amplitude of the oscillations decrease non-linearly, as shown in Figure 24C. When β is greater than ω_0, the system is over-damped, in which case only a single oscillation may occur, as shown in Figure 24D.

Most physical systems have one or more natural frequencies at which they oscillate, when mechanically perturbed from their equilibrium states. In ORMs, a motor is used to continuously perturb the system in order to drive the ORM to oscillate and generate vibration. A device in which an ORM is incorporated vibrates in response to a driving vibration generated by the ORM. In this case, an external

driving force $F(t)$ is applied by the ORM to drive continuous oscillation of the device in which it is included. An external-force-driven linear oscillator can be modeled by the following expression:

$$m\ddot{x} + b\dot{x} + kx = F(t),$$

where $F(t)$ is an external driving force.

With the definition:

$$f(t) = \frac{F(t)}{m},$$

the mathematical model becomes:

$$\ddot{x} + 2\beta\dot{x} + \omega_0^2 x = f(t).$$

A solution for this expression is:

$$x(t) = A\cos(\omega t - \delta)$$

where $f(t) = f_0\cos(\omega t)$;

$$A^2 = \frac{f_0^2}{\left(\omega_0^2 - \omega^2\right)^2 + 4\beta^2\omega^2} \text{ ; and}$$

$$\delta = \arctan\left(\frac{2\beta\omega}{\omega_0^2 - \omega^2}\right).$$

In this expression, the constant ω is the driving frequency of the driving force, which is somewhat less than the natural frequency ω_0. As can be seen in the expression for the square of the amplitude, which is proportional to the energy of the vibration, the amplitude is maximized when the denominator of this expression is a value approaching 0. Maximizing the expression can be carried out either by varying the physical device in order to vary the natural frequency ω_0, while the external-driving-force frequency remains fixed ω, or by varying the driving frequency ω when the natural frequency ω_0 is fixed. When ω_0 varies and ω is fixed, A is maximum when $\omega_0 = \omega$; and when ω varies and ω_0, A is maximum when $\omega = \sqrt{\omega_0^2 - 2\beta^2}$. This is where the term "resonance" arises. The resonant frequency is the frequency at which the amplitude A is maximized. As can be seen, this occurs, in general, when the driving frequency of the motor or other mechanical-force-input mechanism has a frequency

close to or equal to the natural frequency ω_0 of the physical system. A quality factor Q can be expressed, in terms of the natural frequency and damping factor, as:

$$Q = \frac{\omega_0}{2\beta}.$$

This is the reciprocal of the ratio of the width of the amplitude peak at half its maximum value to the natural frequency ω_0.

An ORM Controller

Figure 25 shows a block diagram of a generic device, appliance, or system that employs ORMs to generate vibration. The vibration may be generated for application to people, animals, or objects for various purposes, including therapeutic purposes, or may instead be generated to provide haptic feedback, such as vibration in mobile phones, vibration-based notification, or vibration-based communications. Thus, the current document is directed to particular features of a generic ORM-containing device or system that may be used in a wide variety of different types of applications or included in larger devices and systems. In Figure 25, the device, appliance, or system is represented by an outer rectangle 2502. The device includes four ORMs 2504-2507. The ORMs may be of any of many different types, including the types of ORM discussed above. In general, the ORMs convert input energy, such as an electrical current, to mechanical vibration. The device also includes several vibration sensor 2510-2511. There are a variety of different types of vibration sensors, including piezoelectric accelerometers that measure acceleration in one, two, or three different orthogonal directions. Other types of sensors may include membranes attached to moving coils that generate electronic signals when the membrane vibrates, similar to a reverse audio speaker. In addition, the device or system contains a controller 2516. The controller includes ORM control logic 2418 that transmits control signals, in certain cases electrical signals that also serve to power the ORMs. The ORM control logic may be implemented as a sequence of processor instructions, when the controller 2516 is a processor or processor-controlled controller subsystem. In many of the ORM devices and systems, the controller accesses some type of electronic memory 2520, which stores processor instructions and other types of data for

implementing ORM control logic 2518. Not shown in Figure 25 are various standard components and signal lines, including a power supply and power-transmitting circuitry, display screens, push buttons, other user-interface-related components, and other types of logic and logic-controlled subcomponents particular to particular types of devices, such as transceivers and communications subsystems within mobile phones. A set of double-headed arrows, such as double-headed arrow 2522, represent the fact that the controller may control many other subcomponents and features of the device or system in addition to the ORMs.

In the previous discussion of oscillation, vibration, and resonance, simple mathematical models for one-dimensional harmonic oscillation were developed. However, in the generic ORM-containing device or system, there may be multiple ORMs, activation of which produce very complex three-dimensional spatial vibration. Vibration modes of individual ORMs may couple to produce a large number of complex spatial-vibration modes. The physical characteristics of these vibration modes may be highly dependent on the exact geometry, weight and balance, and the material type of the housing and internal components of a particular device or system. As a result, there may be numerous different natural resonant frequencies for the device or system.

Figures 26A-B illustrate multiple resonant frequencies within a device or system. In Figure 26A, the vibrational energy, or square of the amplitude of the vibration, is plotted with respect to frequency. The vertical axis represents the energy and vibration 2602 and the horizontal axis represents the frequency of vibration 2604. The plotted curve 2606 shows numerous different vibration-energy peaks 2610-2615. The heights and positions of these peaks along the frequency axis 2604 may vary considerably with slight changes to the physical characteristics of a device or system that is vibrated by ORM components.

Figure 26B shows a more complex type of vibration-response plot. The vibration response is represented by a surface 2620 in the plot shown in Figure 26B. Measured amplitudes or vibration energies produce a surface 2620 in a three-dimensional Cartesian coordinate system that includes an x-direction vibration frequency axis 2522, a y-direction frequency axis 2624, and a vibration-energy axis

2626. The device or system for which the vibration-response surface 2620 is obtained includes two ORMs, one of which generates vibrations in the x direction and one of which generates vibrations in the y direction. The two ORMs can be independently controlled to generate vibrations in their respective directions at different frequencies. The x, y plane 2628 below the plotted vibration-energy surface 2620 represents all possible x-direction vibration frequencies and y-direction vibration frequencies that can be generated by the two ORMs within the device or system. As shown in Figure 26B, the surface includes three local vibration-energy maxima 2630-2632. These three local maxima are each associated with x-direction frequency and y-direction frequency components 2634. Thus, in the case shown in Figure 26B, two ORMs which generate vibrations in two different directions within the device or system may generate a complex vibration-response surface with respect to the frequencies at which the two ORMs are operated. Depending on the types and numbers of ORMs, the vibration response may be a hyper-dimensional surface in a much higher dimensional frequency space. In all cases, however, the device or system generally has some number of characteristic resonant frequencies that represent maximal vibration energy or amplitude with respect to the frequencies at which individual ORMs are driven with the device or system. In general, the number of resonant frequencies is equal to the number of vibrational degrees of freedom in the device, appliance, or system.

A vibration-response obtained for a device or system by measuring sensor output can be used to identify and tabulate the natural resonant frequencies for the device or system. Figure 27 provides an example resonant-frequency table for the generic ORM-containing device discussed above with reference to Figure 25. Each row in the resonant-frequency table 2702, such as row 2704, represents a local maxima, or peak, in the vibration response for the generic device. In the example table shown in Figure 27, each peak is characterized by an amplitude in the x 2706, y 2707, and z 2708 directions as well as by the frequency of vibration represented by the peak ω 2710 and by the frequency at which each of the four ORMs are driven by the ORM control logic 2712-2715. Thus, to achieve maximum vibration energy of the vibration of the generic device at any of the resonant frequencies for the device, the ORMs are driven at the control frequencies for that resonant frequency.

Figures 28A-C illustrate how an ORM control scheme combines with a resonant frequency to produce a vibration response. Figure 28A shows the vibration-response for a simple device, vibration of which is stimulated by a single ORM. There is a single natural frequency ω_1 2802 corresponding to the vibration-energy peak 2804 in the vibration-response plot of vibration energy with response to frequency. Figure 28B shows a plot of the frequency of vibration generated by an ORM with respect to time over a time interval that represents an ORM control scheme. In Figure 28B, the vertical axis 2810 represents the frequency at which the ORM is driven by ORM-control input and the horizontal axis 2812 represents time. The control curve 2814 indicates that the ORM is non-linearly driven over an initial time period 2816 to the natural frequency ω_1 2818 for the device in which the ORM is included. At a final point in time t_f 2820, input to the ORM is discontinued. Figure 28C shows a vibration-response curve for the device containing the ORM when the ORM is operated according to the control curve 2814 discussed above with reference to Figure 28B. As shown in the vibration-response curve 2822, there is an initial lag time 2824 following initiation of the control scheme before a perceptible device vibration occurs, at time t_i 2826. The vibrational energy, or amplitude of vibration, very steeply increases from this point on as the ORM is controlled to approach and equal the natural frequency ω_1 for the device. At time t_f 2820, the vibrational energy of the device relatively steeply falls, since the ORM is no longer being driven. However, the vibrational energy does not immediately fall to 0, as in the control curve, but over a short period of time 2828 after the ORM ceases to be driven.

The generic device, as discussed above, contains a memory that may store various types of control schemes, or control patterns, for the ORMs that are controlled by the ORM control logic. Figure 29 shows a few examples of control patterns that may be applied to ORMs by the control logic within the generic device. The example patterns include a linear ramp-up and ramp-down pattern 2802, a constant control over a specified duration of time 2904, and an oscillating control 2906. The patterns may be parameterized by the duration of the pattern 2908 and the maximum input to the ORM 2910. The input may be specified as the current or voltage, for certain types of ORMs. Other ORMs may be controlled by digital control signals in

which numerically encoded commands are transmitted to the ORM. The control patterns can be scaled in both time and frequency in order to generate a variety of equivalent vibration responses for the ORM with similar forms, but different maximum amplitudes and over different periods of time.

A set of scalable control patterns, such as those shown in Figure 29, and a table of resonant frequencies, such as that shown in Figure 27, can be used to generate a table of different types of vibration that can be generated in the generic device by controlling the ORMs within the device according to scaled control patterns. Figure 30 shows an example vibration-type table that may be prepared for the generic device shown in Figure 25. Each row in the table, such as row 3004, represents a different vibration type that can be produced in the generic device by controlling the ORMs within the device. For example, a cell phone may use a variety of different haptic vibration signals to alert the cell phone user of many different types of events. Each different vibration signal corresponds to a different vibration- type. Each vibration type is characterized by a vibration-type identifier 3006, an amplitude range for the vibration 3008, a reference duration for the vibration 3010, and the control pattern and scaling parameters for the pattern for each of the ORMs 3012-3015. Each vibration type can be scaled within the amplitude range and may also be scaled for a desired duration.

By using either external or internal sensors to characterize the natural resonant frequencies for a physical device or system that contains ORMs, a large number of different vibration responses for the physical device or system can be compiled based on the resonant frequencies as well as a set of ORM control patterns. In alternative vibration-control approaches, the different types of vibration responses may be computed, on the fly, rather than tabulated based on a set of control patterns. However, in all cases, characterization of the resonant frequencies of the device or system that is vibrated by the ORMs contained within the device or system is a necessary step in producing predictable vibration responses via ORM control.

Figures 31-36 provide control-flow diagrams to illustrate control logic used in the generic device, discussed above with reference to Figure 25, to produce well-defined vibration modes or vibration responses in the physical device or system.

Figure 31 illustrates the inner control loop of the control logic within the physical device shown in Figure 25. The inner control loop waits, in step 3102, for a next event and then handles the event that occurs. When the event is a characterize-vibration event, as determined in step 3104, the routine *characterize vibration* is called to handle the event in step 3106. When the event is a generate-vibration event, as determined in step 3108, a generate-vibration routine is called in step 3110 to generate a vibration in response to the generate-vibration event. When the next event is a user-input event, as determined in step 3112, a process-input routine is called, in step 3114, to handle the input from the user. Ellipses 3116 are used in Figure 31 to indicate that many other types of events are handled by the inner event loop of the control logic. When, after handling the most recently occurring event, there are other events that are queued for handling which arose while handling the most recently handled event, as determined in step 3118, then a next event is dequeued in step 3120 with control flowing back to step 3104. Otherwise, control flows back to step 3102 where the inner event loop waits for a next event to occur.

The characterize-vibration event 3104 is an event that is raised by control-logic routines, timer-expiration handlers, and by other control logic in order to control the ORMs and sensors within the generic device to carry out a re-characterization of the vibration-response for the physical device, as discussed above with reference to Figures 26A-B, in order to update the resonant-frequency table, such as the resonant-frequency table discussed above with reference to Figure 27. In devices that employ a vibration-type table, such as the vibration-type table discussed with reference to Figure 30, the vibration-type table is also updated following update of the resonant-frequency table.

A generate-vibration event is raised by control logic in order to vibrate the generic device for a variety of different reasons. As one example, the device may be vibrated in response to user input. As another example, the device may be vibrated when the control logic determines that any of various alert conditions have arisen. As yet another example, generate-vibration events may be raised in order to communicate information to a device user.

Figure 32 provides a control-flow diagram for the characterize-vibration event handler, called in step 3106 of Figurer 31. In step 3202, the routine calls a subroutine *sweep* in order to generate a sampling of a vibration-response curve, surface, or hyper-dimensional surface. In step 3204, the routine calls a store-vibration-maxima subroutine in order to identify the resonant frequencies from the curve or surface sampled in step 3202. Finally, in step 3206, the routine calls a compute-and-store-vibration-type-controls subroutine in order to update the vibration-type table based on the new resonant-frequency determination made in steps 3202 and 3204.

Figure 33 provides a control-flow diagram for the subroutine *sweep*, called in step 3202 of Figurer 32. In step 3302, the subroutine *sweep* initializes a data structure for storing a vibration response. As discussed above, the vibration response may be a sampled curve, sampled surface, or sampled hyper-dimensional surface. In the *for*-loop of steps 3304-3306, a frequency sweep of each ORM is initiated. A frequency sweep is a control pattern that continuously sweeps each ORM over a wide range of driving frequencies. Each ORM repeats a single frequency sweep over a different time interval, so that following a number of iterations, the multi-dimensional ORM-driving-frequency space can be sampled. Then, in the *for*-loop of steps 3308-3312, the *sweep* routine continuously samples the vibration amplitude or vibrational energy produced in the device, using sensor output, while the driving-frequency sweeps take place. There are, of course, many alternative methods for sampling the multi-dimensional driving-frequency space in order to generate a sampled vibration-response curve, surface, or hyper-surface.

Figure 34 provides a control-flow diagram for the store-variation-maxima subroutine called in step 3204 of Figure 32. In step 3402, the routine identifies local maxima in the vibration-response curve or surface produced by the *sweep* routine. There are many well-known mathematical techniques for identifying local maxima within a curve, surface, or hyper-surface. Then, in the *for*-loop of steps 3404-3406, data that characterizes each of the local maxima are tabulated in the resonant-frequency table.

Figure 35 provides a control-flow diagram for the compute-and-store-vibration-type-control subroutine called in step 3206 of Figure 32. In a *for*-loop of

steps 3503-3509, each possible set of ORM/control-pattern/resonant-frequency triples is considered. The currently considered triple is used to estimate the vibration mode and intensity of the resulting device vibration, in step 3504. In step 3505, the nearest vibration-type to the estimated vibration mode is identified, if there is one. If a nearest vibration type is found, as determined in step 3506, and when the current ORM/control-pattern/resonant-frequency triple provides a device response closer to the vibration type than the control parameters currently associated with the vibration-type, as determined in step 3507, then, in step 3508, the vibration-type table entry for the found vibration type is updated with the current control parameters represented by the currently considered ORM/control-pattern/resonant-frequency triple. Of course, in certain cases, there may be too many possible ORM/control-pattern/resonant-frequency triples to consider in a reasonable amount of time, in which case the resonant-frequency data may be used in other ways to find the best control parameters for the vibration types in the vibration-type table.

Figure 36 provides a control-flow diagram for the generate-vibration handler called in step 3110 of Figure 31. In step 3602, the handler receives a vibration type, duration, and amplitude associated with the generate-vibration event that is being handled. In step 3604, the appropriate ORM control parameters and patterns are selected from the vibration-type table. In step 3606, the ORM control parameters are scaled according to the received duration and amplitude. In step 3608, a stop time at which the vibration will finish is determined from the received duration. Then, in the *for*-loop of steps 3610-3613, the generate-vibration handler continuously adjusts inputs to each ORM according to the scaled ORM control parameters produced in step 3606.

Precise and Accurate Control of ORMs

The current document is directed to various approaches used within the control logic of an ORM-containing device, appliance, or system, to accurately and precisely control the ORMs to produce time-dependent driving oscillations in conformance with desired control patterns. As discussed above, the combination of controlling ORMs in accordance with control patterns and the accurate characterization

of the resonant frequencies of the device, appliance, or system together allow for reproducible generation of many different types of vibration responses of the device, appliance, or system to the driving oscillations of control-pattern-controlled ORMs.

As further discussed below, many current control regimes fail to accurately reproduce the desired driving time-dependent oscillations in each ORM within a device, appliance, or system. As a result, the vibration response of the device, appliance, or system may vary significantly from a desired vibration response and, perhaps more importantly, may not be accurately reproduced at different points in time, due to the inability to accurately and deterministically control the ORMs to produce driving oscillations in conformance with desired control patterns.

A first approach to more accurately controlling ORMs is to use pulse-width modulation control signals rather than conventional constant-duration control pulses. Figures 37A-D illustrate pulse-width modulation control of an ORM. Figure 37A shows a desired vibration response for an ORM that represents a desired time-dependent driving oscillation for inducing at least a portion of the vibration response of a device, appliance, or system in which the ORM is included. The desired vibration response of the ORM is a sine-wave-like 3702 oscillation that is plotted, in Figure 37A, on an amplitude versus time coordinate system 3704. Figure 37B illustrate a hypothetical control regime that attempts to produce the desired driving oscillation discussed above with reference to Figure 37A in a hypothetical ORM. Constant-width voltage pulses, such as voltage pulse 3706, are input to the ORM to drive the weight or mass in forward and backward directions along the oscillation path. These pulses are plotted in Figure 37B in a voltage versus time coordinate system 3708. Because the constant-width pulses are a rather crude approximation of the desired sine-wave-like vibration response, the control regime shown in Figure 37B comprises a series of positive-voltage, 0-voltage, and negative-voltage constant-width pulses 3706 and 3710-3713 that produce a vibration response, superimposed in Figure 37B over the control pulses, as curve 3716. In general, the pulse widths are controlled by an oscillating clock or clock-based timing signal. The vibration-response curve 3716 differs significantly from the desired driving oscillation shown in Figure 37A. Figure 37C shows the desired vibration response 3702 plotted together with the vibration

response produced by the constant-width voltage-pulse control 3716. In fact, this is actually a relatively favorable case, because the sequence of positive, 0-voltage, and negative voltage pulses shown in Figure 37B has a period close to the period of the desired sine-wave-like vibration response. Otherwise, the actual vibration response would differ even more greatly from the desired vibration response, often having irregularly shaped wave forms.

Figure 37D illustrates pulse-width-modulation control of the ORM. In pulse-width-modulation control, rather than using constant-width voltage pulses to control the ORM, the controller instead uses variable-width pulses. Moreover, much shorter pulses can be used to more precisely control the vibration response of the ORM. In essence, pulse-width modulation allows a variable-frequency control signal to be used, rather than a constant-frequency control signal. Because a variable-frequency control signal can contain a much greater amount of information than a constant-frequency control signal, the pulse-width-modulation control signals can be used to much more precisely steer the vibration response of the ORM towards a desired wave form. As shown in Figure 37D, many more voltage pulses are used in order to achieve the sine-wave-like vibration response of the ORM. For example, in the constant-width-pulse control shown in Figure 37B, a positive-voltage pulse 3706, a 0-voltage pulse, and a negative-voltage pulse 3710 are used to attempt to approximate the first period of the desired vibration response. By contrast, as shown in Figure 37D, four positive-voltage pulses 3720-3722 and 3726 and three negative-voltage pulses 3723-3725 are employed to produce the first period of the desired vibration response. Moreover, these seven pulses have varying pulse widths and are irregularly spaced along the time axis.

Another problem associated with conventional control of ORMs is that the vibration response produced by a control pattern is often very different from the vibration response that might be predicted from the control pattern or desired. For example, in Figure 38A, a control pattern is shown that involves a constant-voltage signal 3802 from an initial time t_i 3804 to a final, end time t_f 3806. Of course, this control pattern may correspond to a large number of positive-voltage pulses in the time interval t_i to t_f. The vibration response of the ORM is shown in Figure 38B. In this figure, the horizontal time axis 3808 has been rescaled to show more detail. The control

pattern 3802 shown in Figure 38A might be initially assumed to produce a pulse of constant-amplitude vibrations over the time interval t_i to t_f. However, as shown in Figure 38B, the actual vibration response of the ORM, shown as curve 3810, includes an initial ramp-up interval 3812 in which the amplitude of the vibration response steadily increases to the desired amplitude, a middle period 3814 in which the ORM is oscillating at the desired amplitude, a short period 3816 at the end of the time interval t_i to t_f during which, in anticipation of the sharp control-pattern edge at time t_f, the control voltage is dropped to 0 so that the vibration will fall to a low level at time t_f, and a fourth undesired ramp-down interval 3818, extending well past the time t_f, during which vibration of the ORM continues at increasingly smaller amplitudes.

Figure 39 illustrates modification of the naïve control pattern, shown in Figure 38A, in order to achieve a better approximation of the desired constant-amplitude oscillation in the time interval t_i to t_f. In a first plot 3902, the naïve control pattern is shown. In a second plot 3904, the naïve control pattern is modified in order to produce the constant-amplitude oscillation that is desired. First, a large-voltage input 3906 occurs prior to time t_i in order to quickly force the ORM to begin vibrating. From time t_i to a time prior to time t_f, a lower-voltage input 3908 is provided in order to control the ORM to oscillate at the desired amplitude. Prior to time t_f, a negative-voltage control signal 3910 is input to the ORM in order to sharply drive the ORM towards oscillation out of phase with the desired driving oscillation during the time interval t_i to t_f. This negative-voltage control signal is then relaxed linearly 3912 in order to stop ORM vibration in a relatively short period of time. As shown in plot 3914 in Figure 39, the vibration response of the ORM much more closely approximates a desired constant-amplitude vibration between time intervals t_i and t_f.

Many different types of control inputs can be used to shape the vibration response of an ORM. For example, short control pulses can push the vibration to a different phase, resulting in cancellation of the previously established oscillation. The various types of inputs depend on the type and form of control signals that can be transmitted to the ORM, which, in turn, depends on the type of ROM, the driving force used to induce oscillation of the moving mass within the ORM, and the type of logic circuitry that receives input signals and translates them into oscillations.

Thus, in addition to pulse-width modulation, a wide variety of different types of complex control signals may be devised in order to achieve the vibration response desired from the simple control patterns discussed above, including control pattern 3802 shown in Figure 38A. Many different control-signal parameters may be varied in order to control an ORM to provide a desired vibration response, including varying the voltage of the control signal, using pulse-width modulation to finely tailor the control signal to produce a desired vibration response, and adjusting the control signal to include pre-response and post-response signals to remove undesired ramp-up and ramp-down periods in the vibration response.

In addition to varying the input control to an ORM, an ORM may be designed to include a variety of different mechanical controls to further increase the range of vibration responses of the ORM. Figures 40A-40F illustrate movable mechanical stops and mechanical latches, two types of mechanical control features that may be included in various types of ORMs. Equivalent electromagnetic features may be included in other types of ORMs. Figure 40A illustrates a first type of ORM. In a first diagram 4002, the ORM is shown in an equilibrium, non-vibrating position. The ORM includes a moveable weight or mass 4002 that is connected to two ends of the ORM 4004 and 4006 by springs 4008 and 4010. Diagram 4012 shows the ORM when the movable mass 4002 has been moved, by application of a translational force, such as an electromagnetic force, to the furthest position in the leftward direction along the oscillation path. In this position, spring 4010 is compressed and spring 4008 is extended. In both cases, the springs have potential energy that produces forces that force the movable mass 4002 back in the rightward direction towards stop 4012. Diagram 4014 shows the ORM with the movable mass in the furthest rightward direction.

Figure 40B shows the equilibrium and largest-amplitude positions of a movable mass in a different type of ORM. In a first diagram 4016, the ORM is shown in an equilibrium position. The ORM features an arc-like oscillation path 4018 along which the moving mass 4020, attached to a rotor 4022, oscillates. The moving mass 4020 is attached to the rotor 4022 by a flexible support 4024. Diagram 4026 shows the ORM with the movable mass in the furthest leftward position and diagram 4028 shows

the ORM with the movable mass in the furthest rightward direction, similar to the positions shown for the ORM of Figure 40A in diagrams 4012 and 4014.

Figure 40C illustrates movable mechanical stops included in the ORM discussed above with reference to Figure 40A. The movable stops are depicted by features 4030 and 4032 in a first diagram 4034. Of course, the depictions do not necessarily reflect the shape, size, and structure of mechanical stops needed to stop motion of the moveable mass in the various different types of ORMs, but are instead used to illustrate positioning of the moveable stops and their deployment. In a second diagram 4036, the movable stops have been repositioned 4038 and 4040 in order to limit the length of travel of the moving mass 4002. The second diagram 4036 shows the leftward extent of motion of the moving mass 4002 with the movable stops deployed and diagram 4042 shows the rightward extent of travel of the moving mass when the movable stops are deployed. Similar illustration conventions are used, in Figure 40D, to illustrate deployment of movable stops in the ORM discussed above with reference to Figure 40B. Use of movable stops can significantly alter the vibration response of the ORM to a given control input. This may include changing the amplitude of the vibration response, the frequency of the vibration response, and changing the force imparted by the moving mass to the ORM when the moving mass strikes the stops versus the original end stops 4002 and 4004. In general, the vibration-response alterations are complex functions of the geometry, material composition, and driving forces used in the ORM.

