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(54) SURFACE PROFILE MEASURING INSTRUMENT

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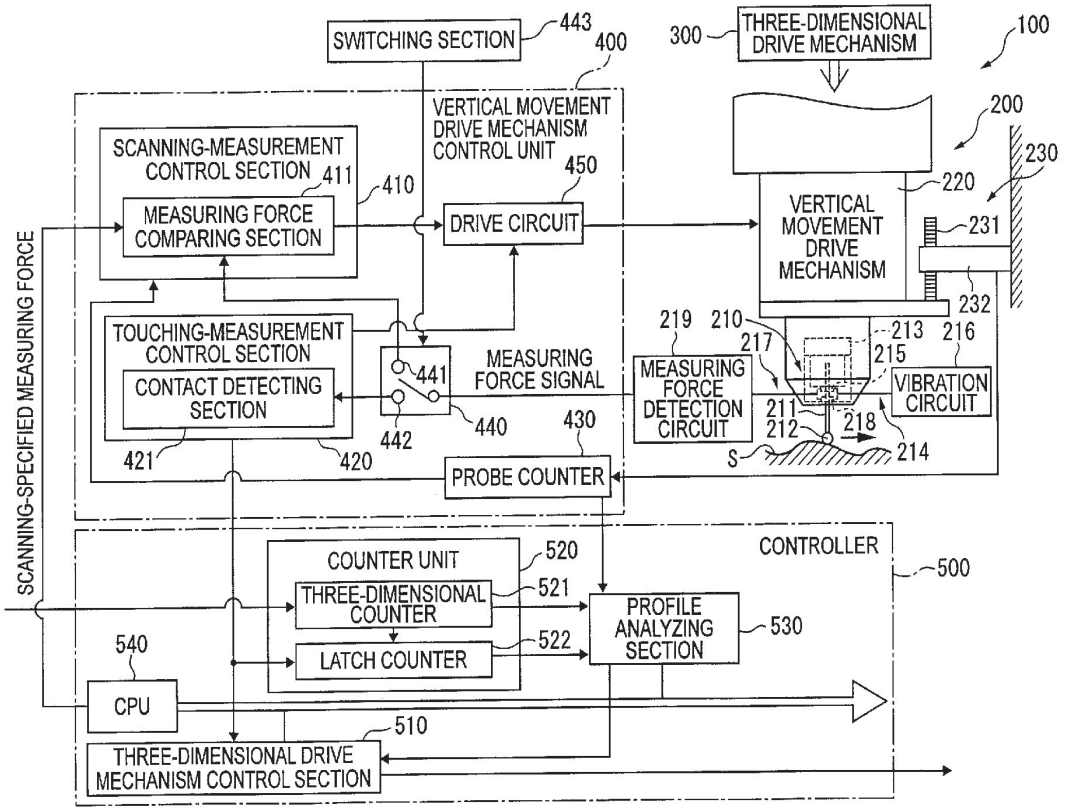
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(57) **ABSTRACT**

Provided are a measuring section (**210**) including a vibrating contact-type probe having a measuring force detection circuit (**219**) which detects a measuring force acting to the contact portion (**212**); a moving unit (a three-dimensional drive mechanism (**300**), a vertical movement drive mechanism (**220**)) that moves the measuring section (**210**) relative to a workpiece surface (S); and a drive control unit (**400**) that controls the moving unit based on the magnitude of the measuring force output from the measuring force detection circuit (**219**). The drive control unit (**400**) includes: a scanning-measurement control section (**410**) that moves for scanning the contact portion along the workpiece surface (S) with the measuring force maintained at the designated scanning measuring force; and a touching-measurement control section (**420**) that conducts touching-measurements on the workpiece surface (S) in a repeated manner, in the measurements the contact portion (**212**) being adapted to intermittently contact the workpiece surface (S) at a touch detecting measuring force.