Figures 40E-F illustrate use of the movable stops, discussed above with reference to Figures 40C and 40D, as latches. As shown in a first diagram 4048 in Figure 40E, the movable stops have been repositioned 4050 and 4052 closer to the center of the oscillation path. As shown in diagram 4054, the left-hand movable stop 4056 has been deployed when the moving mass 4002 has just reached its leftward, stopped position. As a result, motion of the moving mass is stopped, resulting in an immediate cessation of the driving oscillation produced by the ORM and a higher force exerted in the last oscillation on the left-end stop 4004 of the ORM. Diagram 4058 shows the right-hand movable stop 4052 deployed to latch the moving mass 4002 at its furthest right-hand position. Figure 40F shows similar deployment of the movable

stops, in the ORM discussed above with reference to Figure 40B, to latch the moving mass at its leftward and rightward extents. Latching of the moveable mass may trap the moveable mass in a high-potential-energy state, so that immediate, rapid oscillation may ensue when the latch is released. Latching may also significantly alter the relaxation of the oscillation at the end of control-pattern execution.

The current document is directed to employing the various different types of alternative control of ORMs to more accurately generate desired vibration responses. This involves use of a much greater amount of information about the ORM than used in the vibration response table discussed above. Figure 41 shows example information that may be stored in order to more accurately control ORMs according to the methods and considerations disclosed in the current document. The information is stored in five different tables. An ORM table 4102 stores control information for each different ORM in a device, appliance, or system. This information includes an identifier for the ORM 4104, an indication of the ORM type 4105, an indication of the minimum pulse width that can be input in a control signal 4106, an indication of the minimum amplitude 4107 and maximum amplitude 4108 of an input control signal, indications of whether or not mechanical or electromagnetic latches are available in the ORM 4110 and 4112, the oscillation path length within the ORM 4114, the number of movable stops, or path blocks included in the ORM 4115, and the positioning range for each moveable stop 4116-4117. An event-types table 4120 includes various different types of control events. These may include deployment of latches, movement of movable stops, and output of control pulses of various different widths and amplitudes. An events table 4122 includes ordered pairs of event types and relative times that each represents one of the many different types of control events that can be input to ORMs. Each control event includes an event ID 4123, an event type 4124, and a relative time that specifies a time point within a control pattern 4126 at which the event occurs. Table 4128 includes the actual control actions that a logic controller employs to initiate each type of event in each type of ORM. For each type of control, the table includes an indication of the event type 4130, the ORM type 4131, a control ID 4132, a signal type 4133, a signal strength 4134, and any of many different other characterizations of the type of control 4135 executed by the control logic in order

to control an ORM to produce a particular type of event. Finally, table 4140 lists all of the different types of control patterns that can be used to control ORMs. These are equivalent to the previously discussed control patterns. Each control pattern includes a control-pattern identifier 4142, an indication of the number of events in the control pattern 4144, and the event identifiers for those events 4146-4149.

Figure 42 provides an alternative implementation of the routine "generate vibration," discussed above with reference to Figure 36. The alternative information incorporates more accurate control of ORMs using the information and techniques discussed above with reference to Figures 37A-41. In step 4202, the routine receives a vibration type, duration, amplitude, and start time for a desired device, appliance, or system vibration response. Then, in the *for*-loop of steps 4204-4212, the routine prepares for controlling each of the ORMs in the device, appliance, or system. In step 4205, a control-pattern ID is selected from the vibration-type table for the ORM, modified with respect to the previously described vibration-type table to include the identifiers of control patterns that are tabulated in the control-patterns table 4149. In step 4206, the identified control pattern is selected from the control-patterns table. In the inner *for*-loop of steps 4207-4212, each event is selected from the control pattern selected in step 4206. For each event, a corresponding event control entry is selected from the event-control table, in step 4208. The controls are scaled, in step 4209, according to the desired duration and amplitude for the vibration response. In step 4210, the time associated with the event, selected from the events table, is also scaled. In step 4211, the scaled controls and times are added to a list of time-ordered events, the controls for which are issued to the ORM during generation of the desired vibration response. In step 4214, the routine waits until the desired start time for the vibration response. Note that the desired start time takes into consideration any pre-vibration-response controls needed to produce the desired vibration response. Then, in the *while*-loop of steps 4216-4222, the routine carries out ORM control over a set of time points spanning the desired vibration-response duration. In the inner *for*-loop of steps 4217-4220, the routine initiates a control sequence for each of the time-ordered events for each of the ORMs at the points in time in which the control sequence is specified for issuance. Then, in step 4221, the routine waits for a next update-control time point.

The above-discussed methods for more accurate and reliable control of ORMs provide increased opportunities for generating increasingly complex vibration responses in devices, appliances, and systems that contain ORMs. However, with increasing complexity, attention is needed to simplifying and increasing the efficiency of driving-oscillation sensing in order to provide feedback-based control to ORMs. In addition, with more accurate control, it is possible to increase the complexity of ORM time-dependent driving oscillations, significantly increasing the types of time-dependent driving oscillations that can be encoded in control patterns and thus increasing the device, appliance, and system vibration responses to controlled ORM driving oscillations.

Figure 43 illustrates both methods for increasing the complexity of ORM time-dependent driving oscillations as well as increasing and simplifying feedback control. Figure 43 provides a simplified ORM-containing device architecture similar to that provided by Figure 25, discussed above. However, as shown in Figure 43, each of the ORMs, such as ORM 2504, is coupled to an additional passive oscillator, such as passive oscillator 4302. In various different implementations, a given ORM may be coupled to one, two, or more passive oscillators. When an ORM is mechanically coupled to one or more additional passive oscillators, the passive oscillators greatly increase the number of degrees of freedom for vibration of the combined ORM and one or more passive oscillators. The mathematical models for the vibration modes and resonant frequencies become far more complex, involving eigenvalue problems arising from coupled differential equations. As discussed above, the number of resonant frequencies for a system is generally proportional to the number of vibrational degrees of freedom. Furthermore, coupling passive oscillators to ORMs may provide new, complex vibrational modes with different frequencies and amplitudes. Thus, vibration components comprising an ORM and one or more passive oscillators can significantly increase the complexity of the time-dependent driving oscillations produced by these vibration components, and therefore greatly expand the types, frequencies, and modes of vibration responses produced in a device, appliance, or system containing the complex vibration components.

In the simpler system shown in Figure 25, two vibration sensors 2510 and 2511 were included. These vibration sensors detected vibration in one, two, or three orthogonal directions of the device, appliance, or system 2502 in which multiple ORMs are included. However, as shown in Figure 43, sensors that provide information regarding the driving oscillations produced by ORMs and passive oscillators, such as sensors 4304 and 4305 in ORM 2504 and passive oscillator 4302, respectively, may also provide information to local control logic, such as control logic 4306, within ORMs as well as the controller 2516 that controls one or more ORMs within the device, appliance, or system 2502. The sensors local to ORMs and passive oscillators may be designed to sense driving-oscillation characteristics while vibration sensors 2510 and 2511 are designed to sense the vibration response of the entire device, appliance, or system 2502.

By including a variety of different types of sensors within different positions and components of an ORM-containing device, appliance, or system, an opportunity is provided for hierarchical sensing and corresponding feedback control within a device, appliance, or system. In many cases, the output from a vibration sensor may be difficult to translate into accurate feedback information and corresponding control signals. For example, the vibration sensed by the vibration sensors 2510-2511 may be indirectly related to the individual driving oscillations produced by the ORM-based vibration components, such as the vibration component comprising ORM 2504 and mechanically coupled passive oscillator 4302. In such cases, significant inference is necessary to logically infer the driving oscillations of the vibration components producing the vibration-sensor signals and to compute corresponding adjustments to ORM control. Furthermore, there may be significant temporal lags between sensor vibration and the driving oscillations that produce the sensor vibration. Many of the common techniques for sensing ORM driving oscillations in order to provide local feedback to ORMs may suffer similar problems. Furthermore, there may be many different types of interferences and couplings between electromechanical driving forces, electromagnetic sensors, and other device components that mask or entirely prevent accurate inference of the real-time characteristics of ORMs and the vibration-response of the entire device, appliance, or system. For this reason, simpler and direct

types of sensing and control can provide enormous benefits in achieving desired vibration responses of the entire device, appliance, or system, particularly in devices, appliances, and systems that include multiple vibration components, each consisting of an ORM and one or more passive oscillators as well as various types of vibration sensors external to ORMs and passive oscillators as well as sensors within, or coupled to, ORMs and passive oscillators.

Figure 44 illustrates one type of ORM driving-oscillation sensor that can be employed to provide feedback information for ORM control. In Figure 44, a linear ORM 4402, used in previous examples, is again shown as an example ORM. The linear ORM includes a mass or weight 4404 that is driven electromagnetically by a drive coil 4406 to oscillate along a linear tube 4408. In this ORM, two sensor coils 4410 and 4412 are additionally included in order to detect motion of the weight or mass 4404 within the ORM as it is driven to oscillate. The sensor information may be provided to an internal ORM control logic 4414 or to the controller 2516 within the device, appliance, or system that includes the ORM. In certain cases, both the internal ORM control logic as well as the device controller may receive sensor information, for various different types of feedback-based control purposes. In the lower portion 4420 of Figure 44, a small control-flow diagram is provided to indicate how the sensor information is used. When a controller receives a target frequency ω_t at which the ORM is to oscillate, in step 4422, the control logic or controller initiates oscillation of the weight or mass, in step 4424, and then, in the *while*-loop of steps 4426-4430, continues to monitor the sensor output and modify control input to the ORM in order that the ORM oscillates at the target frequency ω_t. This involves reading the sensor data to determine the actual frequency of oscillation ω_a, in step 4427, then determining a difference between the target and actual frequencies in step 4428, using the determined difference to compute modifications to the current control of the ORM and modify the control in a way estimated to result in the ORM achieving the target frequency ω_t, in step 4429, and executing the modified control in step 4430. In many cases, the computations are sufficiently complex that the feedback-based control needs to be implemented by control routines running on a processor. Furthermore, because the sensors 4410 and 4412 are essentially external to the actual oscillating mass or

weight and oscillation path, the data that they output does not directly correspond to position and velocity data for the moving mass or weight, but is instead a signal proportional to the current induced in the sensor coils by the moving mass. A fair amount of interpretation is required to convert the sensor information into velocity and position information, or even into information related to the actual frequency ω_a of oscillation. Moreover, there may be significant electromagnetic interference between the drive coil 4406 and the sensor coils 4410 and 4412, limiting the accuracy at which the actual frequency ω_a or mass position and velocity can be determined. Sensor-coil-based inferences may also suffer from significant lag times between passing of the moving weight through the sensor coil and generation of a corresponding signal. In a complex system in which many different sensors are being monitored for many different ORMs, as well as sensors that detect the vibration response for a device, appliance, or system containing the ORMs, use of inferential feedback information, such as that provided by the sensor coils shown in Figure 44, may be problematic, at best.

Figure 45 illustrates an alternative approach to sensing the driving oscillations produced by an ORM. In this approach, rather than inferential sensing, as described above with reference to Figure 44, the ORM 4502 includes a direct sensor 4504 that directly determines the position and velocity of the moving weight or mass 4506. This direct position and velocity information is output to an internal ORM control logic 4508 that can directly use the position and velocity information to update ORM control in order to achieve a target frequency ω_t. The lower portion of Figure 45 4510, includes a small control-flow diagram, similar to that included in Figure 44, to illustrate internal control using the data provided one or more direct sensors. When a target frequency ω_t is received in step 4512, the control initiates oscillation of the mass in step 4514. In addition, in step 4616, the control logic initiates sensor output. Then, in the *while*-loop of steps 4518-4521, the control logic continuously receives position and velocity data from the one or more direct sensors and executes immediate control based on that position and velocity data. In step 4519, the control logic reads the position and velocity data from the sensor. This may involve a certain amount of computation, such as computing the difference and position with time over several

readings, but because of the direct nature of the position sensing, is not inferential and is less computationally intensive than in the case of indirect sensing. Then, in step 4520, the appropriate control is computed based on the target frequency ω_t and the current position and velocity of the moving mass p and v. This computation may be made based on a predetermined function, based on tables with values, or computed as another of the initiation steps, including initiation steps 4514 and 4516. Finally, in step 4521, the computed control is executed by the controller. In many cases, the determination of the appropriate control corresponding to sensed velocity and position data can be made by logic circuitry, rather than a programmed processor. In many cases, the position and velocity data is more accurate and far more timely provided than position and velocity data derived from indirect sensing and inference.

There are many different approaches to direct sensing of the position and velocity of a moving mass within an ORM. Figures 46A-B illustrate several possible direct-sensing approaches. As shown in Figure 46A, the ORM may contain a series of apertures, such as aperture 4602, through which an illumination source shines light. Across the tubular channel containing the oscillation path, there is a photodiode sensor for each aperture, such as photodiode sensor 4604 corresponding to aperture 4602. The current position of the moving mass can be determined from the pattern of high and low photodiode-sensor outputs, shown above the ORM in Figure 46A 4606. A series of captured photodiode-sensor outputs at consecutive points in time provides the information needed to accurately compute the velocity of the moving mass. As shown in Figure 46B, another approach to computing the position and velocity of the moving mass involves a series of regularly spaced pressure or presence sensors, such as pressure or presence sensor 4610. Similar to the photodiode-sensor output, the output from the pressure or positions sensors provides a pattern in which the position of the moving mass can be recognized. Various types of Hall-effect electronic sensors, reflection-path sensors, and other types of sensors may be employed to directly determine the position and velocity of a moving mass within an ORM.

To clarify, direct sensors directly sense, in real time, the location of the moving mass of an ORM. Optical sensors, such as that shown in Figure 46, use light sources to directly identify the location of the moving mass, and the rate of change of

the accurately identified positions is straightforwardly converted into a very good approximation to the instantaneous velocity of the moving mass by simple arithmetic operations. A direct sensor provides position and velocity data in real time, constrained principally by the time needed for propagation of light, the time needed for propagation of electrical-current propagation, sensor response times, and the time needed for carrying out a small number of computer-instruction executions. These times are all far faster than the time needed for an ORM moving mass to move far enough for the motion to produce a different sensor reading, so that, in essence, a direct sensor easily produces an accurate, real-time position and velocity for the moving mass. Indirect sensors, by contrast, do not directly detect the position and velocity of an ORM moving mass. For example, as discussed with reference to Figure 44, above, the sensor-coil sensors may exhibit signal changes prior to and following the moving mass being located adjacent to them and as a result of current changes in the driving coil. Therefore, only by retrospective computational analysis can an approximate location of the moving mass be indirectly inferred. Furthermore, the sensor-coils may respond differently to the moving mass depending on a variety of external factors and even depending on the velocity of the moving mass. Indirect sensors cannot produce real-time position and velocity values for an ORM moving mass, and the accuracy of the approximations of the position and velocity may significantly deteriorate when the oscillation frequency is changing. Vibration detectors are even less accurate, since the directions and amplitudes of the vibrations of an entire device may not align with the direction of moving-mass vibration, may vary due to many different external factors, including the orientation of the device with respect the gravitational field, the local mechanical environment of the device, the model of the moving-mass trajectory they use for inferring moving-mass position, and other such factors. In these cases, inferring the position and velocity of the ORM moving mass is generally associated with large errors and computational time lags. Direct moving-mass position-and-velocity sensors therefore provide accurate and real-time, nearly instantaneous moving-mass position and velocity data. Indirect moving-mass position-and-velocity sensors do not provide real-time, nearly instantaneous moving-mass position and velocity data, and do not

achieve the accuracy, in the non-real-time position and velocity values they produce that is achieved by direct sensors.

Although the present invention has been described in terms of particular embodiments, it is not intended that the invention be limited to these embodiments. Modifications will be apparent to those skilled in the art. For example, any of many different design and implementation parameters may be varied in order to provide different implementations of the ORM control logic discussed above, including choice of type of logic control, programming language, in the case of a processor-controlled controller, modular organization, data structures, control structures, logic circuitry, processor type, and many other such design and implementation parameters. Many different types of direct sensors that directly determine the velocity and position of the oscillating mass within an ORM can be used in different types of ORMs. Various types of electromagnetic sensors that sense position, precious-metal brush-contact sensors, and Reed switches are examples of the many types of direct sensors that can be used to directly determine oscillating-mass position and velocity and induce direct, corresponding control of the ORM.

The foregoing description, for purposes of explanation, used specific nomenclature to provide a thorough understanding of the invention. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the invention. The foregoing descriptions of specific embodiments of the present invention are presented for purpose of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. The embodiments are shown and described in order to best explain the principles of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the following claims and their equivalents:

CLAIMS

1. An oscillating resonant module comprising:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

2. The oscillating resonant module of claim 1 wherein the one or more sensors are selected from among one or more:

mechanical sensors;

electromagnetic sensors; and

optical sensors.

3. The oscillating resonant module of claim 1 wherein the control component determines, from the received sensor output, the velocity of the mass from the positions of the mass at two or more points in time.

4. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass.

5. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed as the output value of a function that takes, as input, the current position of the mass and the current velocity of the mass.

6. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

7. The oscillating resonant module of claim 3 wherein the control output, output by the control component to the actuator, is computed from pre-computed values indexed by the current position of the mass and the current velocity of the mass.

8. The oscillating resonant module of claim 1 mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

9. The oscillating resonant module of claim 8 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

10. A physical device that exhibits a vibration response when mechanical driven by one or more oscillating resonant modules included in the physical device, the physical device comprising:

the one or more oscillating resonant modules, each of which responds to control inputs to produce driving oscillations and includes a sensor that provides sensor data to a control component within the oscillating resonant module;

one or more vibration sensors;

a stored characterization of the natural vibration frequencies of the physical device; and

a controller that uses accesses the stored characterization of the natural vibration frequencies of the physical device to control the one or more oscillating resonant modules to drive the physical device to exhibit a predetermined vibration response.

11. The physical device of claim 10 wherein each of the one or more oscillating resonant modules comprises:

a mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along an oscillation path that represents a segment of a space curve;

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time; and

a control component that

receives control signals input to the oscillating resonant module,

receives output from the one or more sensors, and

controls oscillation of the mass to produce a predetermined vibration response according to the received control signal by repeatedly generating a control output, to an actuator that drives the mass to oscillate, corresponding to one or more most recently received sensor outputs.

12. The physical device of claim 10 wherein the characterization of the natural vibration frequencies of the physical device is determined by simultaneously sweeping the driving oscillations of the one or more oscillating resonant modules over driving-oscillation ranges and monitoring the physical device vibration response using output from the one or more vibration sensors to identify the maximum-amplitude frequencies.

13. The physical device of claim 12 wherein the characterization of the natural vibration frequencies of the physical device is determined periodically by the controller.

14. The physical device of claim 10 further including stored control information for the one or more oscillating resonant modules for each of one or more predetermined vibration responses that is based on the stored characterization of the natural vibration frequencies of the physical device.

15. The physical device of claim 10 wherein at least one of the each of the one or more oscillating resonant modules is mechanically coupled to one or more passive oscillating resonant modules to provide a wider range of vibration responses for the combination of the oscillating resonant module and the one or more passive oscillating resonant modules.

16. The physical device of claim 15 wherein the passive oscillating resonant modules are driven by the oscillating resonant module to which they are mechanically coupled.

17. An oscillating resonant module comprising:

a first mass that is driven by energy supplied to the oscillating resonant module to travel back and forth along a first oscillation path that represents a segment of a space curve;

a second mass that is driven by oscillations of the first mass to travel back and forth along a second oscillation path that represents a segment of a space curve; and

a control component that

receives control signals input to the oscillating resonant module, and

controls oscillation of the first mass to produce a predetermined vibration response according to the received control signals by generating a control output to an actuator that drives the first mass to oscillate.

18. The oscillating resonant module of claim 17 further comprising:

one or more direct sensors that output real-time indications of the position of the mass within the oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

19. The oscillating resonant module of claim 17 further comprising:

one or more sensors that output indications directly correlated with the position of the second mass within the second oscillation path at specific points in time that are used by the control component to generate corresponding control outputs to the actuator that drives the first mass to oscillate.

20. The oscillating resonant module of claim 17 included within a physical device to drive a vibration response in the physical device.

ABSTRACT OF THE DISCLOSURE

The current document is directed to various types of oscillating resonant modules ("ORMs"), including linear-resonant vibration modules, that can be incorporated in a wide variety of appliances, devices, and systems to provide vibrational forces. The vibrational forces are produced by back-and-forth oscillation of a weight or member along a path, generally a segment of a space curve. A controller controls each of one or more ORMs to produce driving oscillations according to a control curve or control pattern for the ORM that specifies the frequency of the driving oscillations with respect to time. The driving oscillations, in turn, elicit a desired vibration response in the device, appliance, or system in which the one or more ORMs are included. The desired vibration response is achieved by selecting and scaling control patterns in view of known resonance frequencies of the device, appliance, or system.

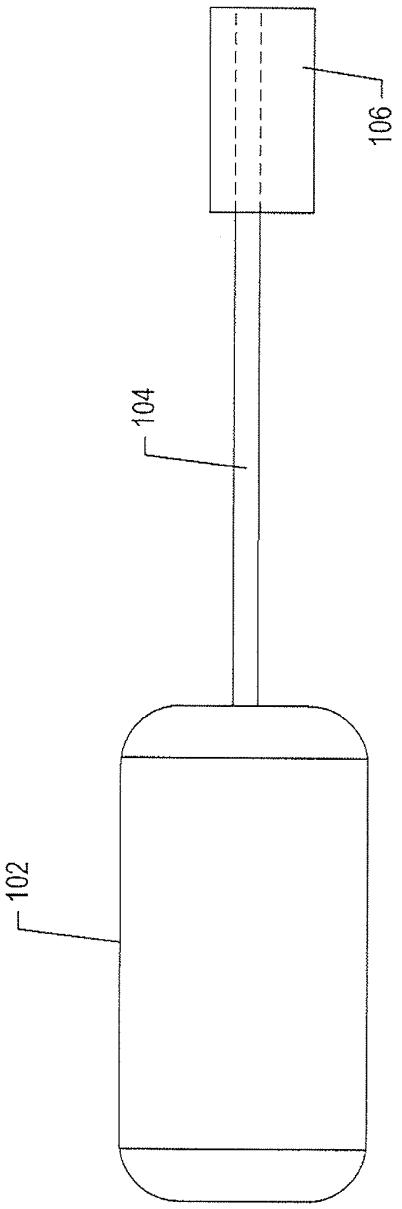


FIG. 1A
--Prior Art--

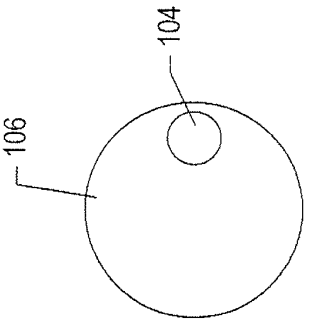


FIG. 1B
--Prior Art--

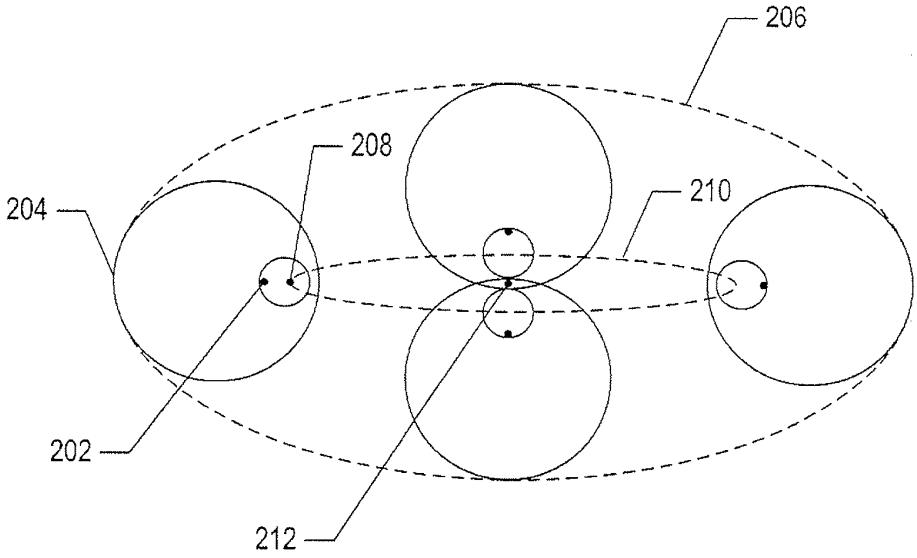


FIG. 2A

--Prior Art--

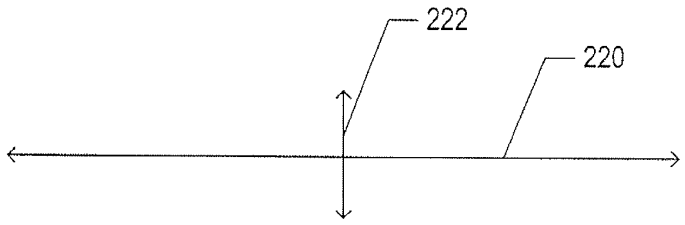


FIG. 2B

--Prior Art--

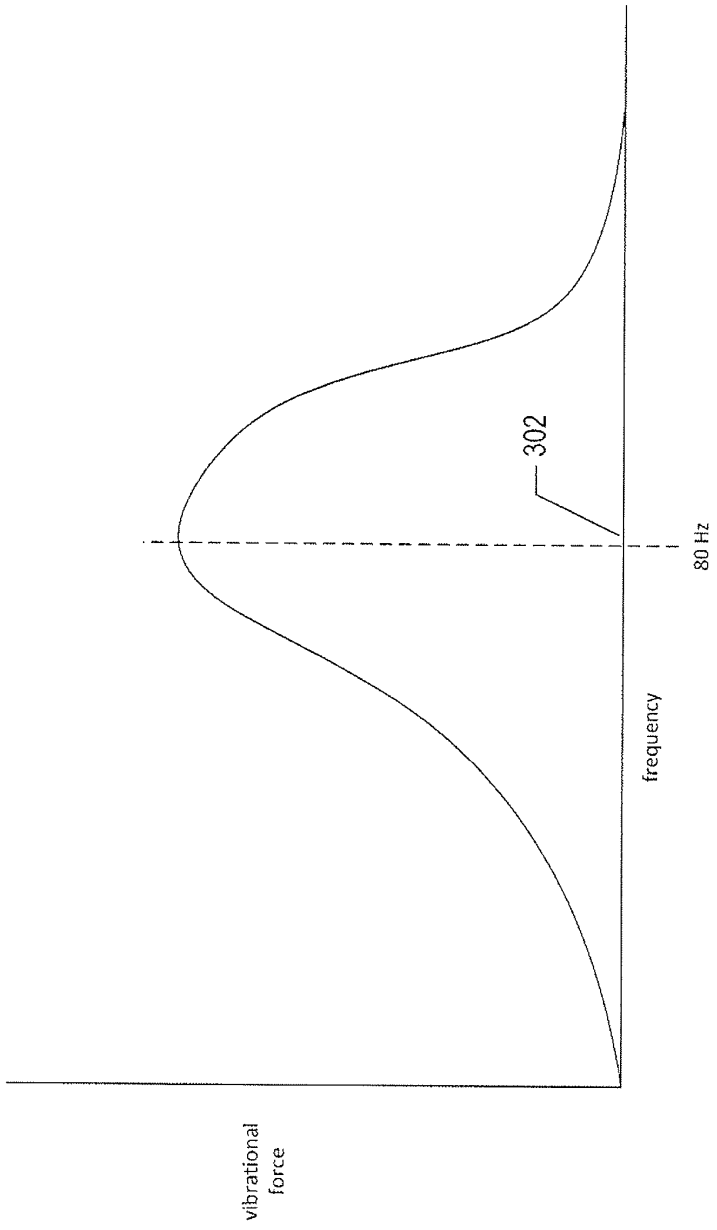


FIG. 3
--Prior Art--

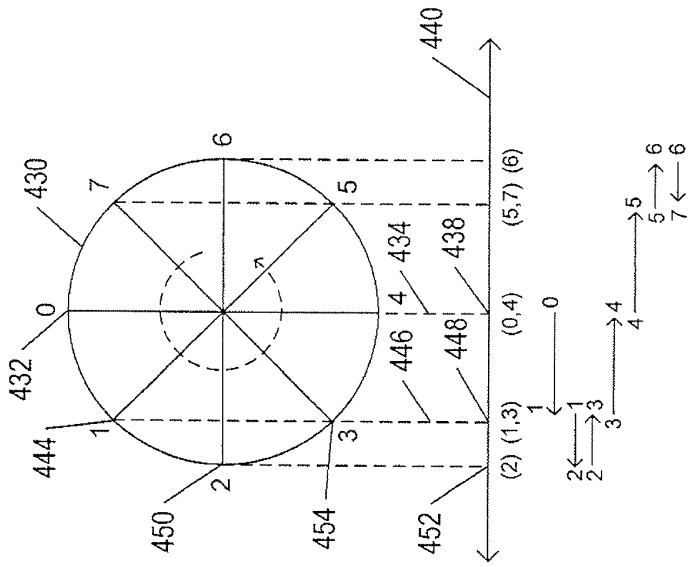

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FIG. 4B

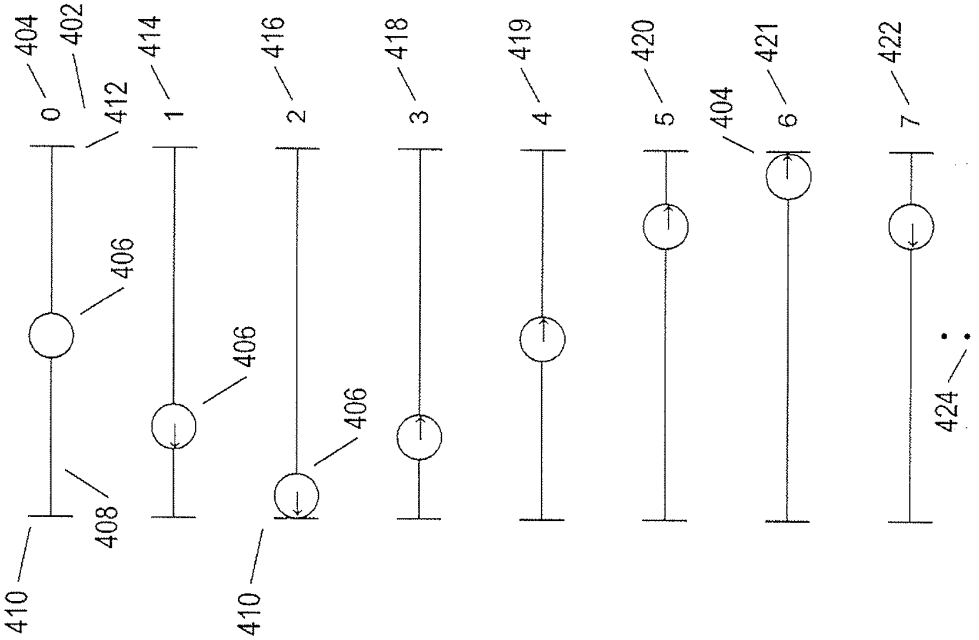

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FIG. 4A

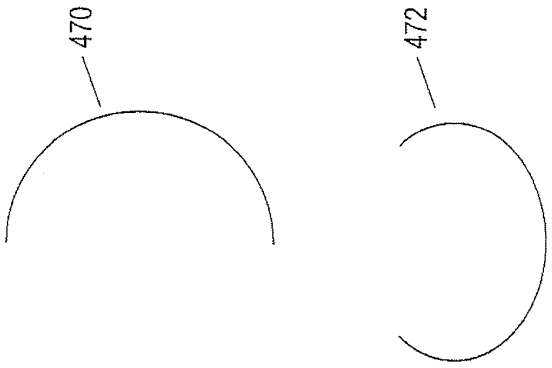


FIG. 4D

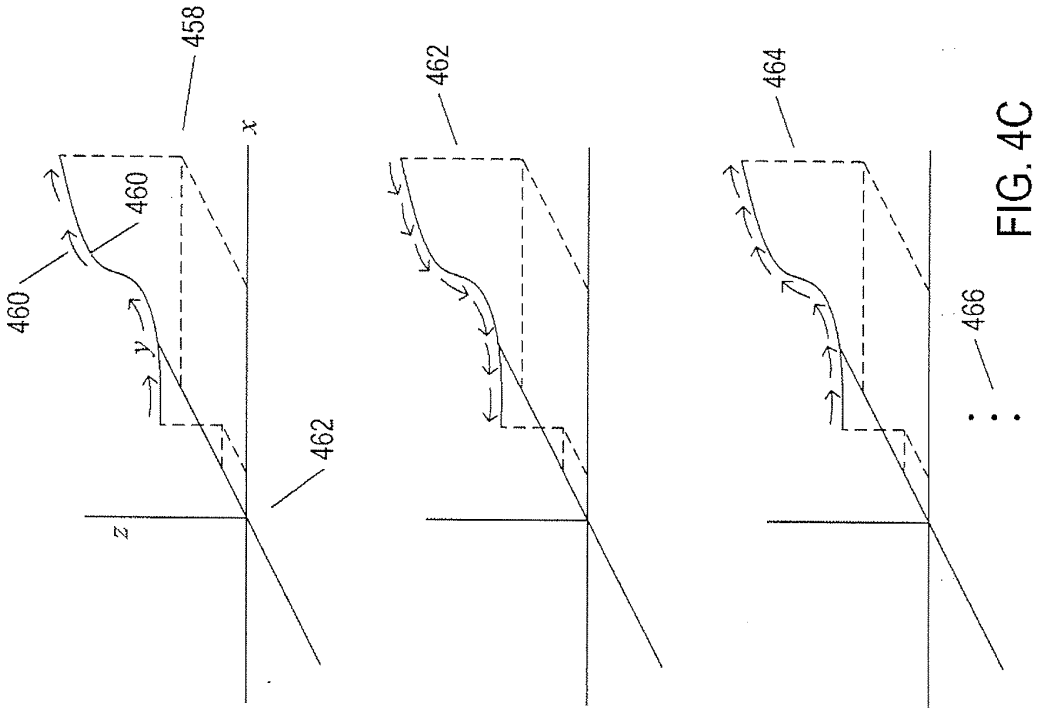


FIG. 4C

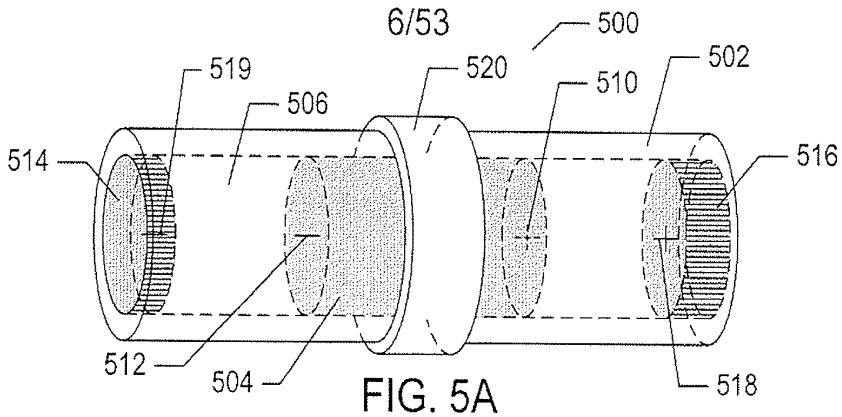


FIG. 5A

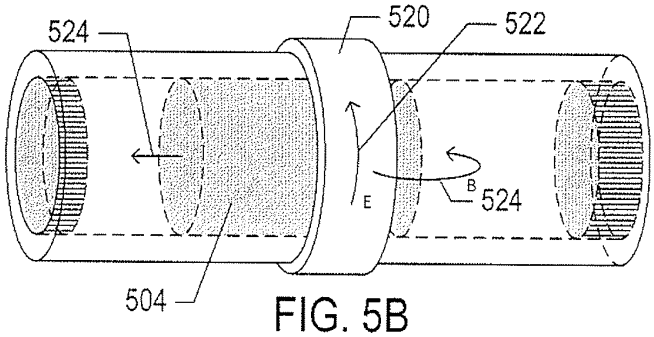


FIG. 5B

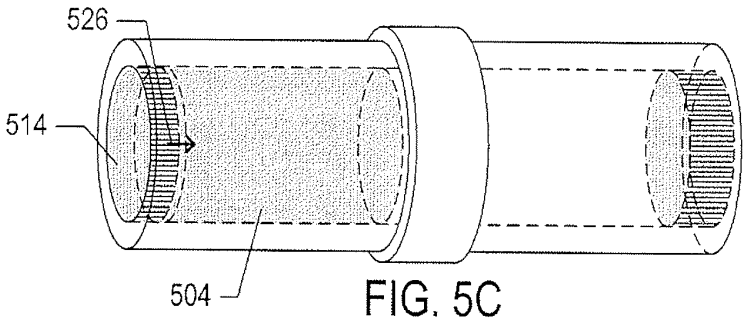


FIG. 5C

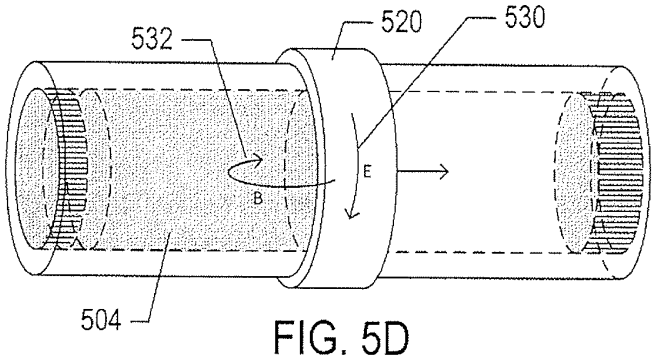


FIG. 5D

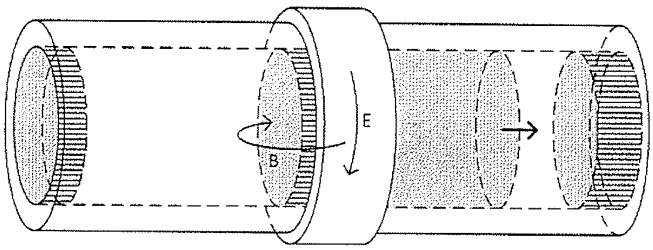


FIG. 5E

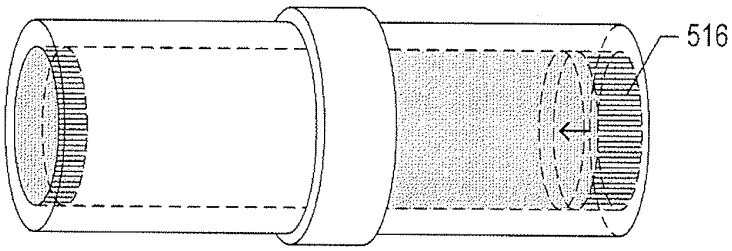


FIG. 5F

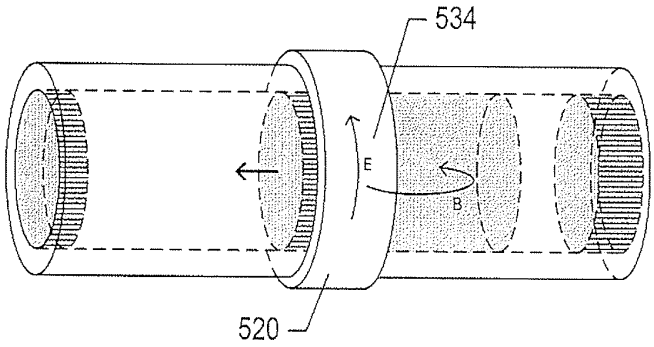


FIG. 5G

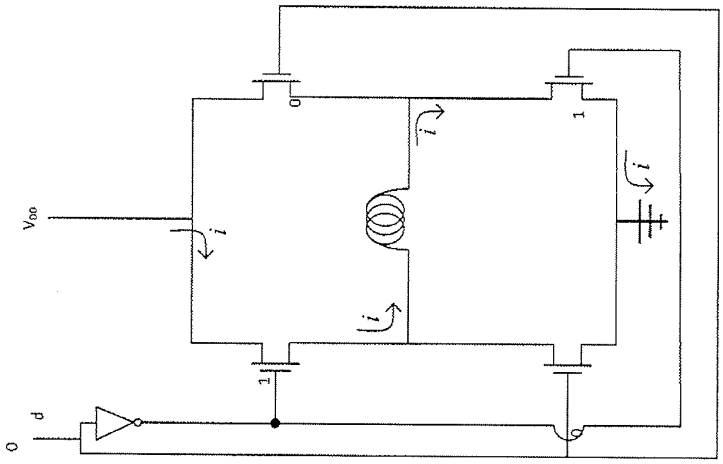


FIG. 6B

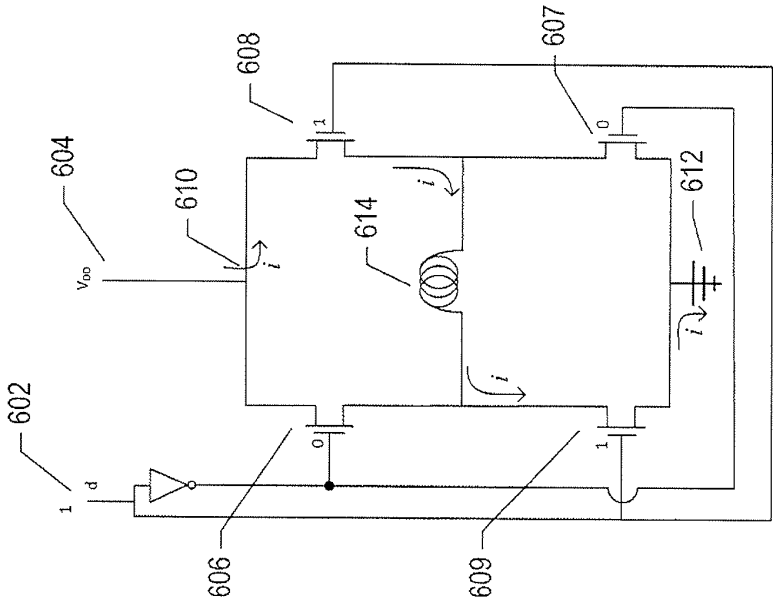


FIG. 6A

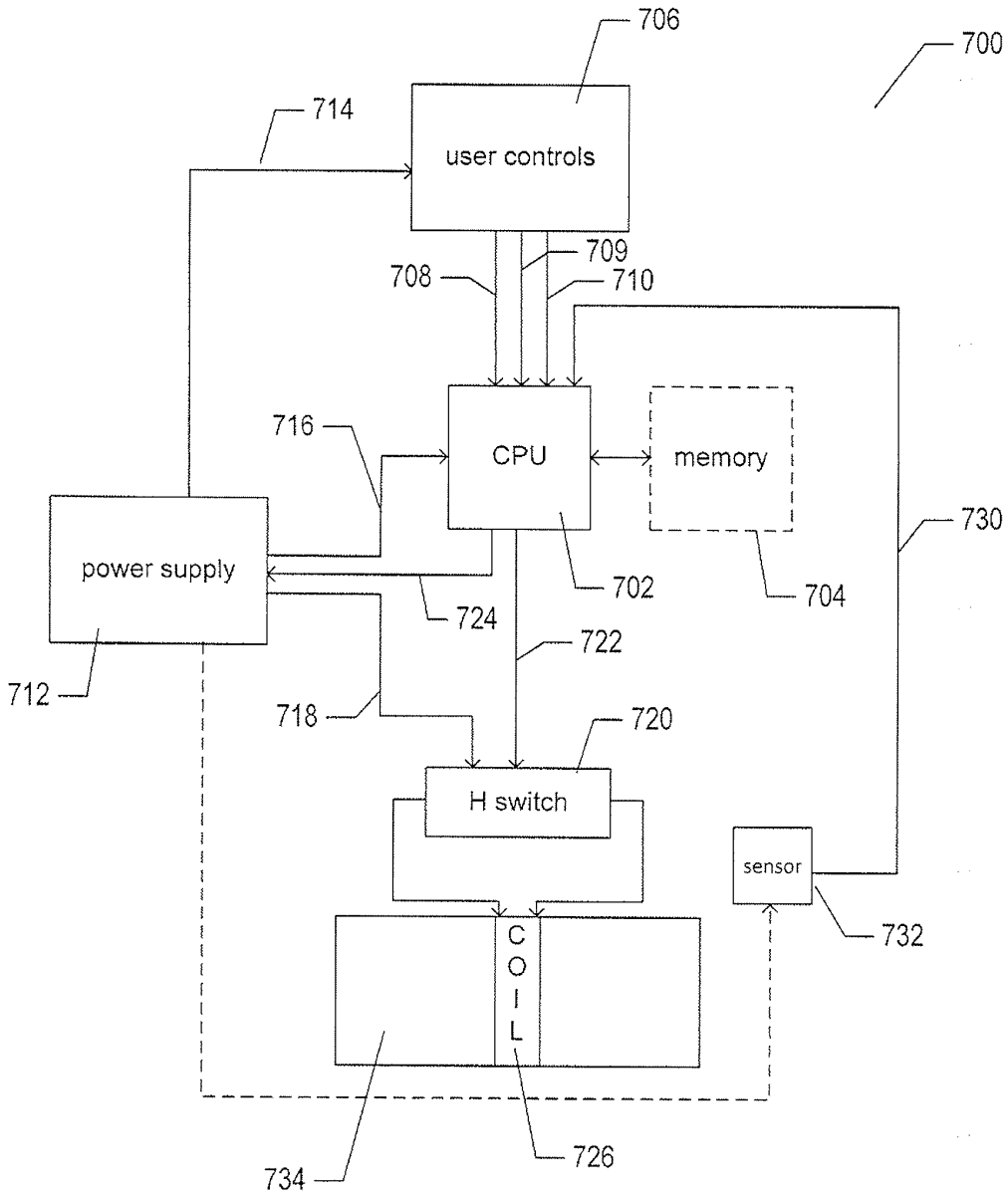

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user controls
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732
C
O
I
L
734
726

FIG. 7

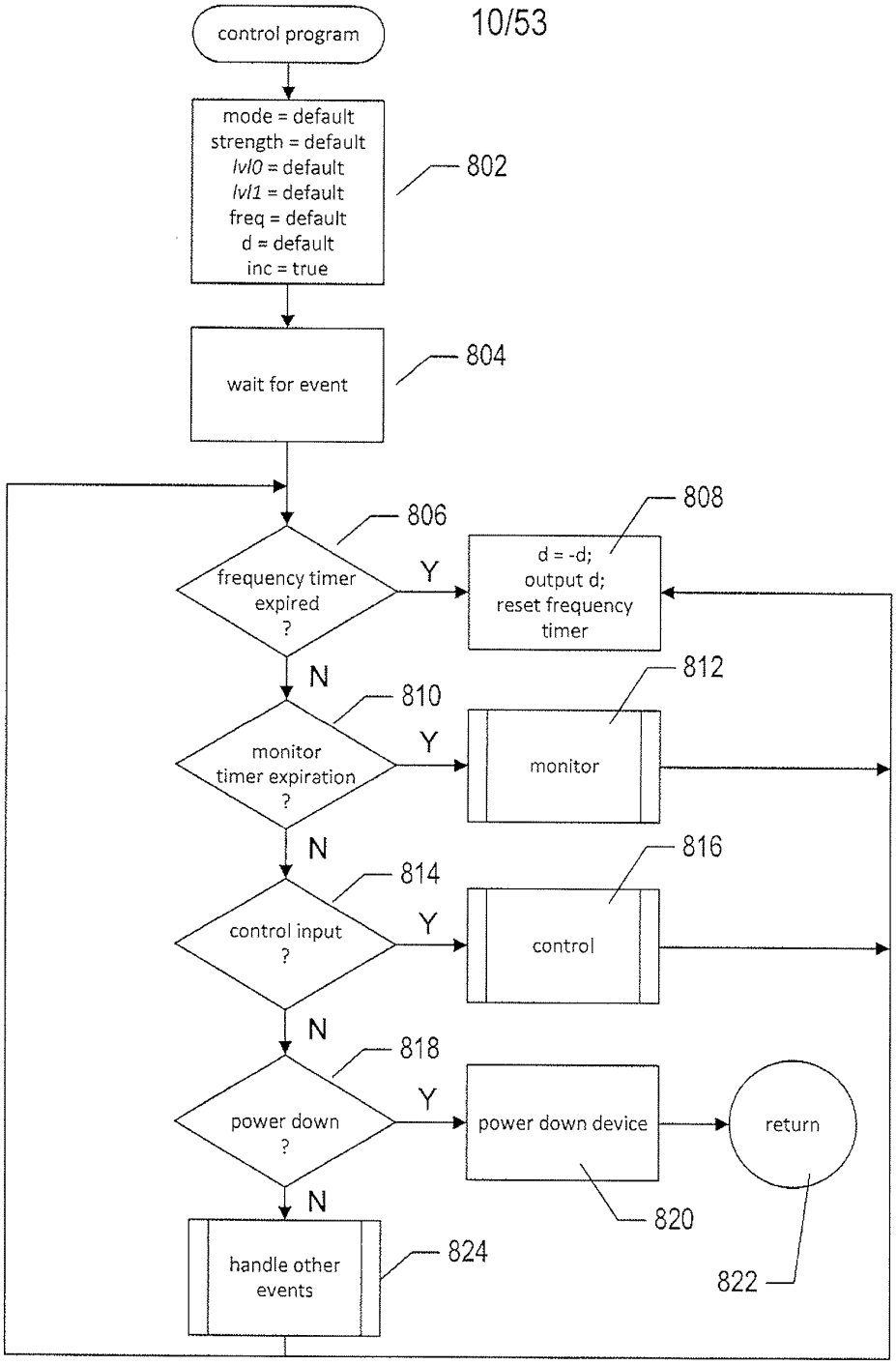

control program
mode = default
strength = default
lvl0 = default
lvl1 = default
freq = default
d = default
inc = true
802
wait for event
804
806
frequency timer expired ?
Y
808
d = -d;
output d;
reset frequency timer
N
810
monitor timer expiration ?
Y
812
monitor
N
814
control input ?
Y
816
control
N
818
power down ?
Y
power down device
return
820
N
handle other events
824
822