Shenzhen Tuozhu 1012

FIG. 1

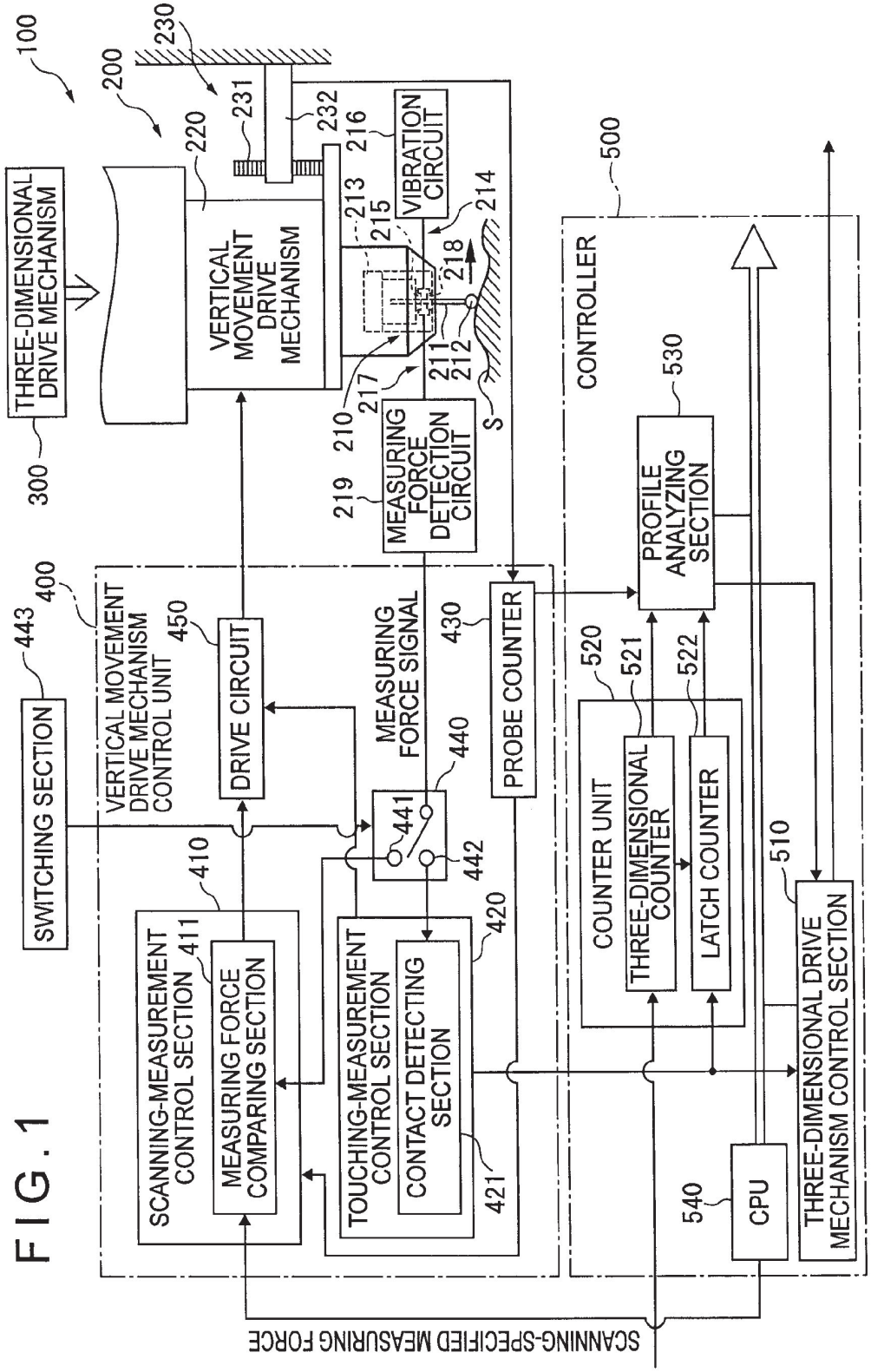

100
200
230
231
232
220
216
VIBRATION CIRCUIT
213
215
214
218
211
212
S
217
210
219
MEASURING FORCE DETECTION CIRCUIT
THREE-DIMENSIONAL DRIVE MECHANISM
300
VERTICAL MOVEMENT DRIVE MECHANISM
CONTROLLER
500
530
PROFILE ANALYZING SECTION
443
400
VERTICAL MOVEMENT DRIVE MECHANISM CONTROL UNIT
450
DRIVE CIRCUIT
MEASURING FORCE SIGNAL
430
PROBE COUNTER
520
521
522
SWITCHING SECTION
440
441
442
410
420
COUNTER UNIT
THREE-DIMENSIONAL COUNTER
LATCH COUNTER
SCANNING-MEASUREMENT CONTROL SECTION
411
MEASURING FORCE COMPARING SECTION
TOUCHING-MEASUREMENT CONTROL SECTION
CONTACT DETECTING SECTION
421
510
540
CPU
THREE-DIMENSIONAL DRIVE MECHANISM CONTROL SECTION
SCANNING-SPECIFIED MEASURING FORCE