FIG. 8A

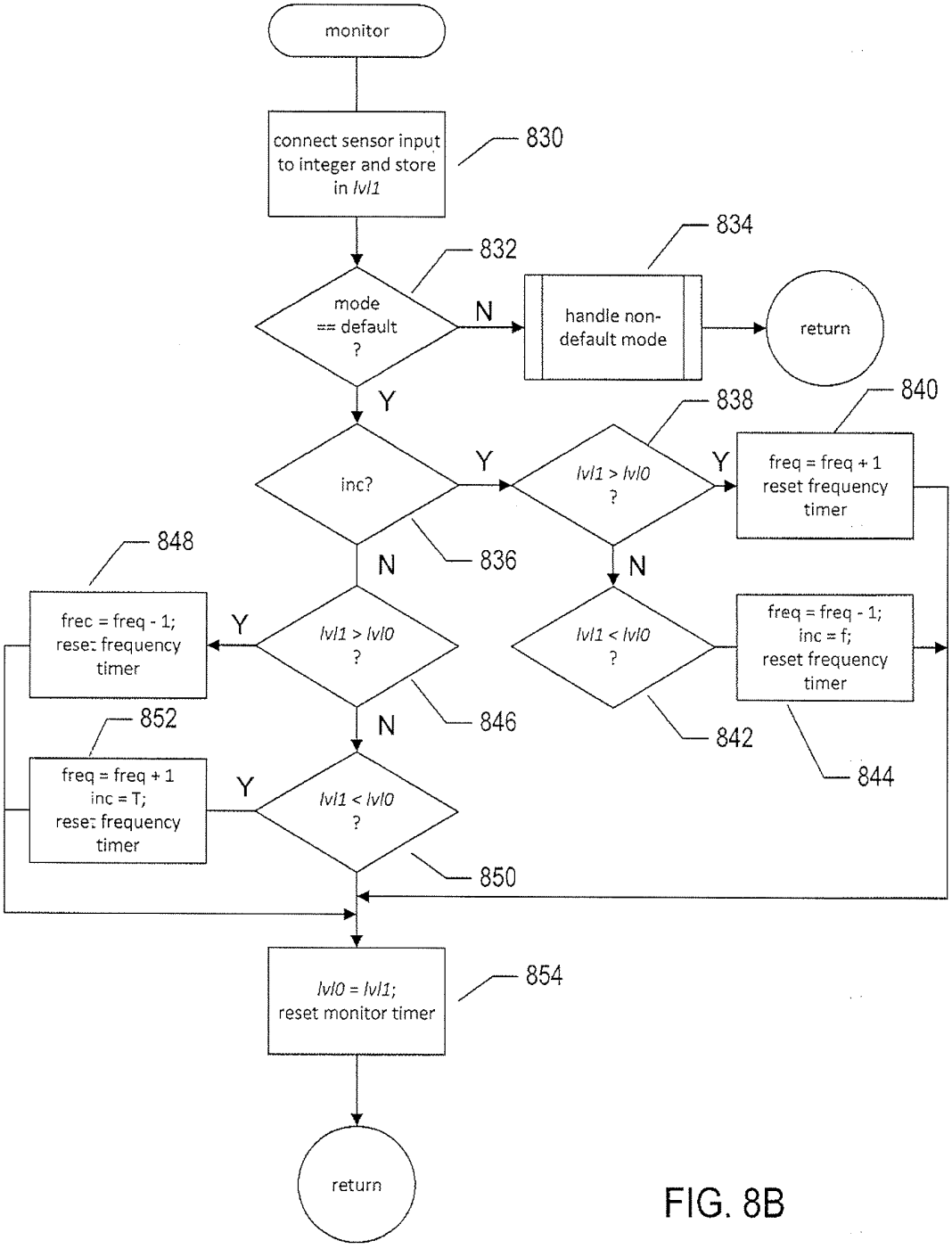

monitor
connect sensor input to integer and store in lvl1
830
832
mode == default ?
N
834
handle non-default mode
return
Y
838
inc?
Y
lvl1 > lvl0 ?
Y
840
freq = freq + 1 reset frequency timer
N
836
N
848
frec = freq - 1; reset frequency timer
Y
lvl1 > lvl0 ?
lvl1 < lvl0 ?
freq = freq - 1; inc = f; reset frequency timer
852
N
846
842
844
freq = freq + 1 inc = T; reset frequency timer
Y
lvl1 < lvl0 ?
850
lvl0 = lvl1; reset monitor timer
854
return

FIG. 8B

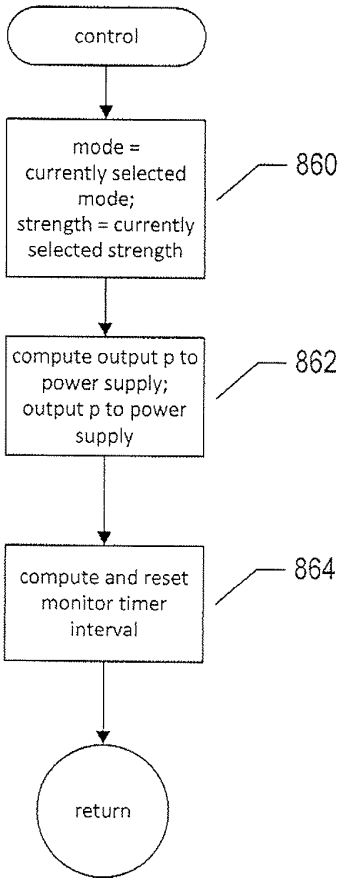

control
mode = currently selected mode; strength = currently selected strength
860
compute output p to power supply; output p to power supply
862
compute and reset monitor timer interval
864
return

FIG. 8C

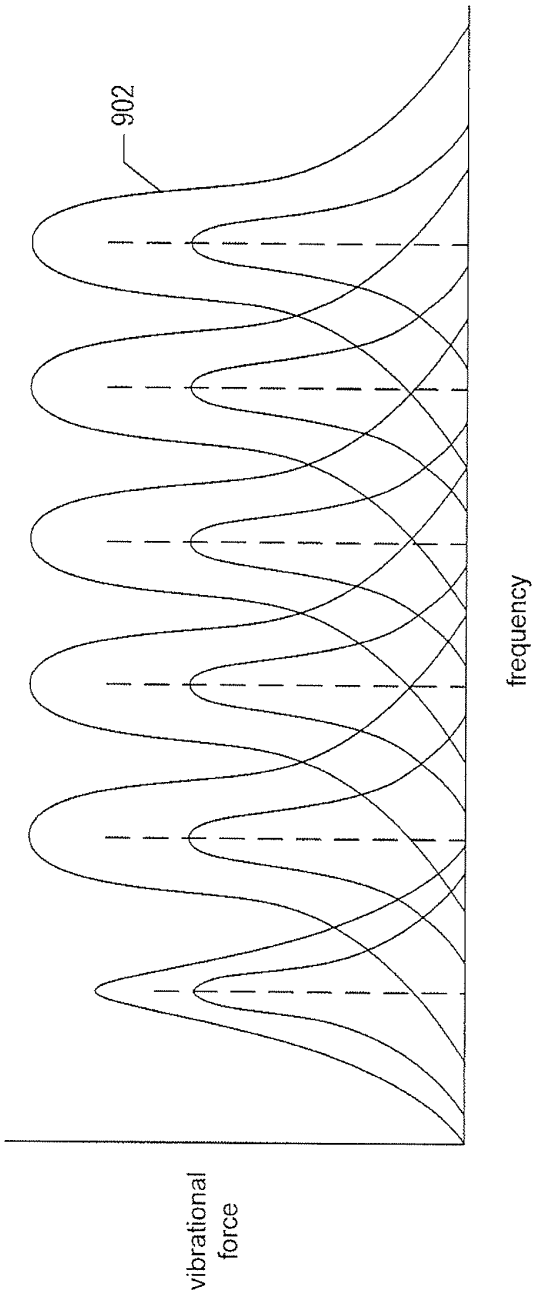


FIG. 9

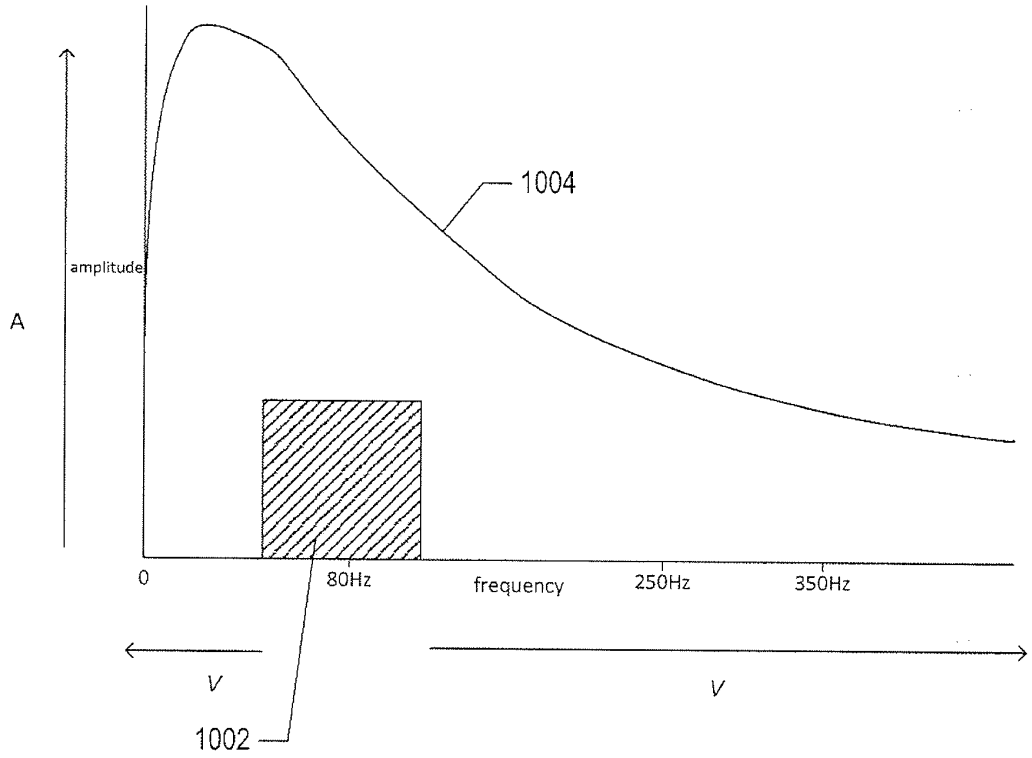


FIG. 10

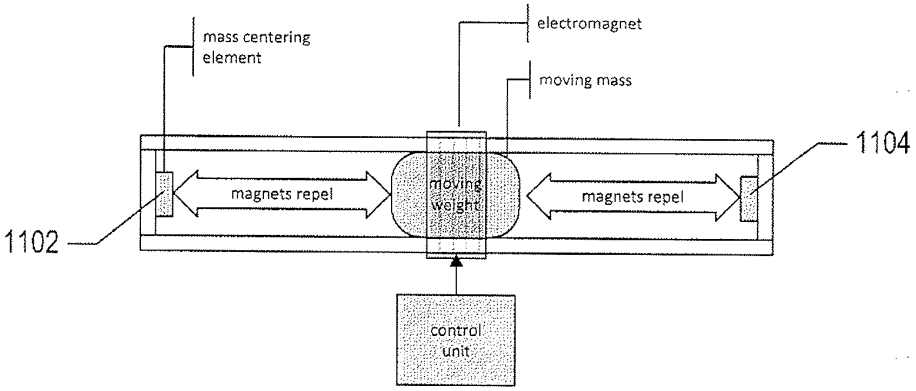


FIG. 11

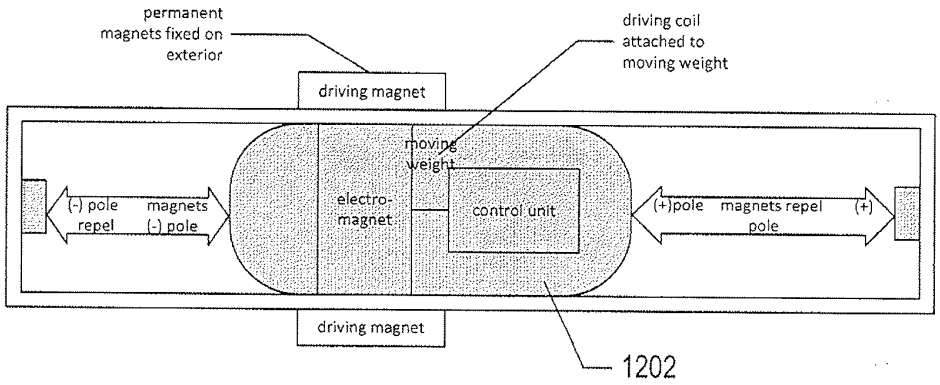


FIG. 12

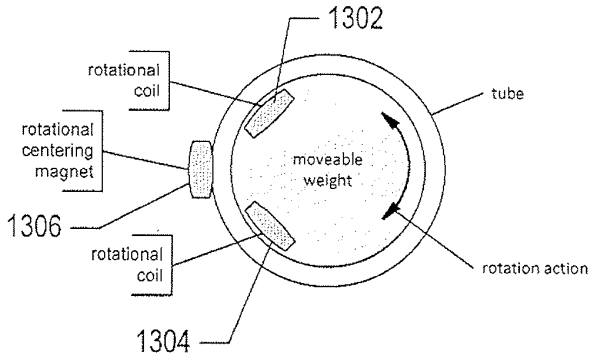


FIG. 13

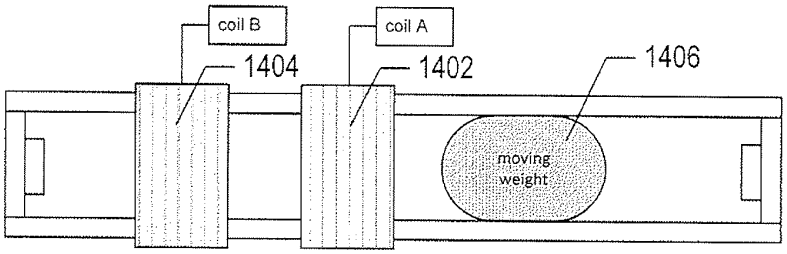


FIG. 14

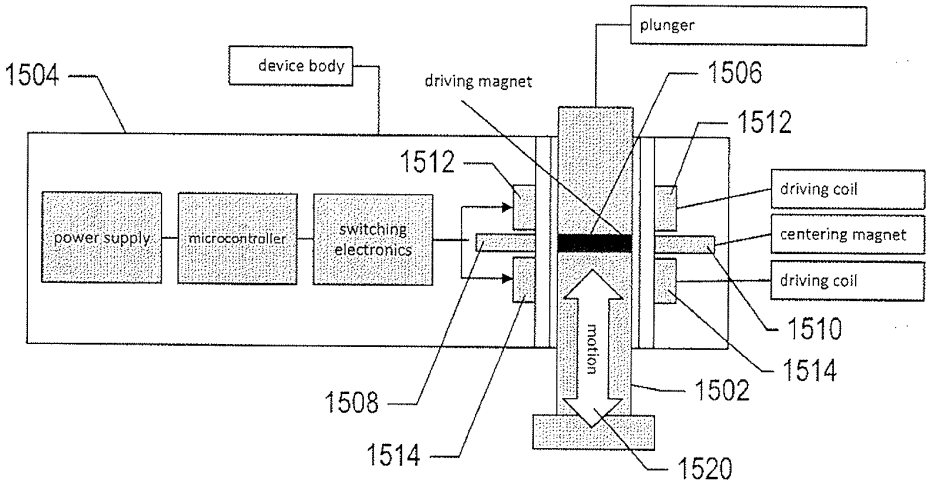


FIG. 15

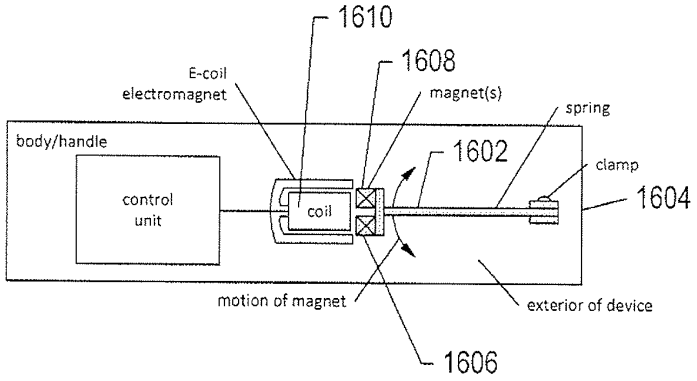


FIG. 16

17/53

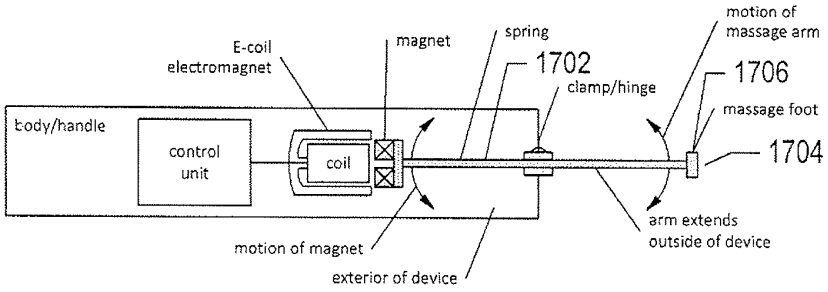


FIG. 17

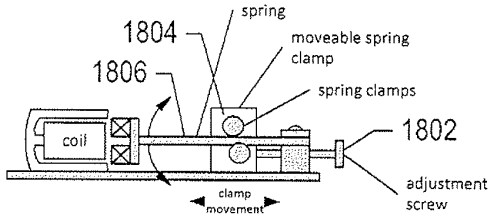


FIG. 18

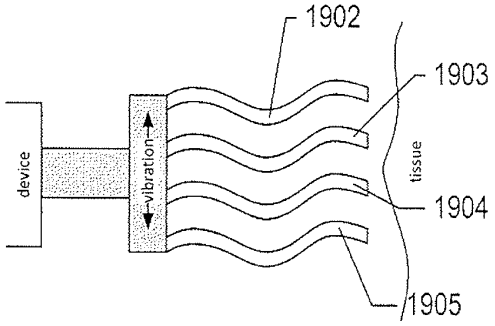


FIG. 19

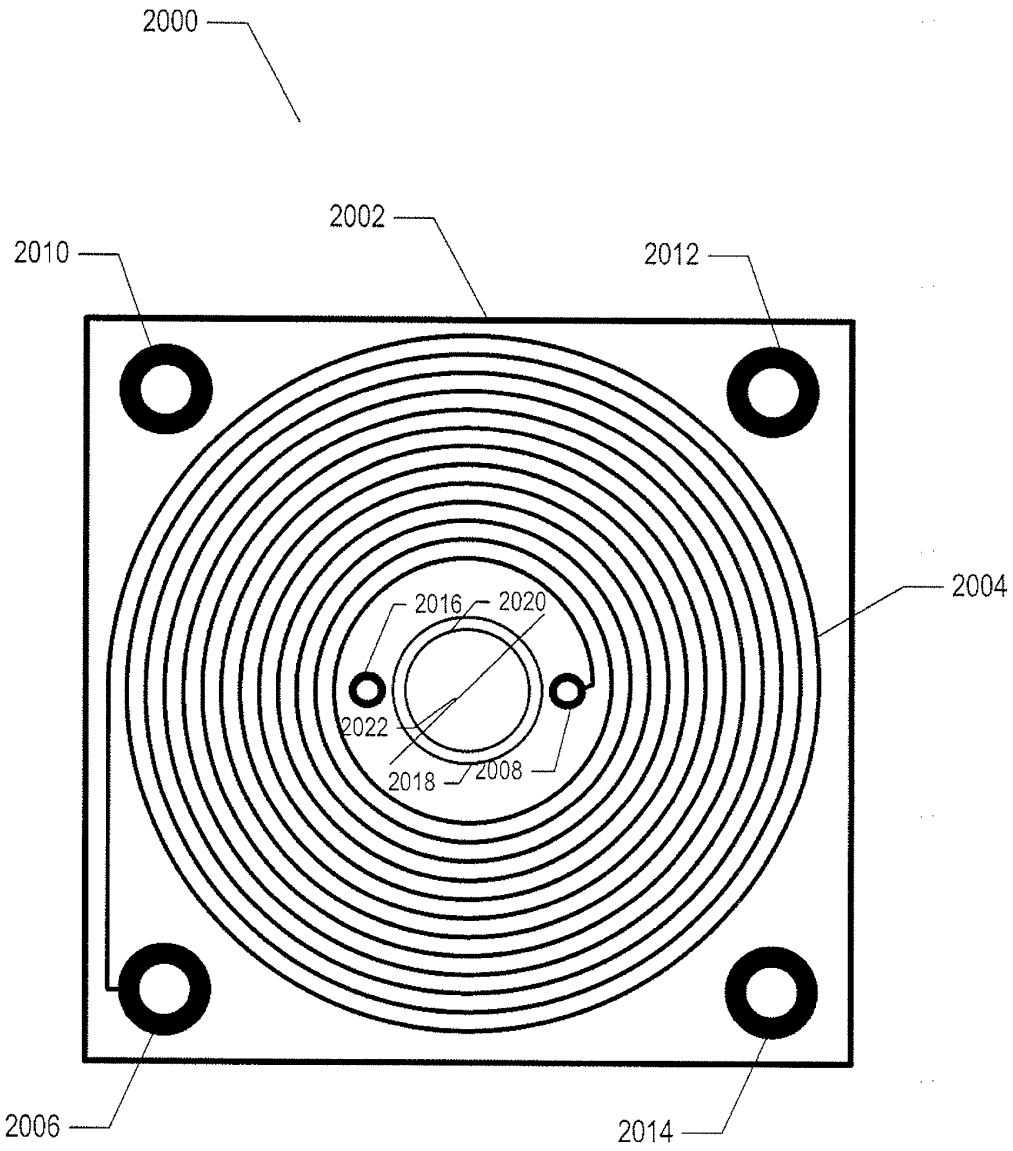


FIG. 20

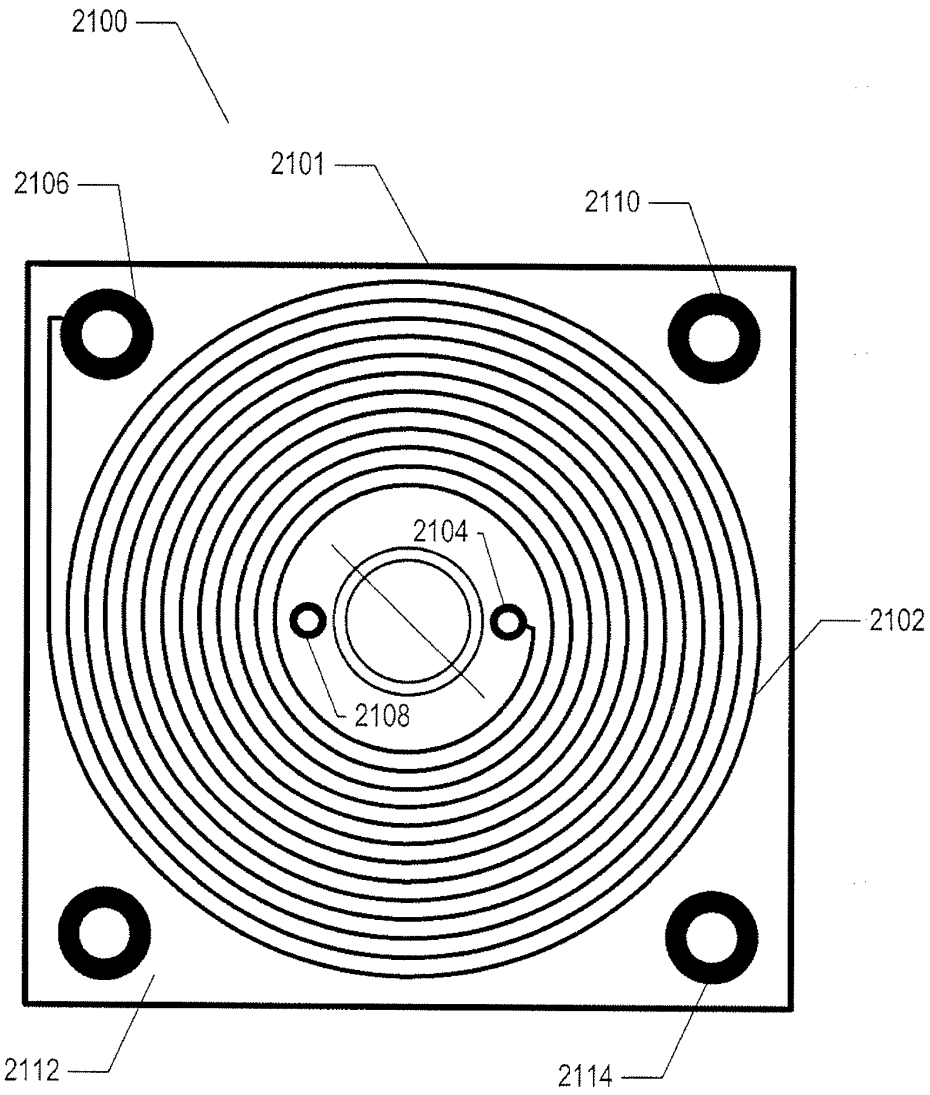


FIG. 21

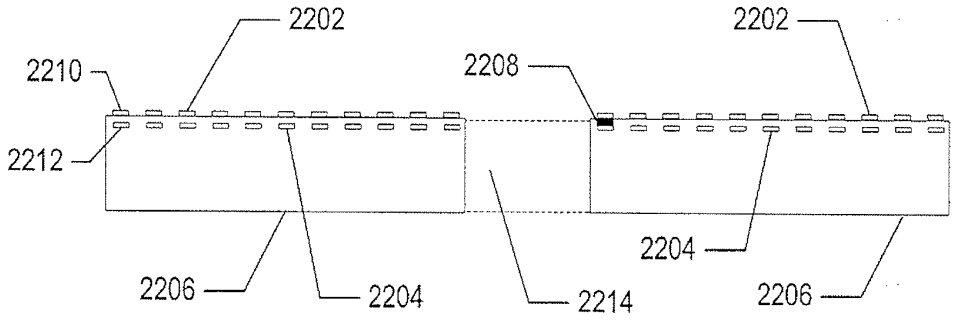


FIG. 22A

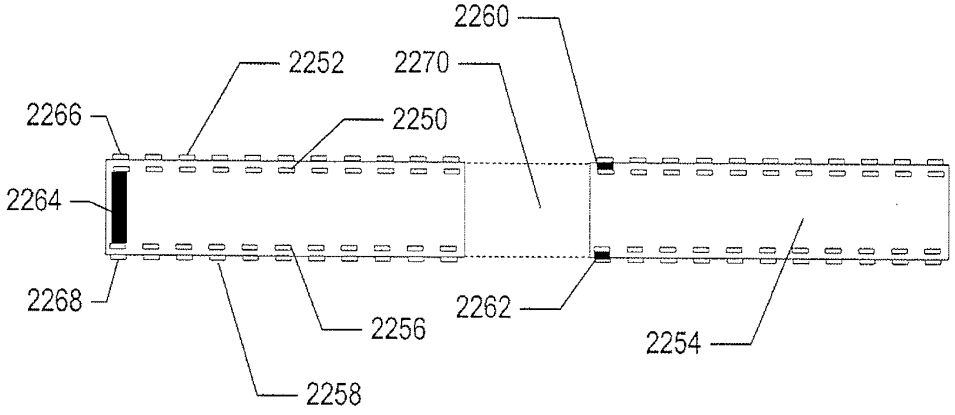


FIG. 22B

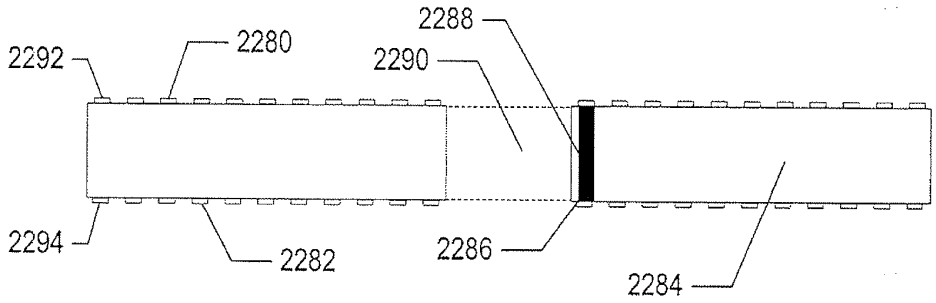


FIG. 22C

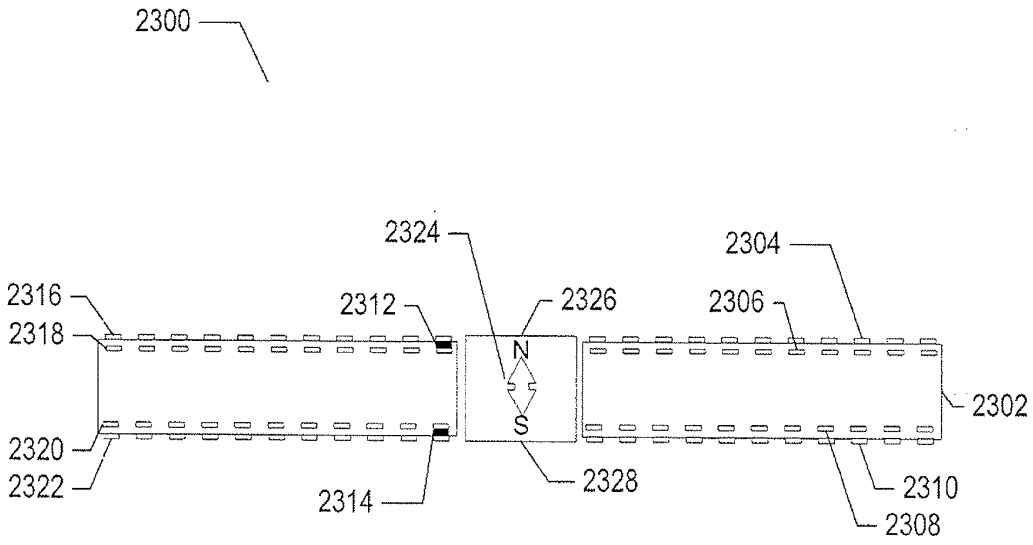

2300
2324
2304
2316
2318
2312
2326
2306
N
S
2302
2320
2322
2314
2328
2310
2308

FIG. 23A

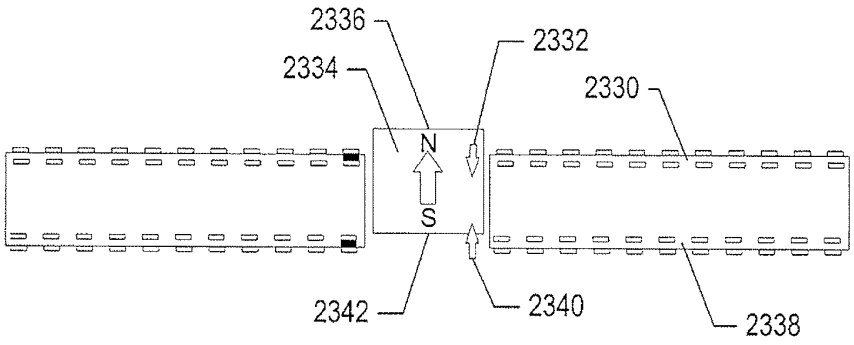


FIG. 23B

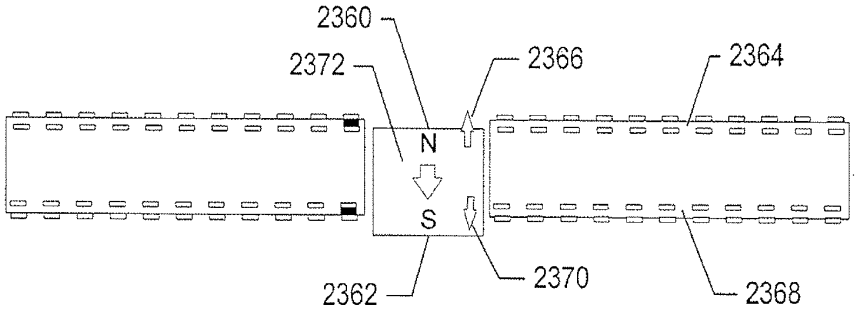


FIG. 23C

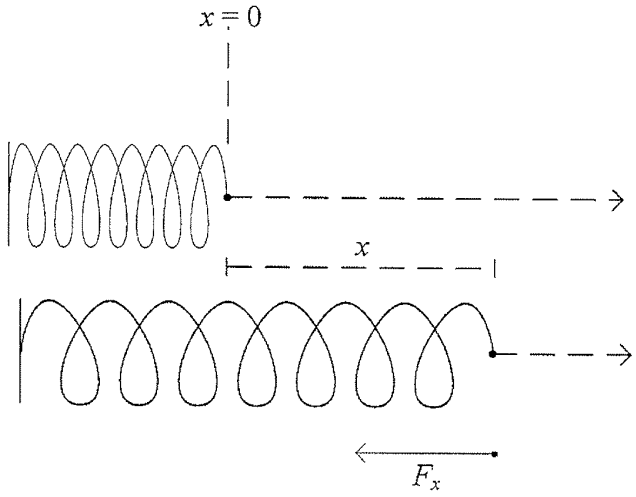


FIG. 24A

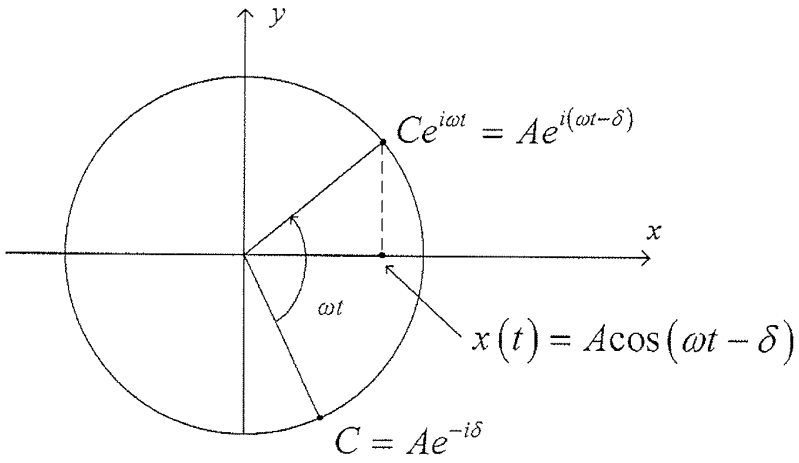


FIG. 24B

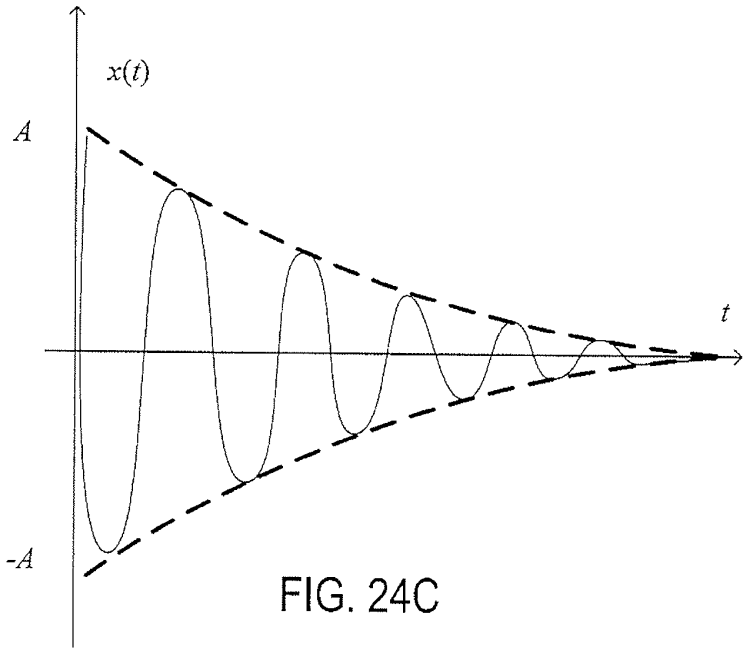


FIG. 24C

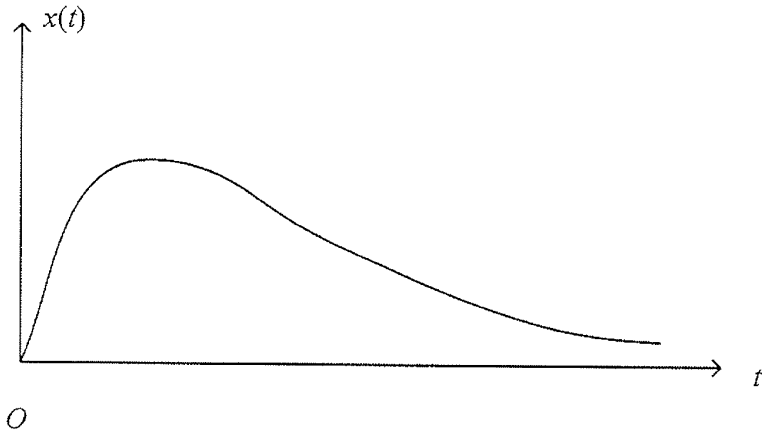


FIG. 24D

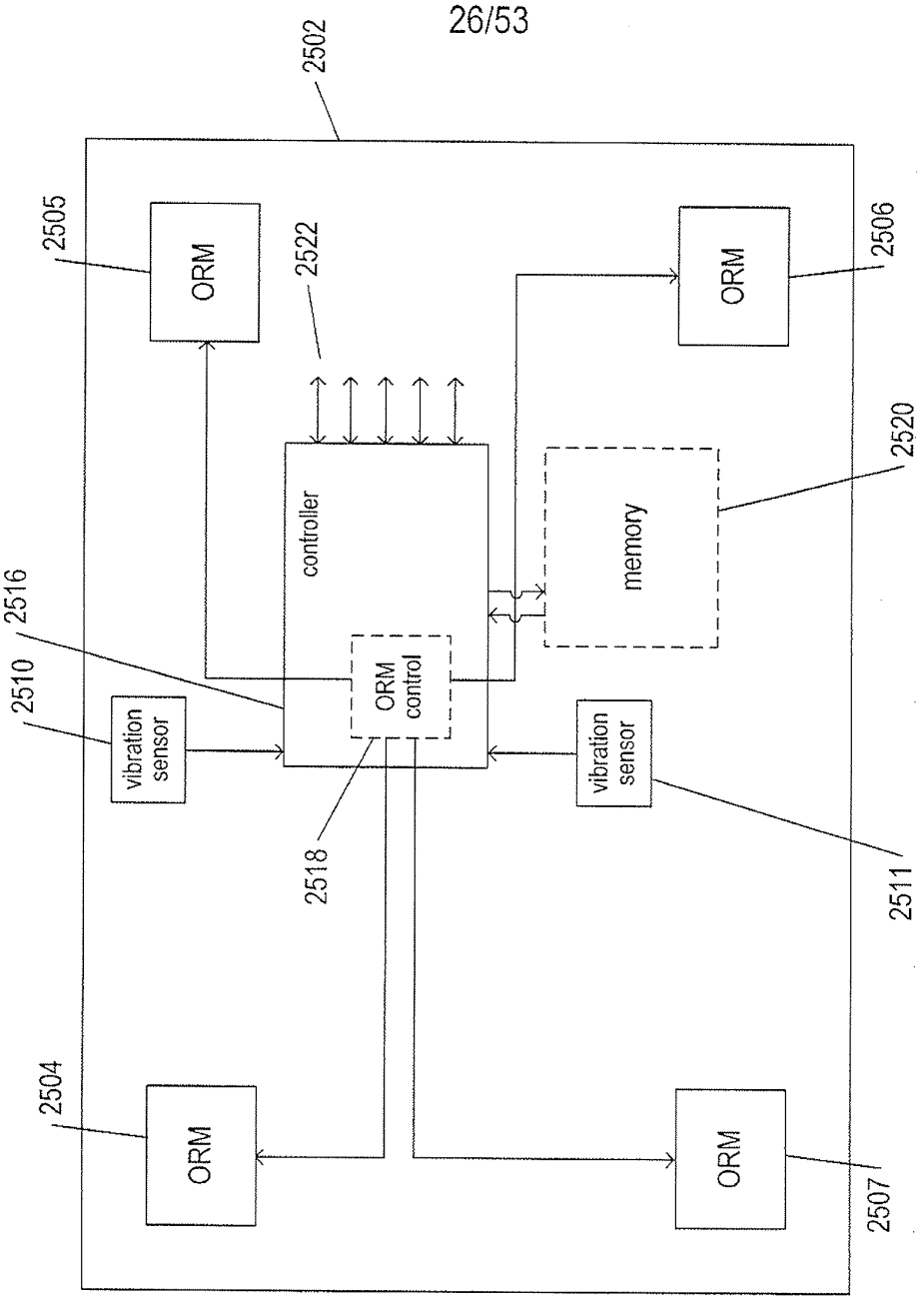

2502
2505
ORM
2522
2506
ORM
2520
memory
controller
2516
2510
ORM control
vibration sensor
vibration sensor
2518
2511
2504
ORM
ORM
2507

FIG. 25

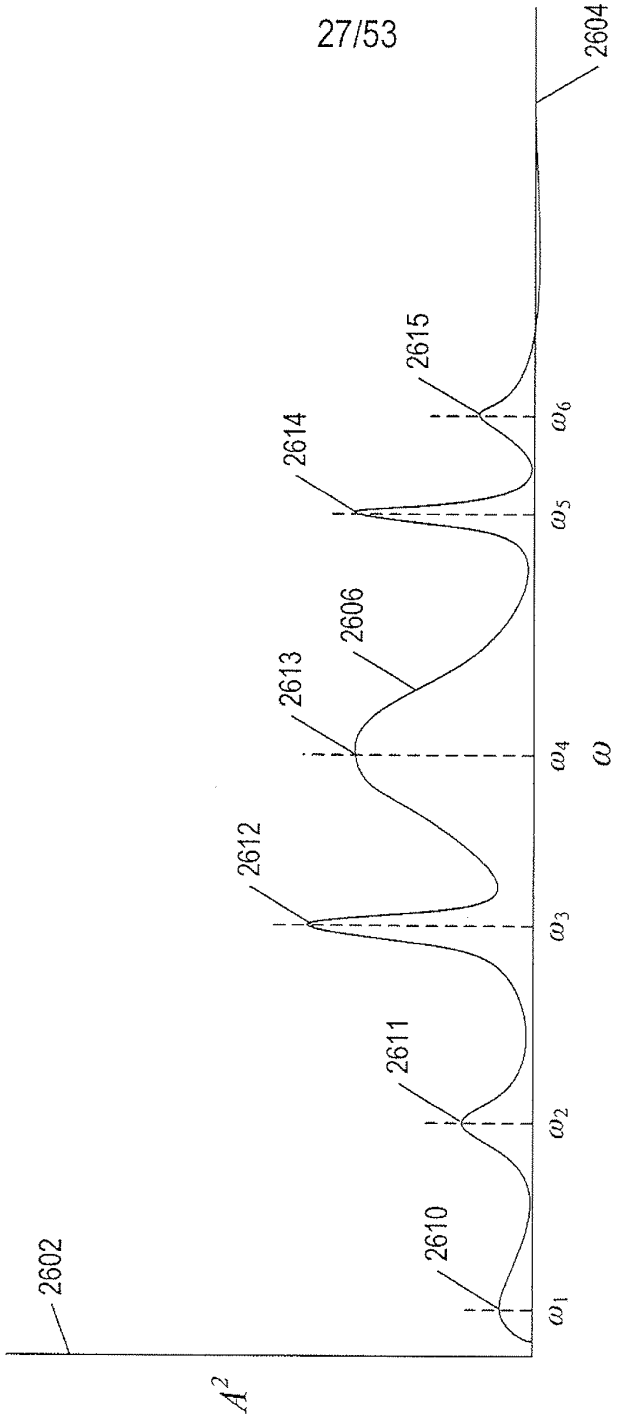

2602
2604
2610
2611
2612
2613
2606
2614
2615
ω_1
ω_2
ω_3
ω_4
ω_5
ω_6
ω
A^2

FIG. 26A

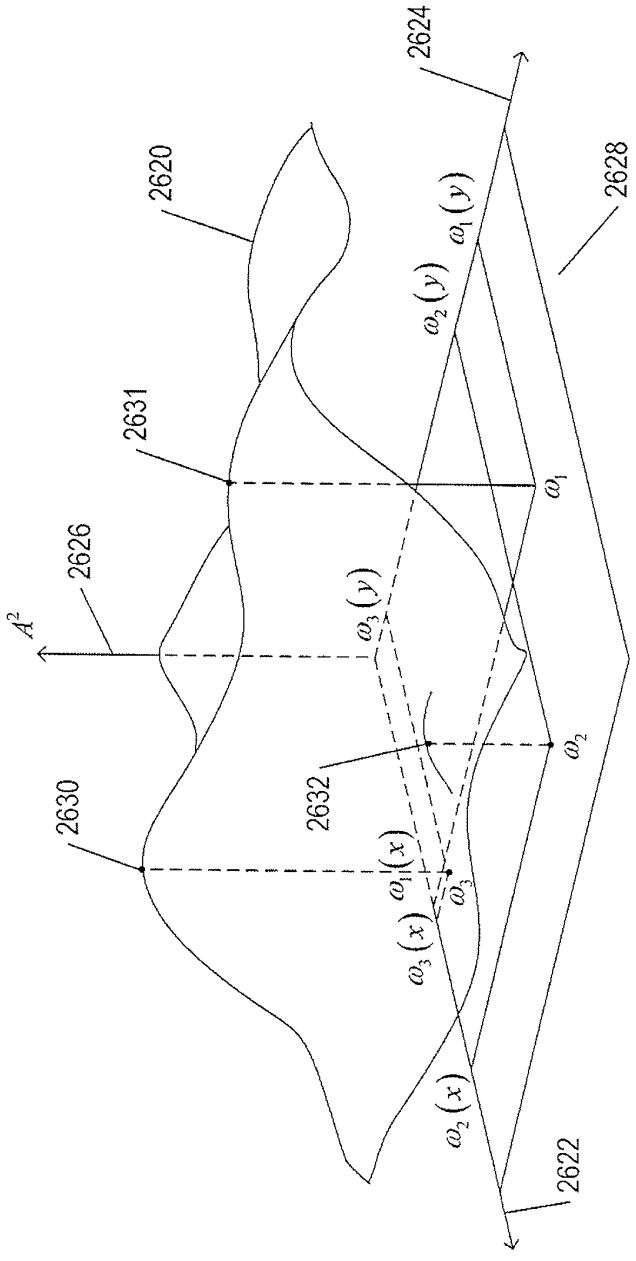

2624
2620
2628
2631
2626
2630
2632
2622
A^2
$\omega_1(y)$
$\omega_2(y)$
$\omega_3(y)$
ω_1
ω_2
ω_3
$\omega_1(x)$
$\omega_3(x)$
$\omega_2(x)$
2634
$\omega_1(x,y)$
$\omega_2(x,y)$
$\omega_3(x,y)$

FIG. 26B

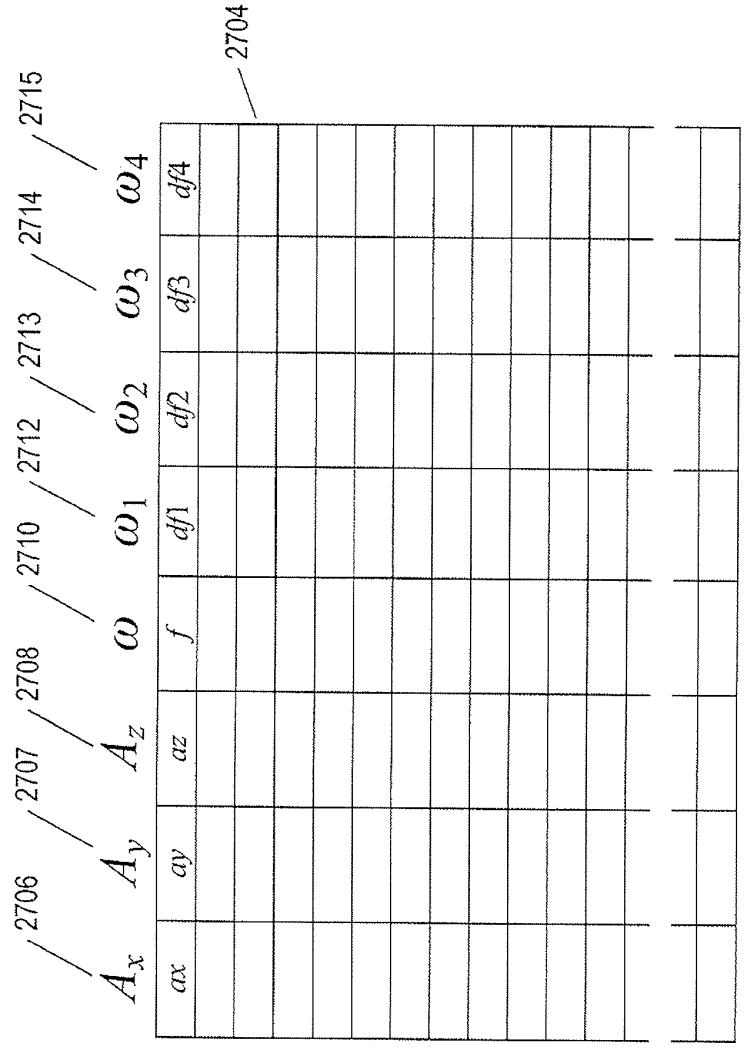

2704
2715
2714
2713
2712
2710
2708
2707
2706
2702
ω_4
ω_3
ω_2
ω_1
ω
A_z
A_y
A_x
df4
df3
df2
df1
f
az
ay
ax