FIG. 2

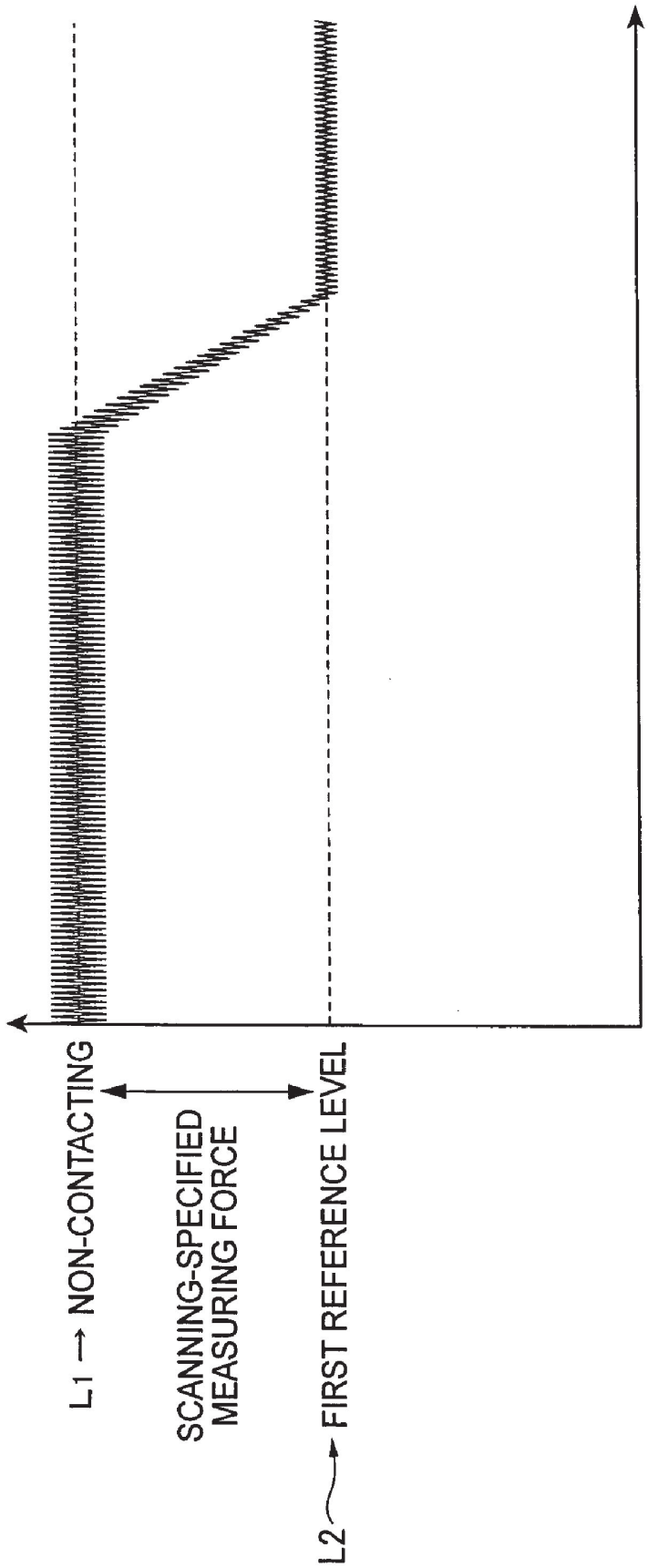

L1 → NON-CONTACTING
SCANNING-SPECIFIED MEASURING FORCE
L2 → FIRST REFERENCE LEVEL

FIG. 3

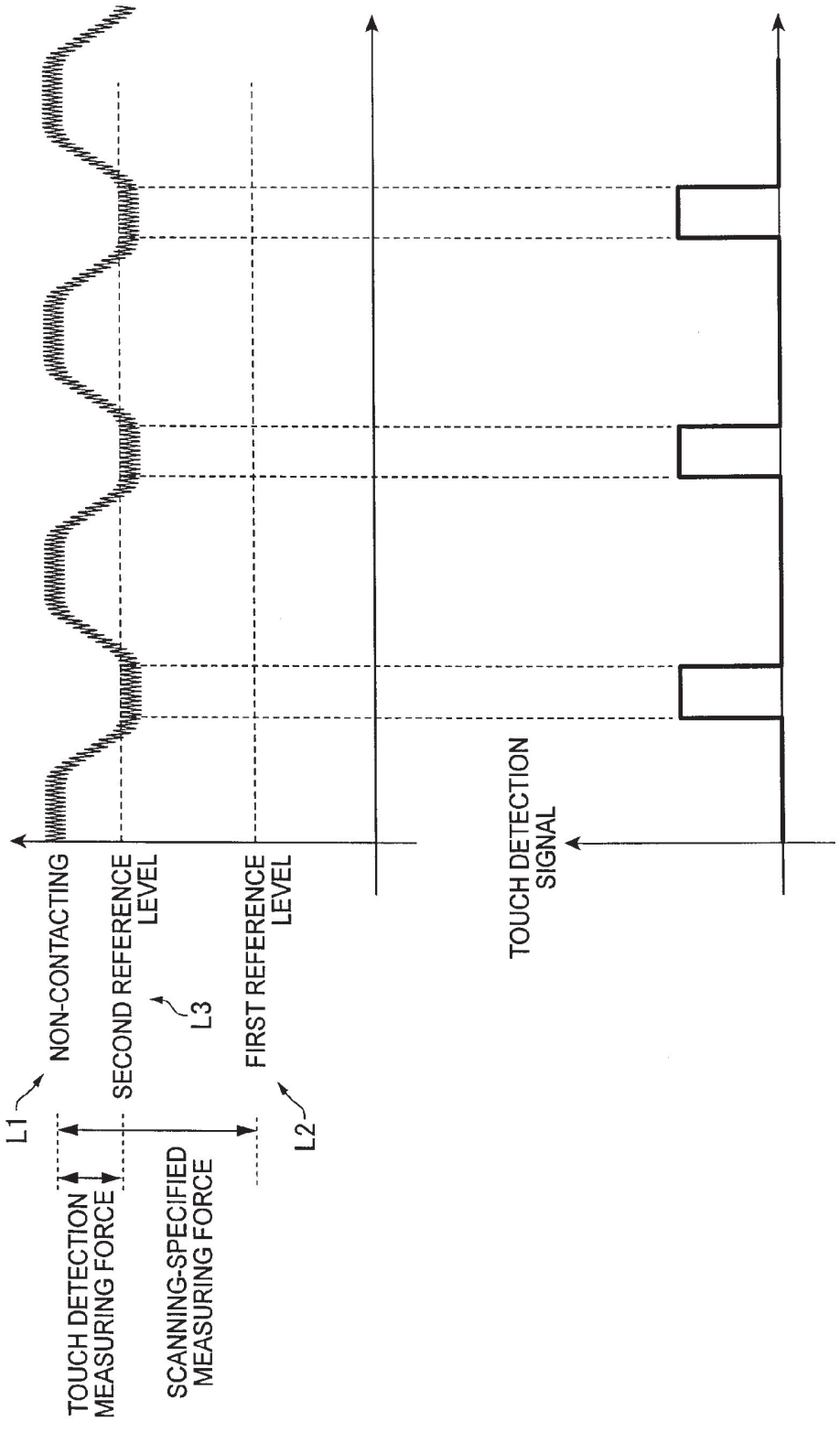

NON-CONTACTING
SECOND REFERENCE LEVEL
L3
FIRST REFERENCE LEVEL
L1
L2
TOUCH DETECTION MEASURING FORCE
SCANNING-SPECIFIED MEASURING FORCE
TOUCH DETECTION SIGNAL