FIG. 27

FIG. 28A

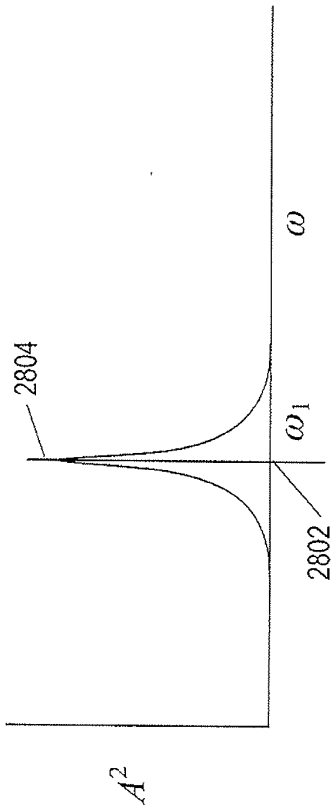


FIG. 28B

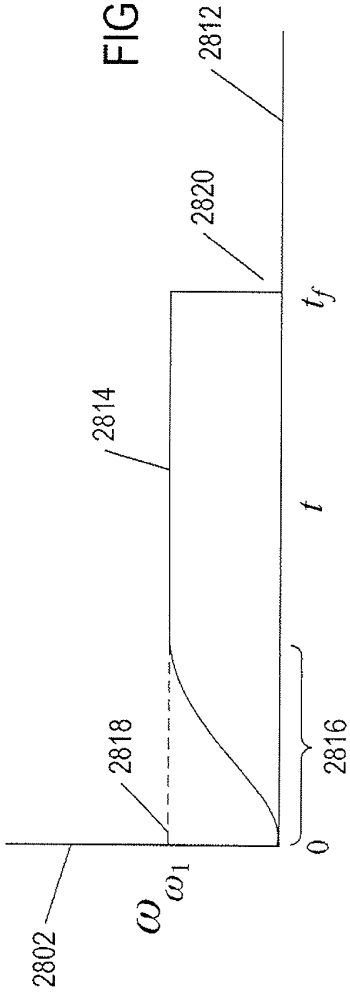
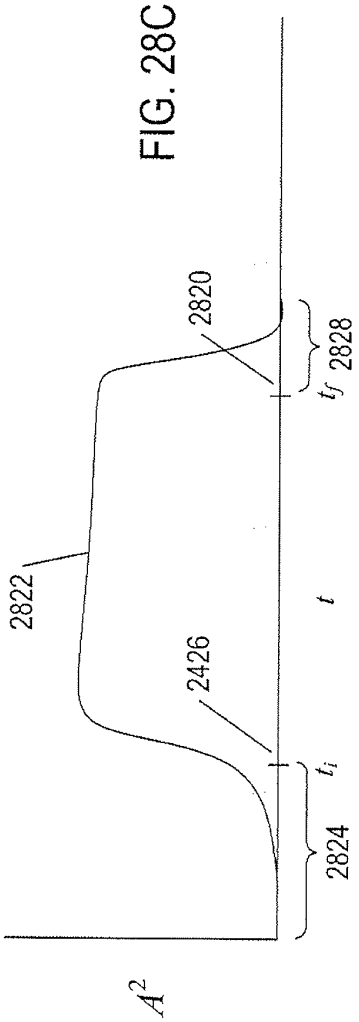


FIG. 28C



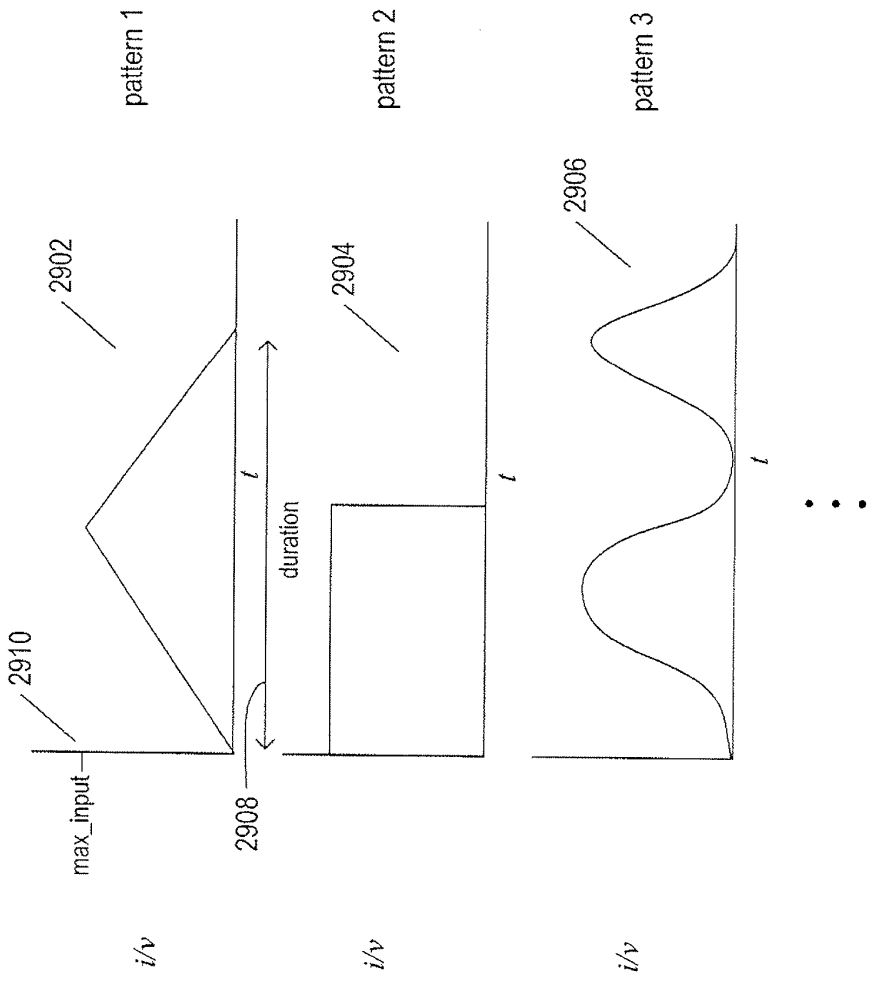

pattern 1
pattern 2
pattern 3
2902
2904
2906
2910
2908
max_input
duration
t
t
t
i/v
i/v
i/v

FIG. 29

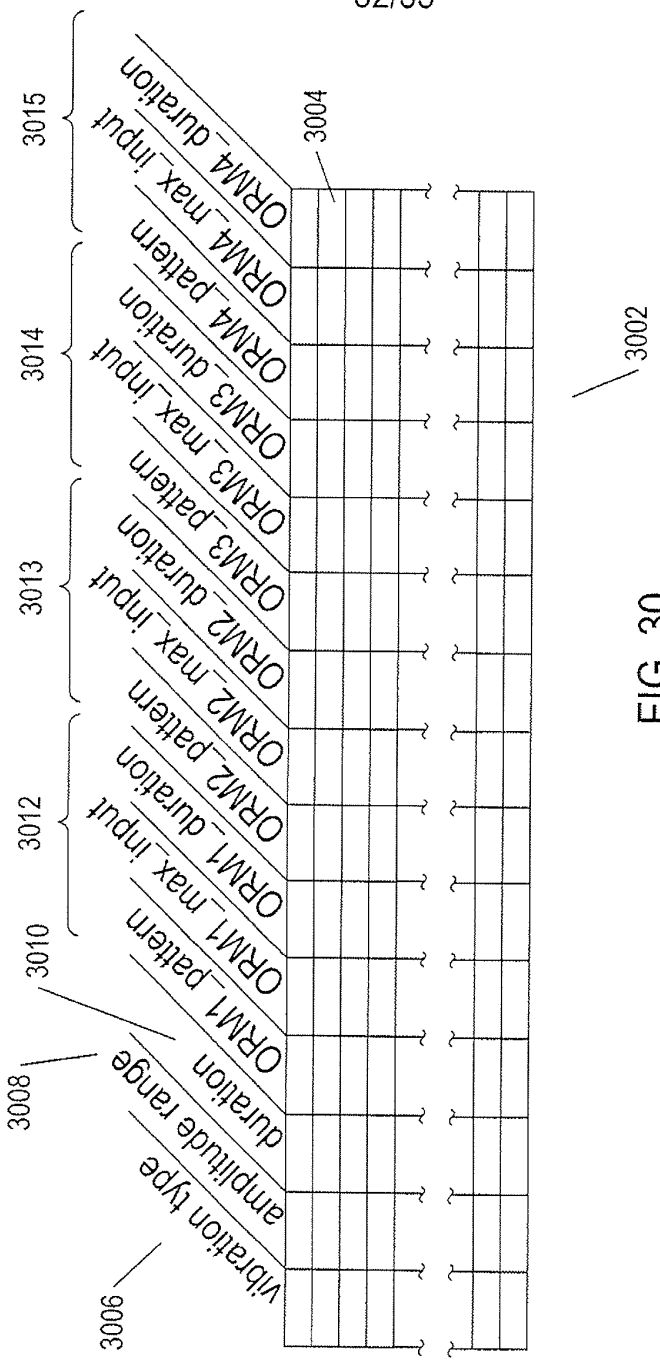

3015
3014
3013
3012
3010
3008
3006
3004
3002
ORM4_duration
ORM4_max_input
ORM4_pattern
ORM3_duration
ORM3_max_input
ORM3_pattern
ORM2_duration
ORM2_max_input
ORM2_pattern
ORM1_duration
ORM1_max_input
ORM1_pattern
duration
amplitude range
vibration type

FIG. 30

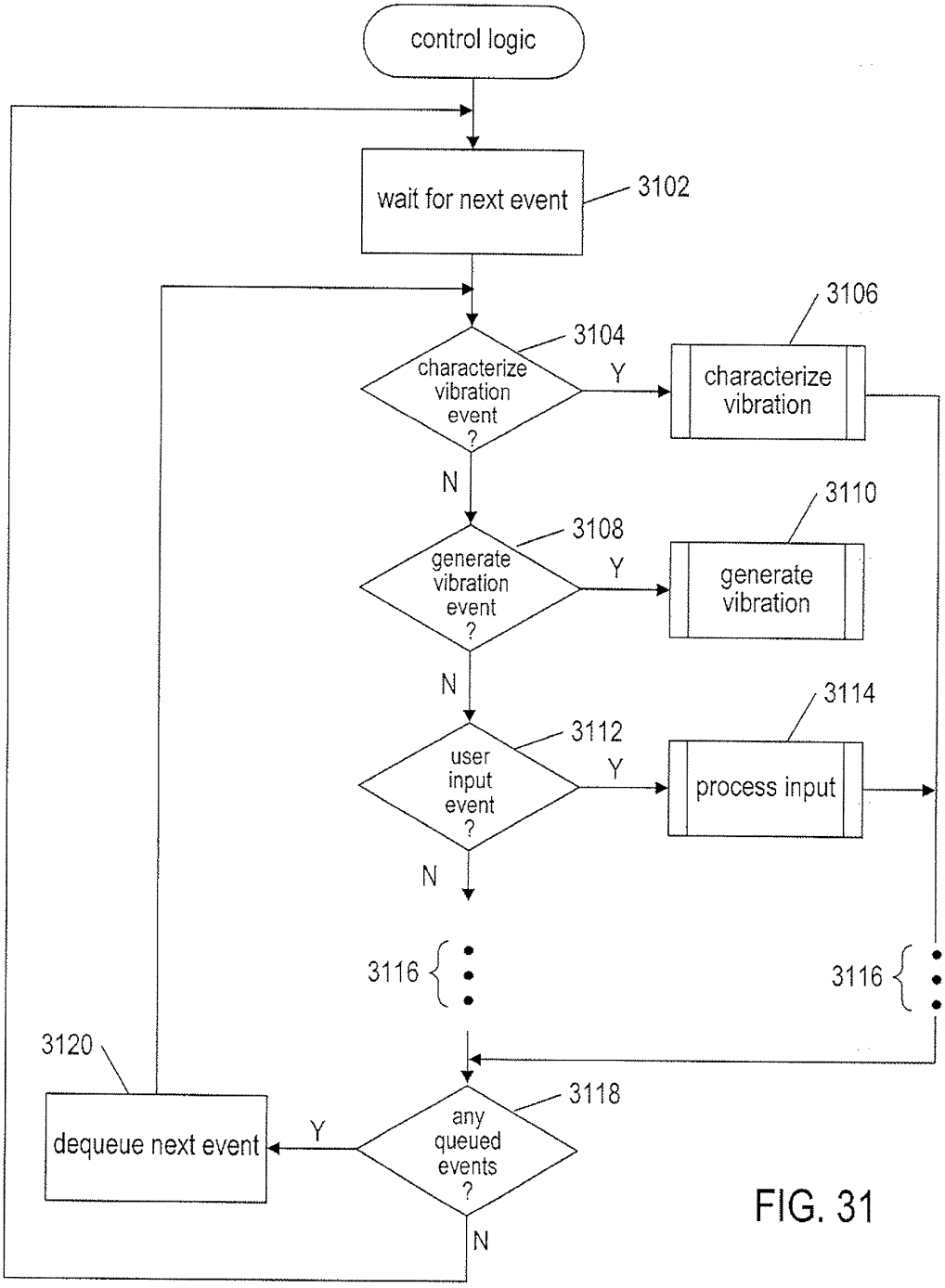

control logic
wait for next event
3102
characterize vibration event ?
3104
Y
N
characterize vibration
3106
generate vibration event ?
3108
Y
N
generate vibration
3110
user input event ?
3112
Y
N
process input
3114
3116
3116
any queued events ?
3118
Y
N
dequeue next event
3120

FIG. 31

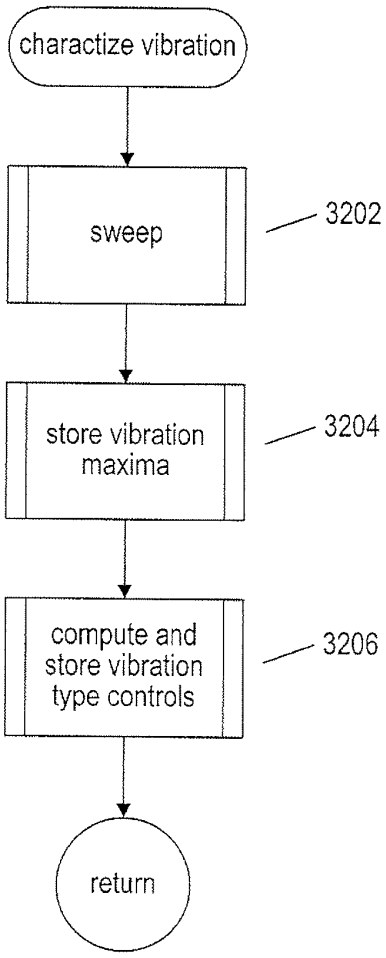

charactize vibration
sweep
3202
store vibration maxima
3204
compute and store vibration type controls
3206
return

FIG. 32

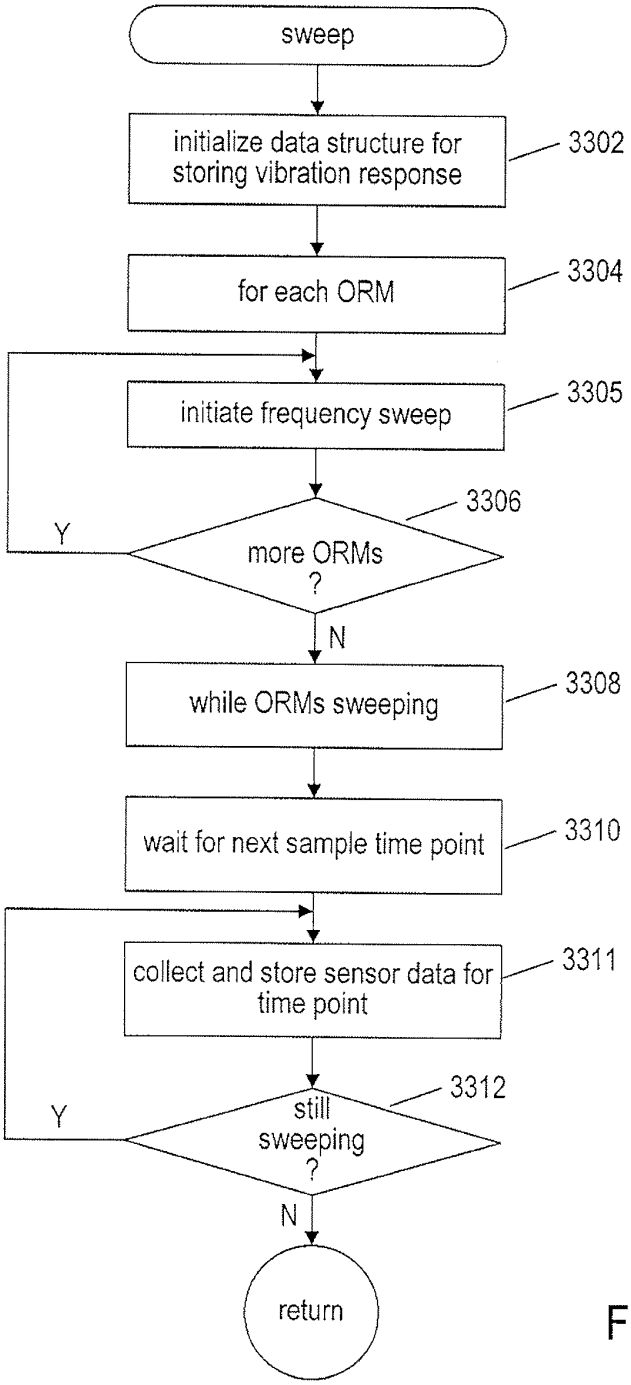

sweep
initialize data structure for storing vibration response
3302
for each ORM
3304
initiate frequency sweep
3305
3306
more ORMs ?
Y
N
while ORMs sweeping
3308
wait for next sample time point
3310
collect and store sensor data for time point
3311
3312
still sweeping ?
Y
N
return

FIG. 33

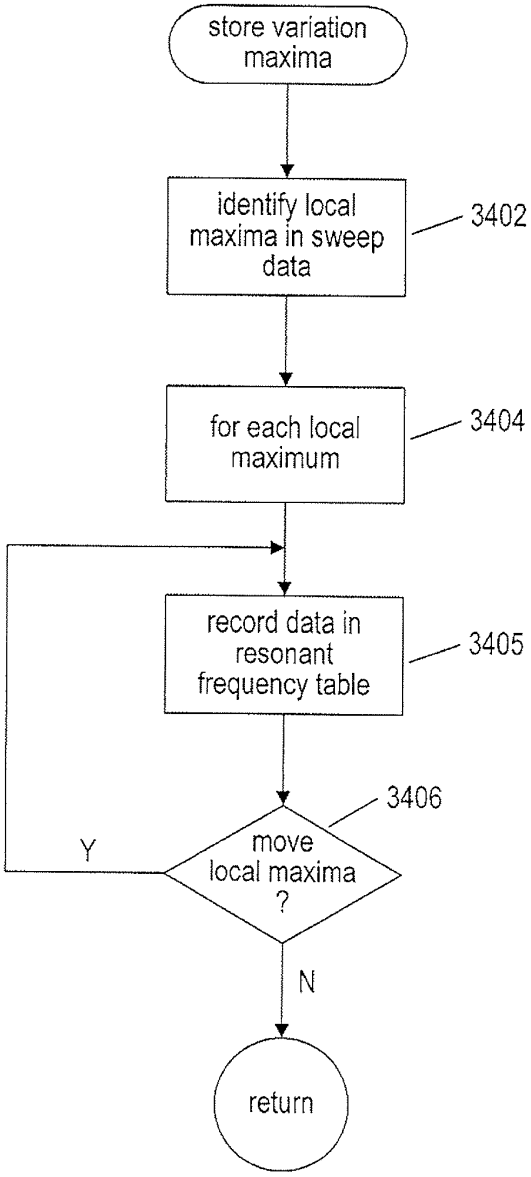

store variation maxima
identify local maxima in sweep data
3402
for each local maximum
3404
record data in resonant frequency table
3405
3406
move local maxima ?
Y
N
return

FIG. 34

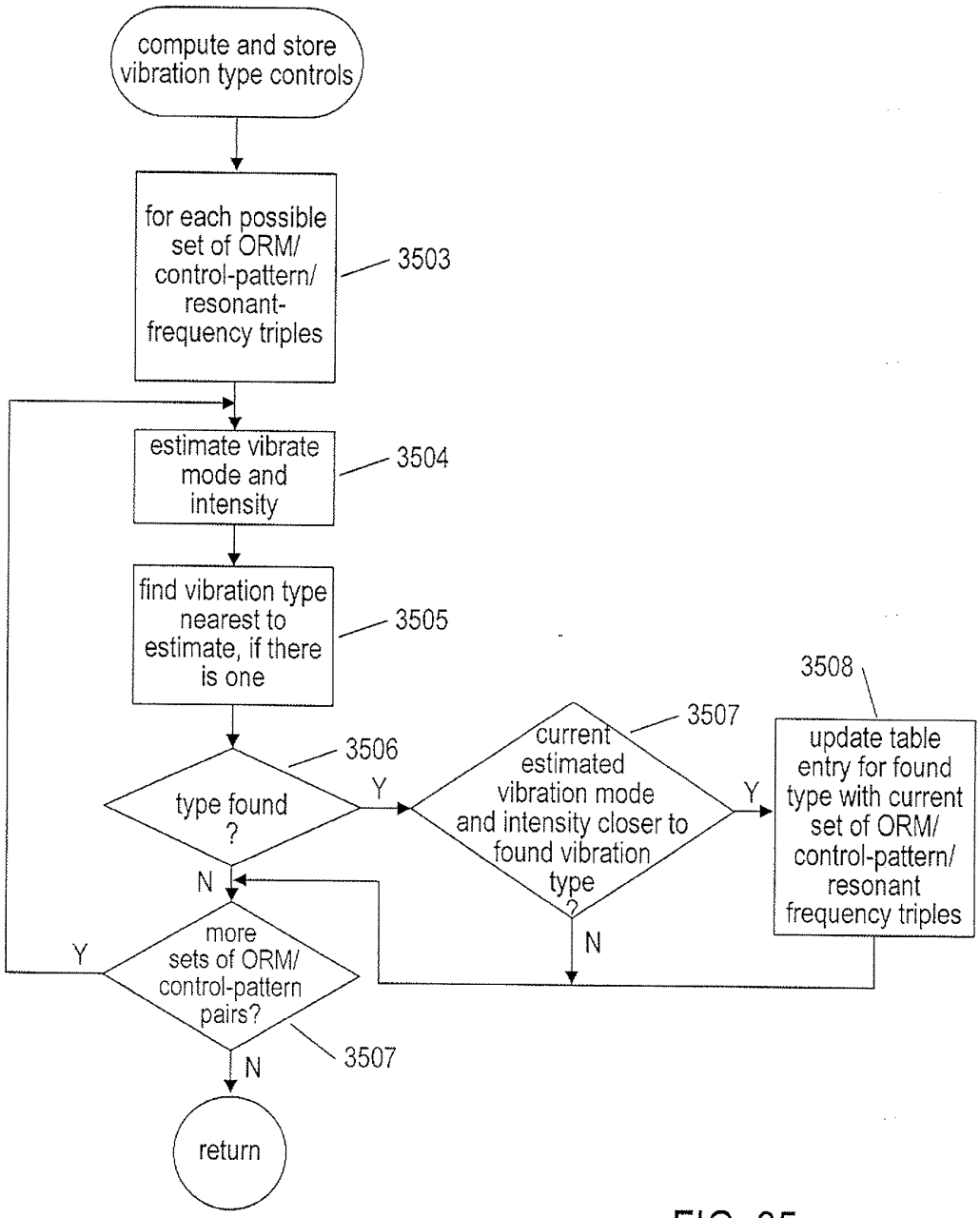

compute and store vibration type controls
for each possible set of ORM/ control-pattern/ resonant-frequency triples
3503
estimate vibrate mode and intensity
3504
find vibration type nearest to estimate, if there is one
3505
type found ?
3506
Y
N
current estimated vibration mode and intensity closer to found vibration type ?
3507
Y
N
update table entry for found type with current set of ORM/ control-pattern/ resonant frequency triples
3508
more sets of ORM/ control-pattern pairs?
Y
N
3507
return

FIG. 35

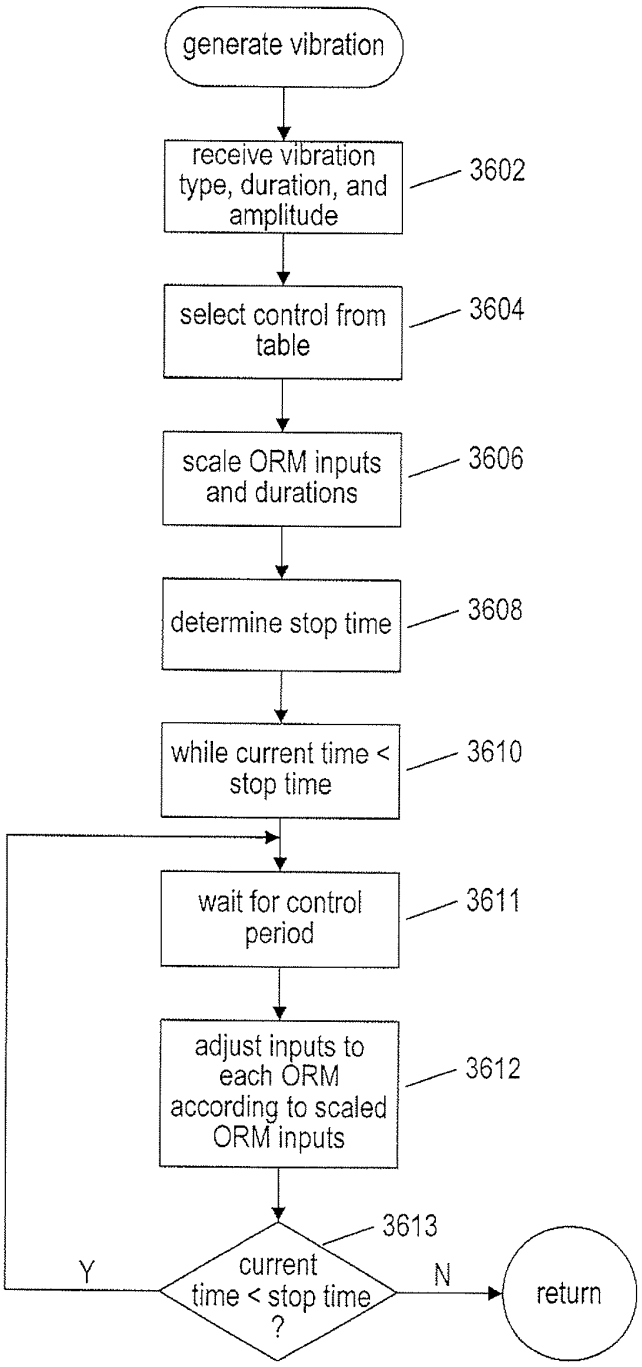

generate vibration
receive vibration type, duration, and amplitude
3602
select control from table
3604
scale ORM inputs and durations
3606
determine stop time
3608
while current time < stop time
3610
wait for control period
3611
adjust inputs to each ORM according to scaled ORM inputs
3612
3613
current time < stop time ?
Y
N
return

FIG. 36

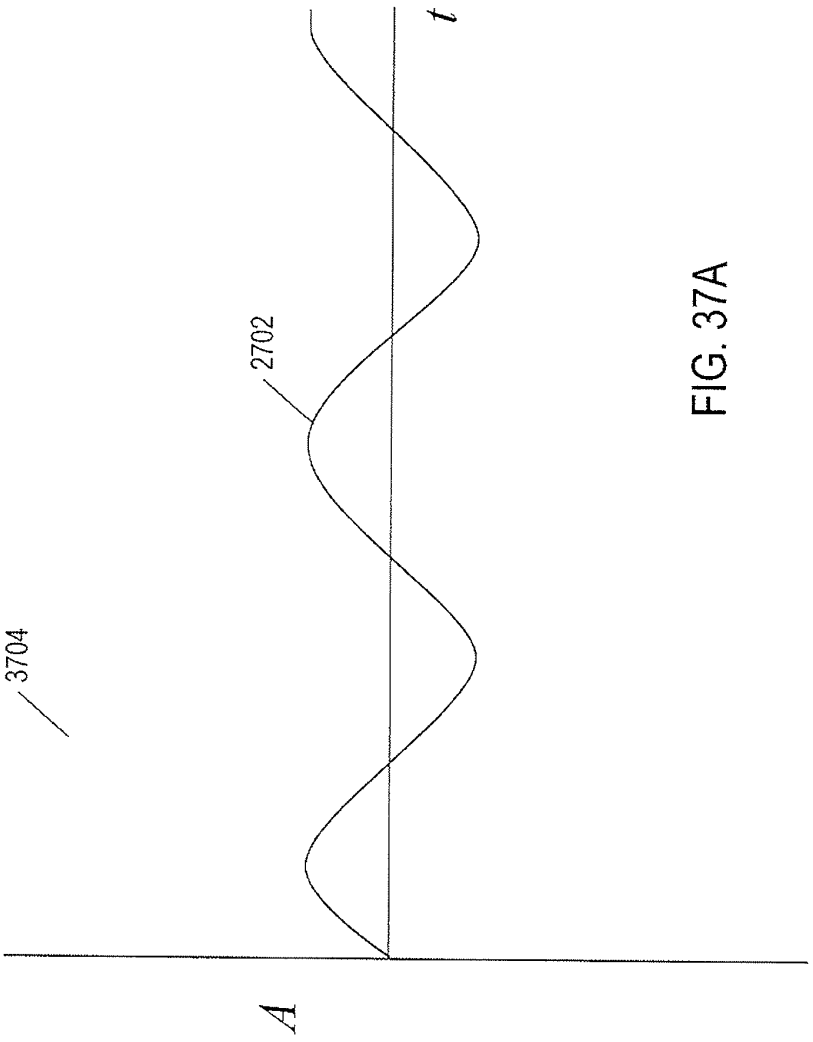


FIG. 37A

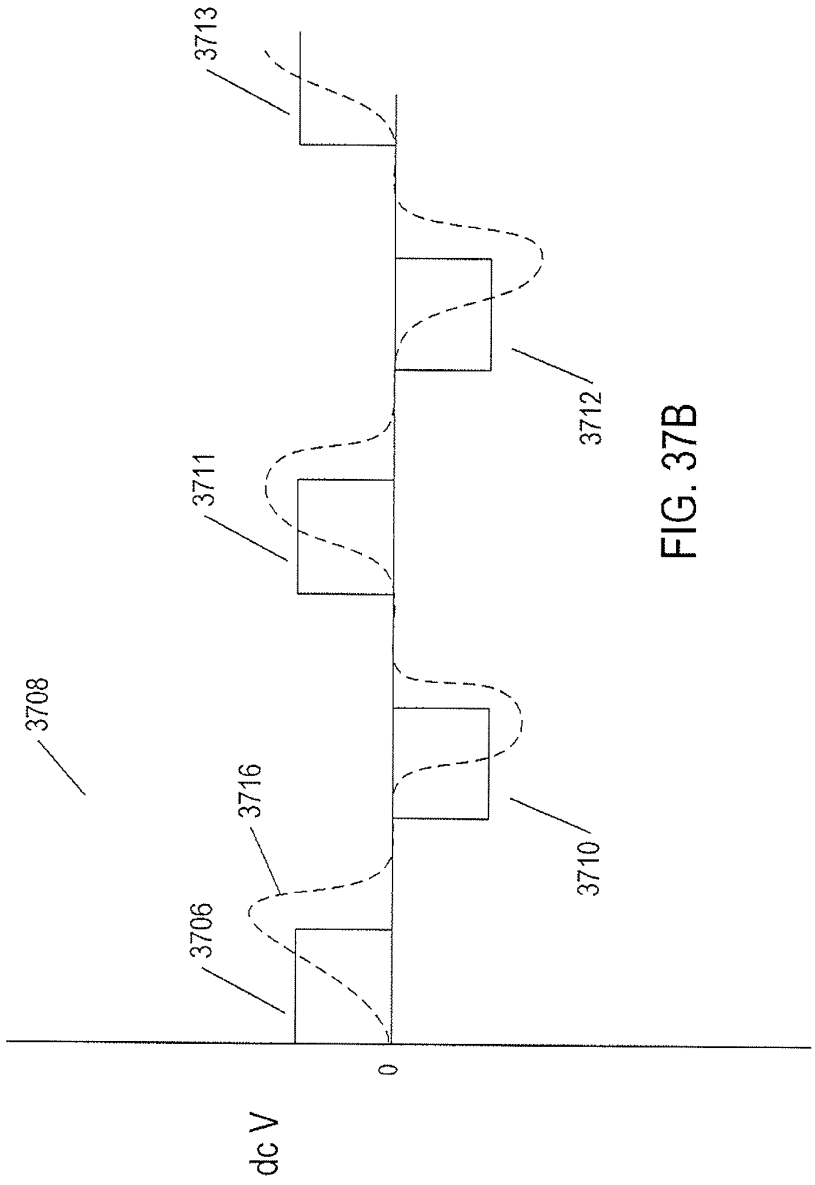


FIG. 37B

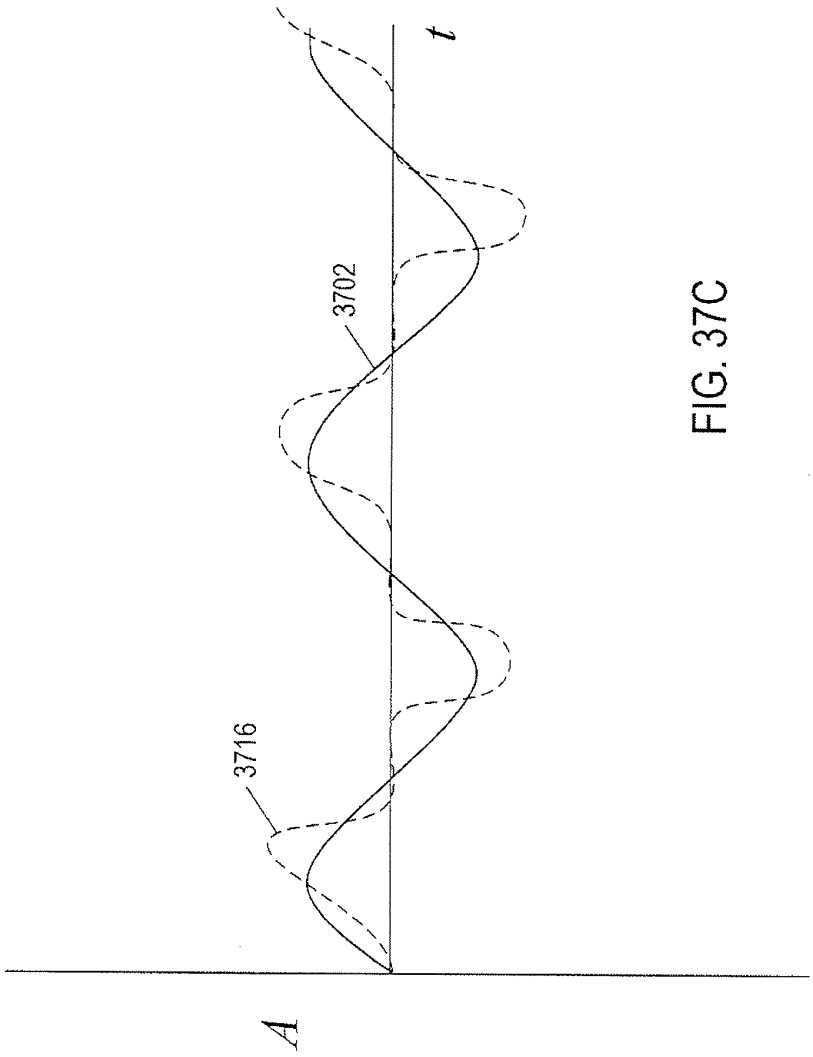


FIG. 37C

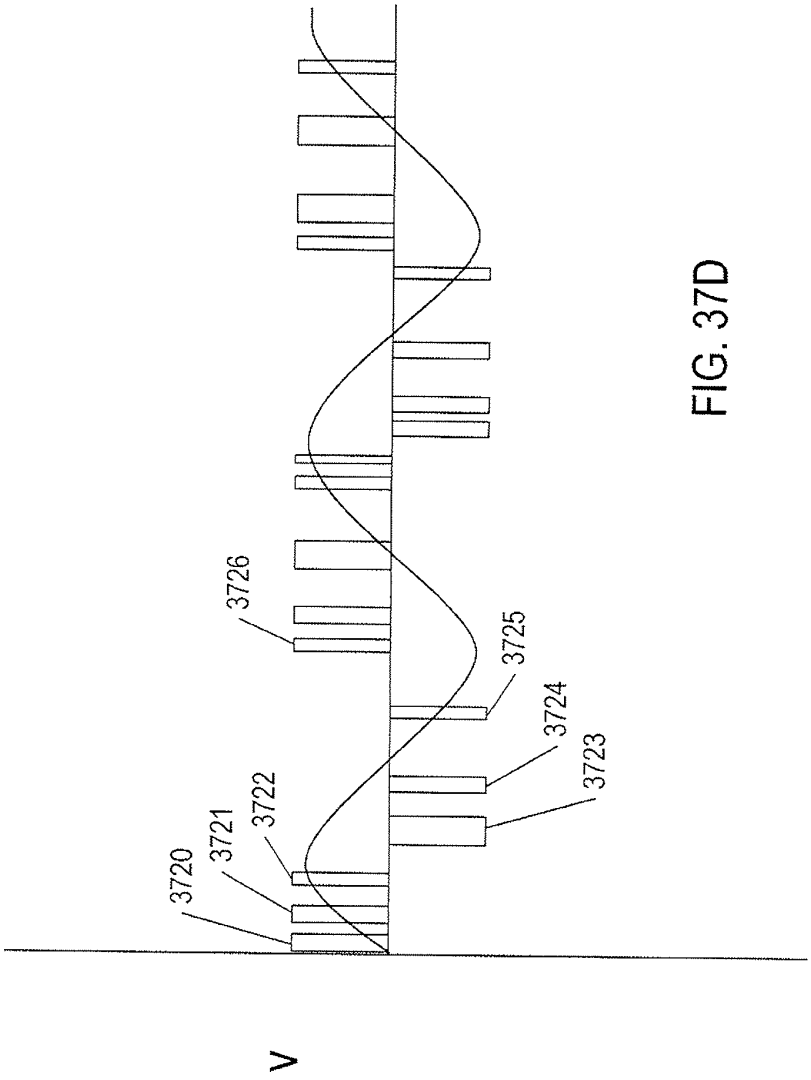


FIG. 37D

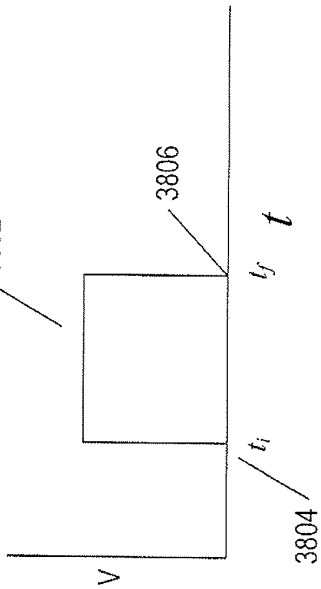


FIG. 38A

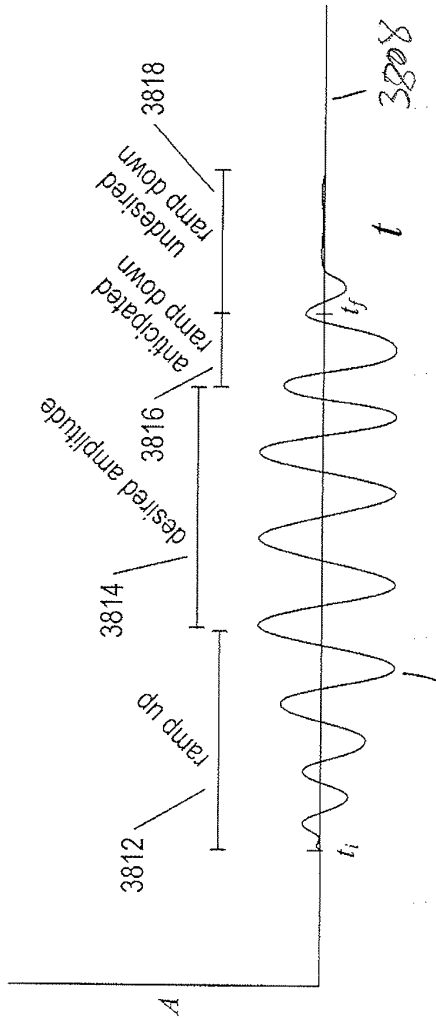


FIG. 38B

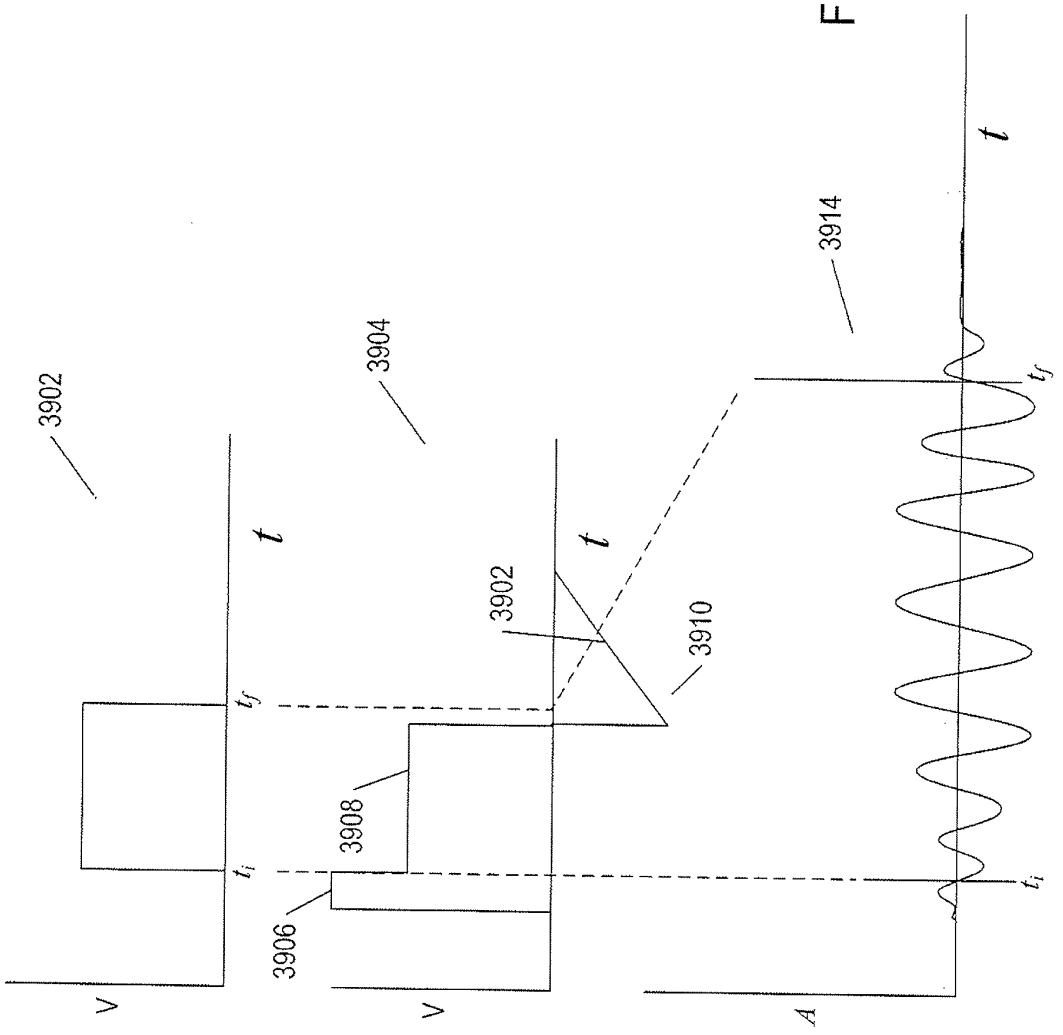


FIG. 39

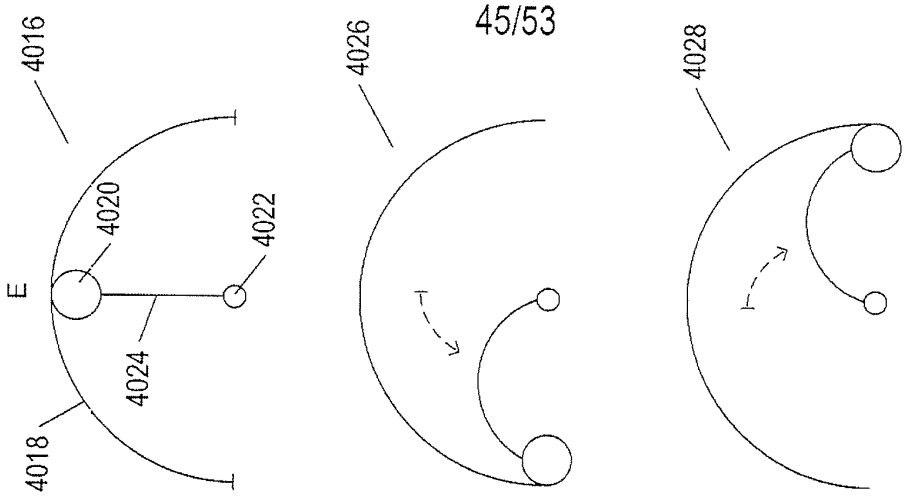


FIG. 40B

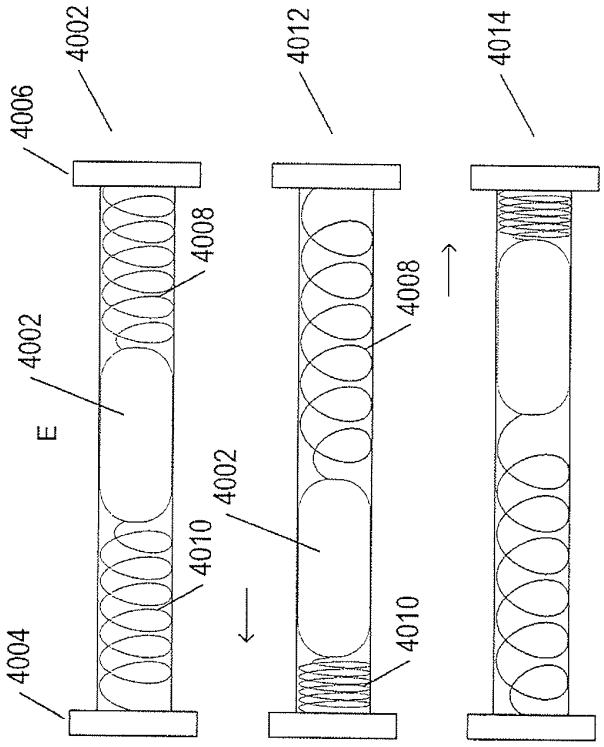


FIG. 40A

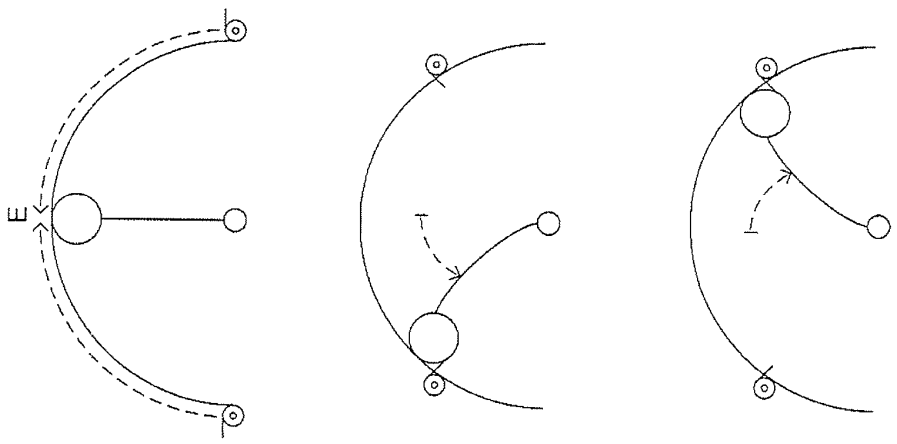


FIG. 40D

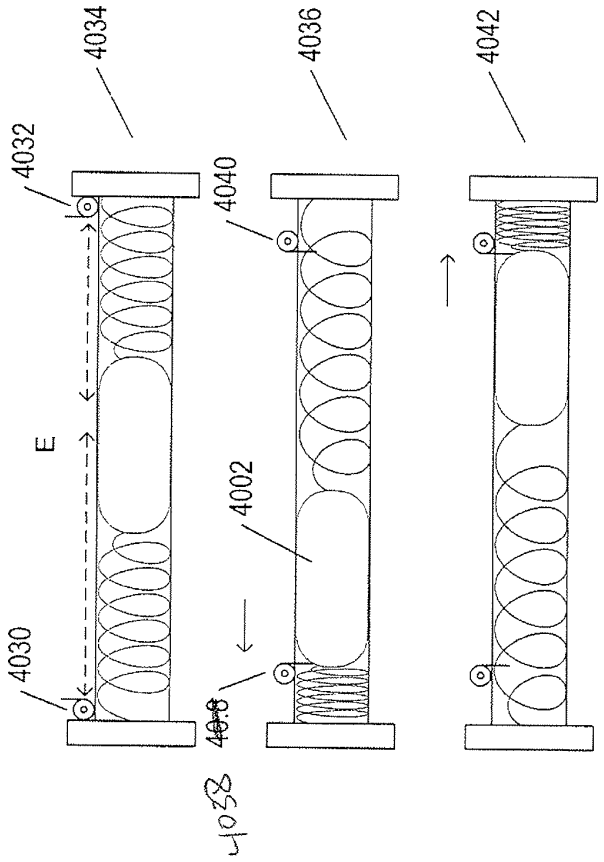


FIG. 40C

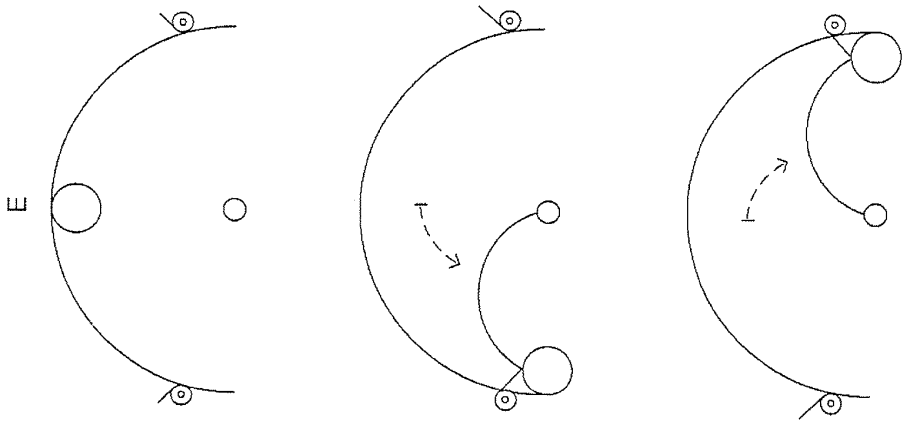


FIG. 40F

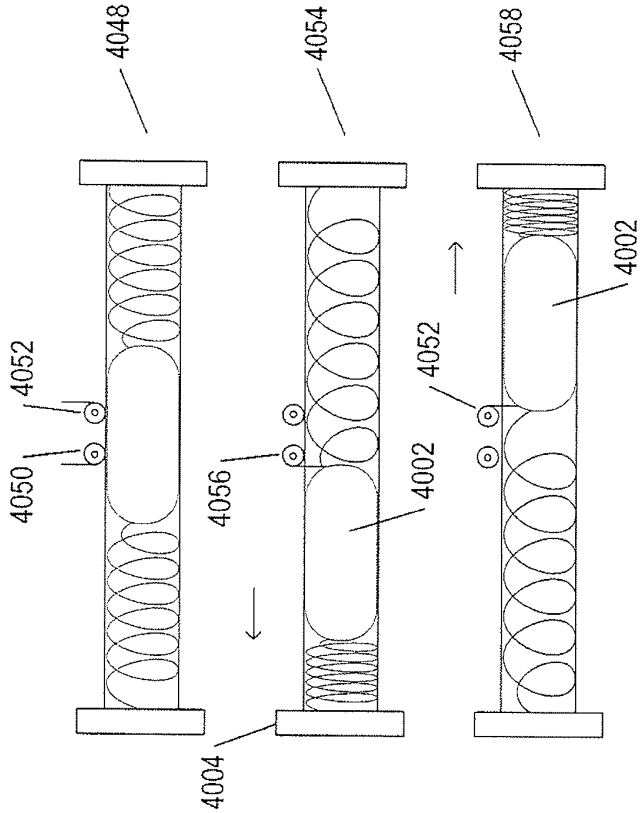


FIG. 40E

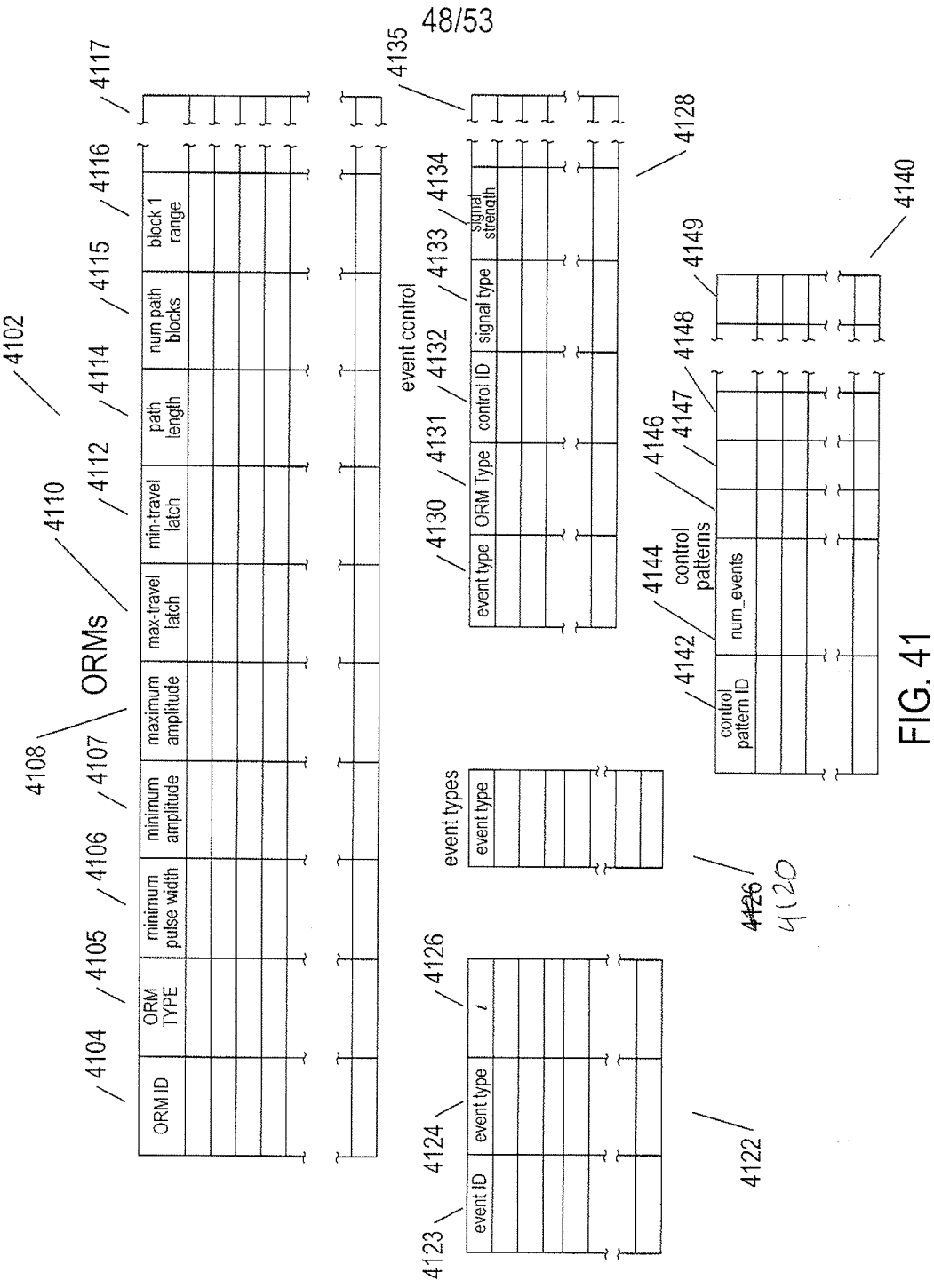

4102
ORMs
4104
ORM ID
4105
ORM TYPE
4106
minimum pulse width
4107
minimum amplitude
4108
maximum amplitude
4110
max-travel latch
4112
min-travel latch
4114
path length
4115
num path blocks
4116
block 1 range
4117
4135
event control
4130
event type
4131
ORM Type
4132
control ID
4133
signal type
4134
signal strength
4128
4140
4149
4148
4147
4146
4144
control patterns
4142
control pattern ID
num_events
4120
4126
event types
event type
4122
4124
event ID
event type
t
4123

FIG. 41

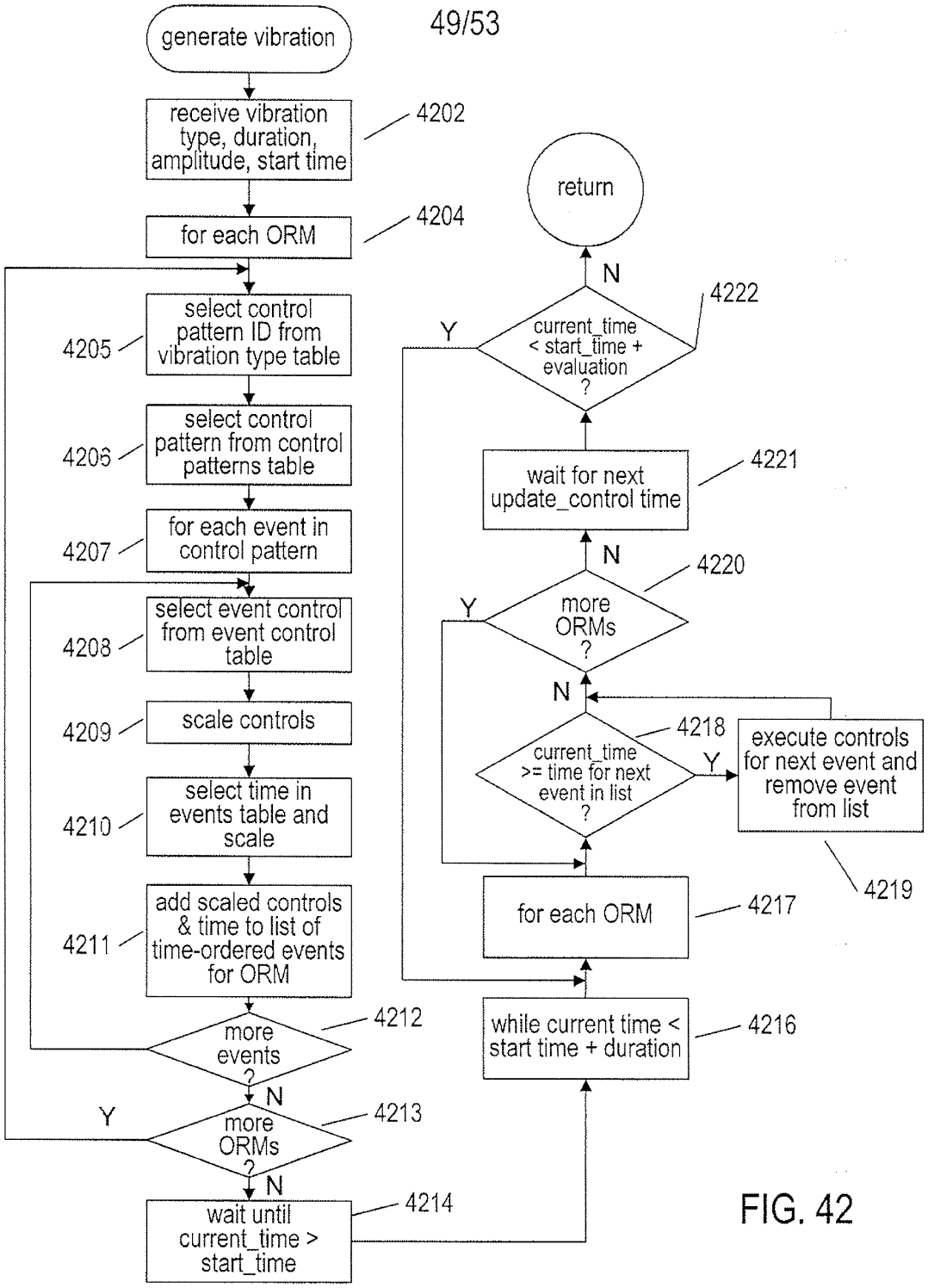

generate vibration
receive vibration type, duration, amplitude, start time
4202
for each ORM
4204
select control pattern ID from vibration type table
4205
select control pattern from control patterns table
4206
for each event in control pattern
4207
select event control from event control table
4208
scale controls
4209
select time in events table and scale
4210
add scaled controls & time to list of time-ordered events for ORM
4211
more events ?
4212
N
Y
more ORMs ?
4213
N
wait until current_time > start_time
4214
while current time < start time + duration
4216
for each ORM
4217
current_time >= time for next event in list ?
4218
Y
execute controls for next event and remove event from list
4219
N
more ORMs ?
4220
Y
N
wait for next update_control time
4221
current_time < start_time + evaluation ?
4222
Y
N
return

FIG. 42

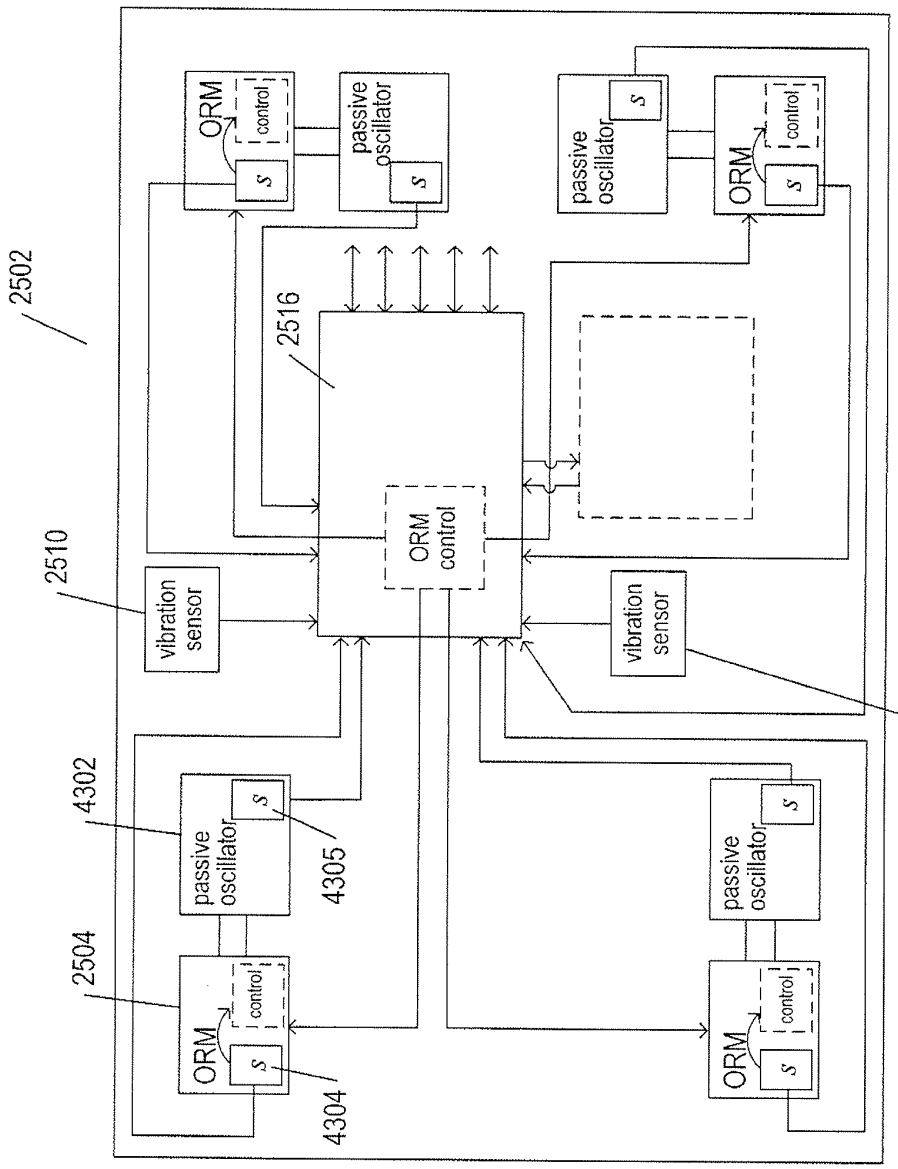

2502
2516
2510
ORM
control
s
passive oscillator
ORM control
vibration sensor
2511
4302
4305
2504
4304

FIG. 43

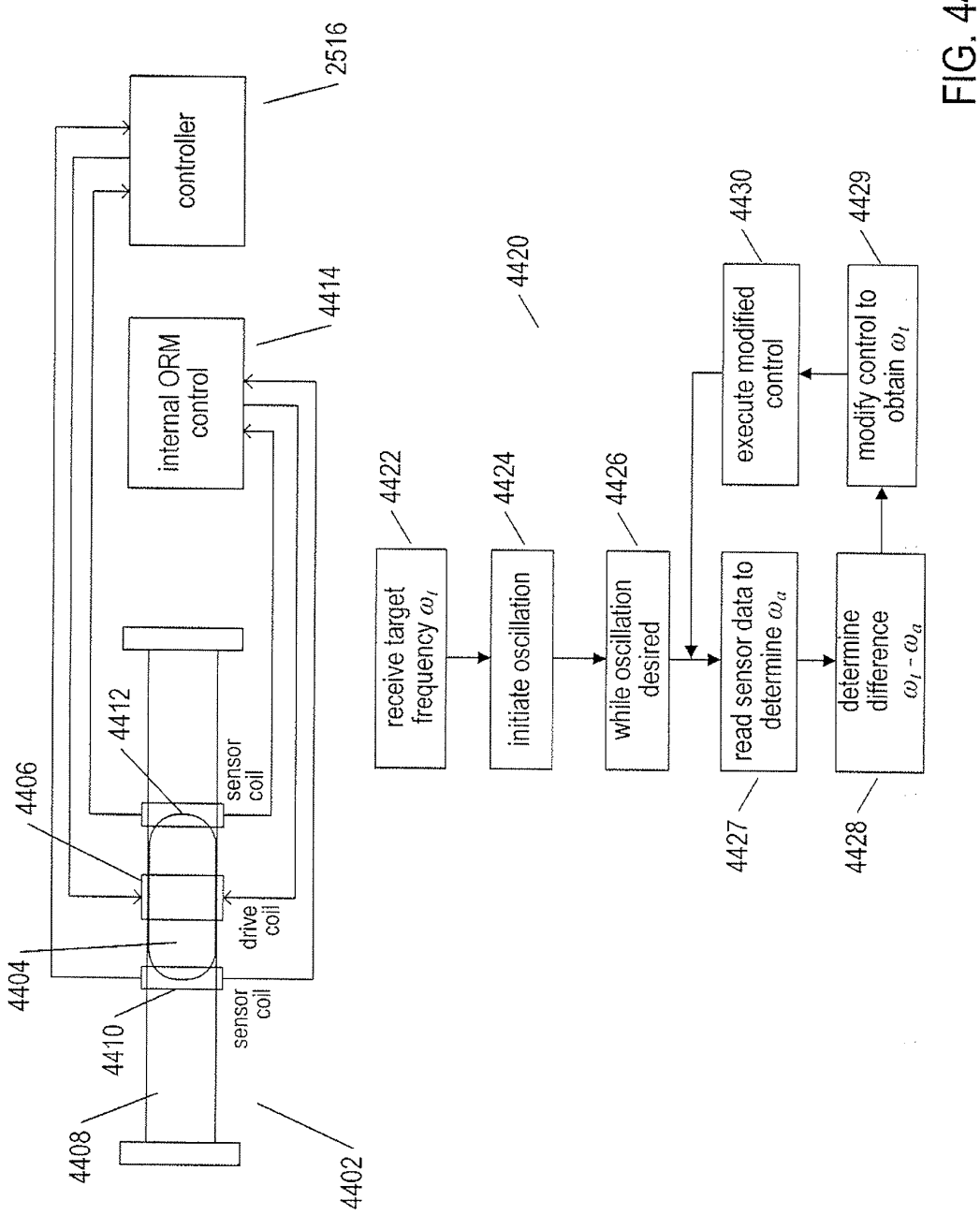

controller
2516
internal ORM control
4414
4420
4412
sensor coil
4406
drive coil
4404
sensor coil
4410
4408
4402
4422
receive target frequency ω_t
4424
initiate oscillation
4426
while oscillation desired
4427
read sensor data to determine ω_a
4428
determine difference $\omega_t - \omega_a$
4429
modify control to obtain ω_t
4430
execute modified control

FIG. 44

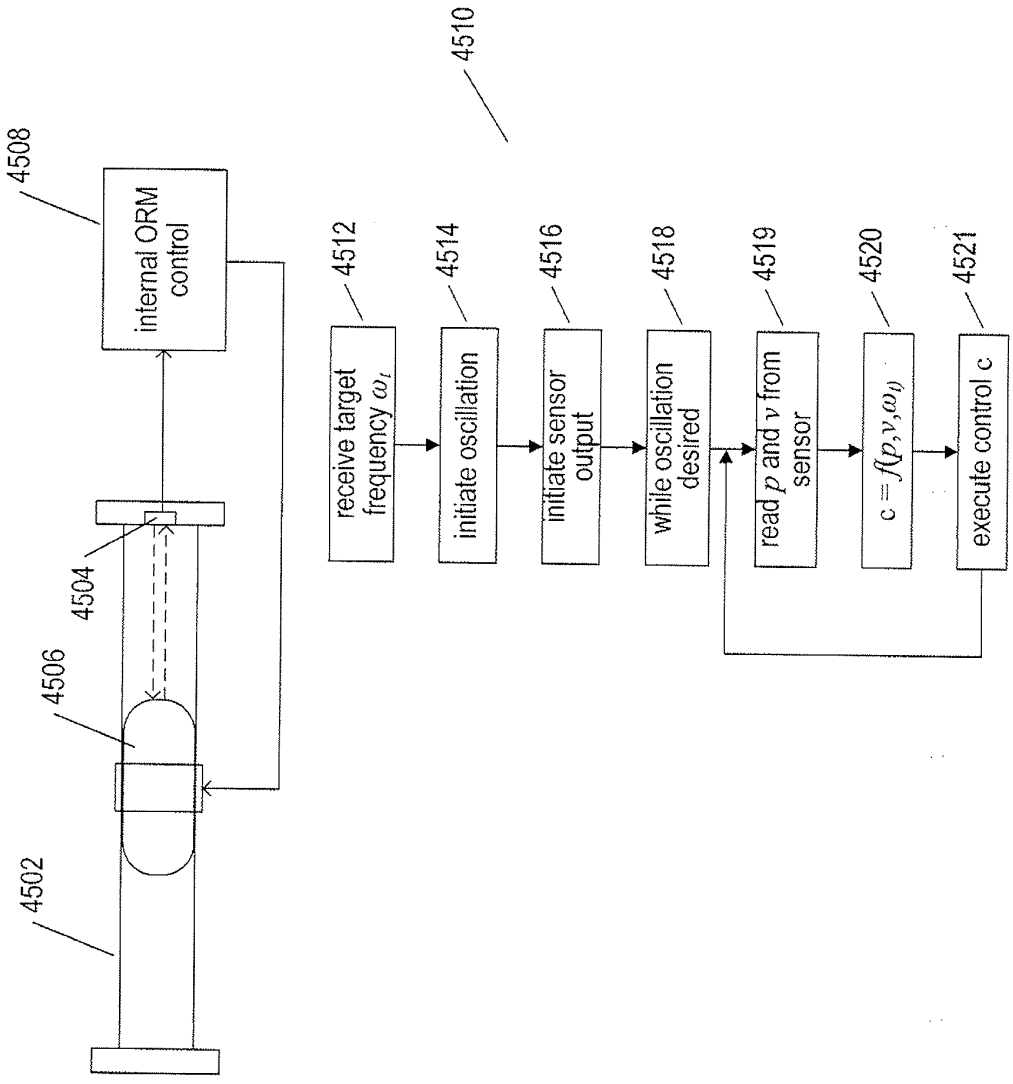

4508
internal ORM control
4504
4506
4502
4510
4512
receive target frequency ω_t
4514
initiate oscillation
4516
initiate sensor output
4518
while oscillation desired
4519
read p and v from sensor
4520
c = $f(p,v,\omega_t)$
4521
execute control c

FIG. 45

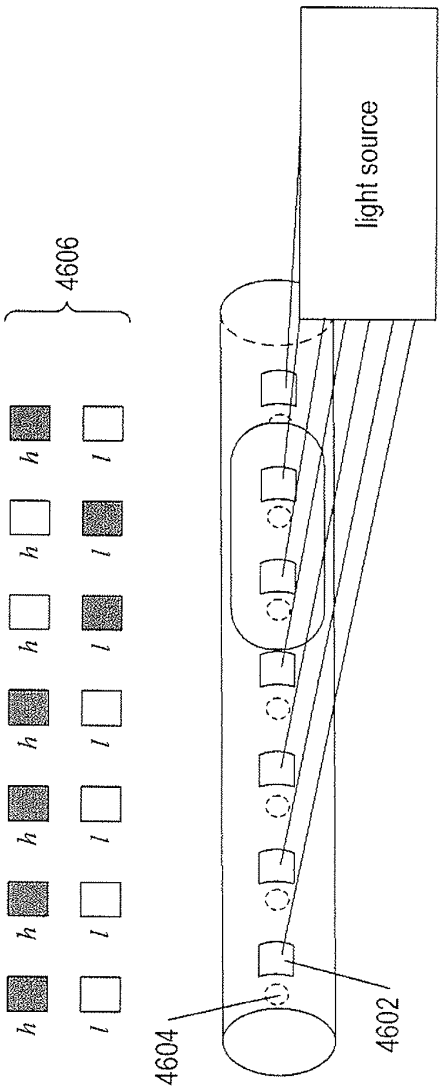


FIG. 46A

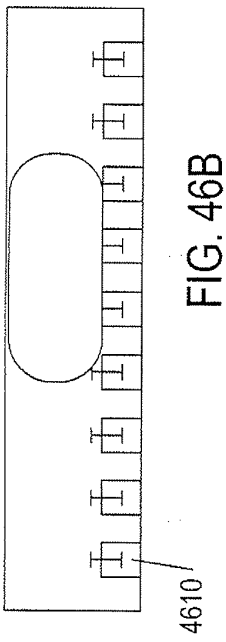


FIG. 46B

Electronic Acknowledgement Receipt	
EFS ID:	38746789
Application Number:	16806925
International Application Number:	
Confirmation Number:	7971
Title of Invention:	OSCILLATING-RESONANT-MODULE CONTROLLER
First Named Inventor/Applicant Name:	Robin Elenga
Customer Number:	34395
Filer:	Robert Walter Bergstrom/Joanne Bourguignon
Filer Authorized By:	Robert Walter Bergstrom
Attorney Docket Number:	35099.008C1
Receipt Date:	02-MAR-2020
Filing Date:	
Time Stamp:	18:45:43
Application Type:	Utility under 35 USC 111(a)

Payment information:

Submitted with Payment	no

File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		35099-008C1-E-APP.pdf	4313917 98359c6f35985a60d6fe1b250f847f734f71f868	yes	117

	Multipart Description/PDF files in .zip description		
	Document Description	**Start**	**End**
	Transmittal of New Application	1	1
	Application Data Sheet	2	9
	Specification	10	59
	Claims	60	63
	Abstract	64	64
	Drawings-only black and white line drawings	65	117
Warnings:			
Information:			
	Total Files Size (in bytes):	4313917	

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.
National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.
New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.