FIG. 4

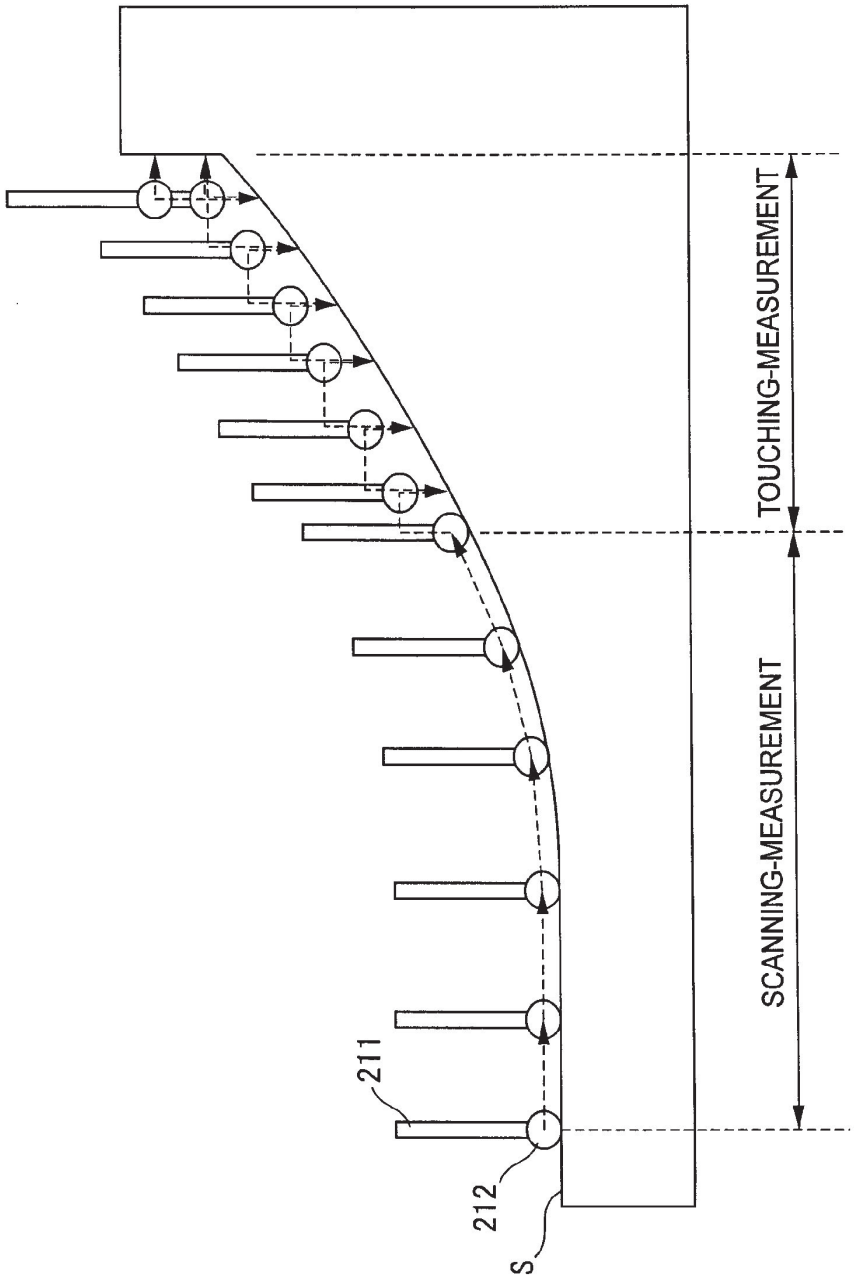


FIG. 5

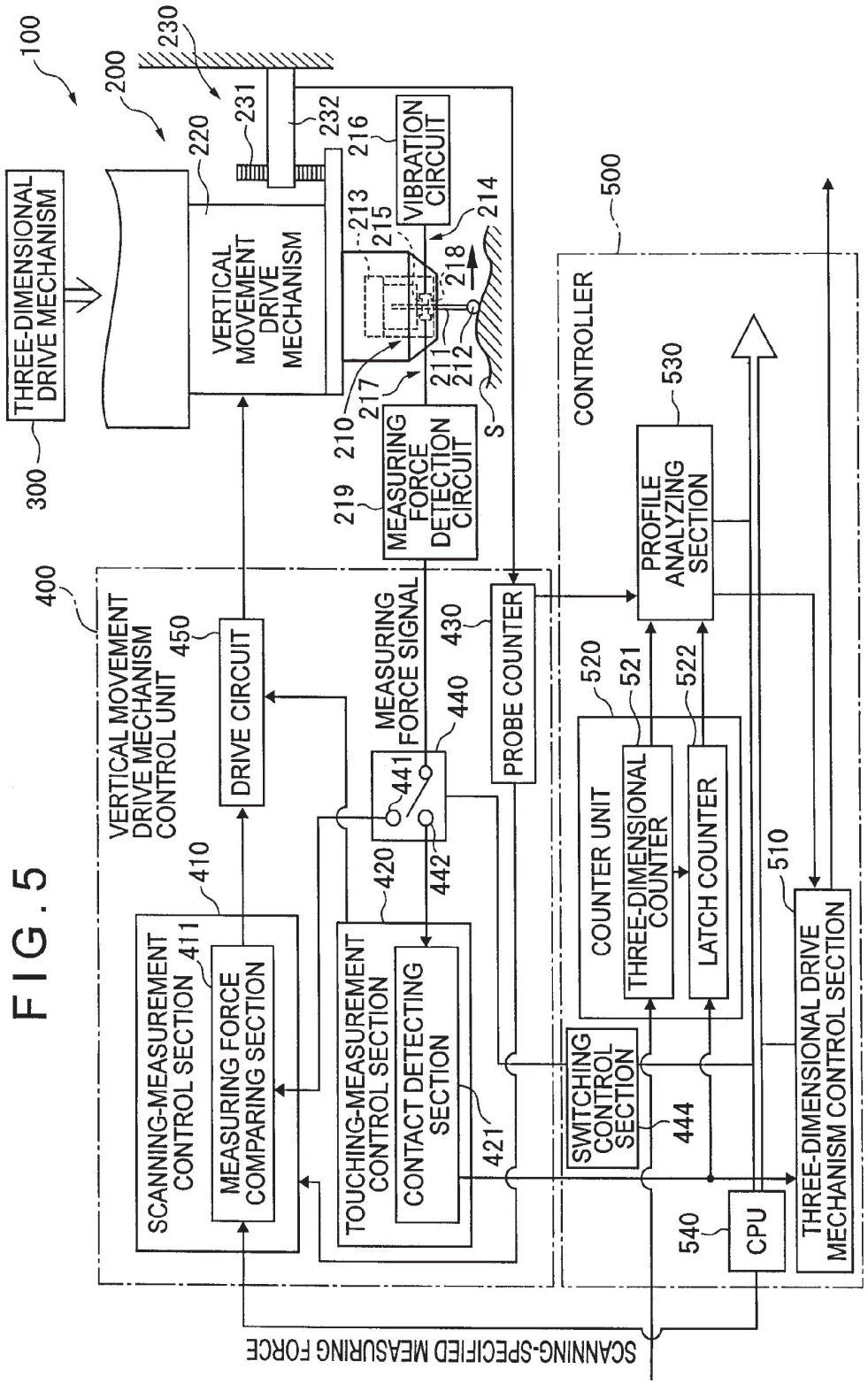

100
200
230
231
232
220
216
VIBRATION CIRCUIT
213
215
214
218
211
212
217
210
219
MEASURING FORCE DETECTION CIRCUIT
S
VERTICAL MOVEMENT DRIVE MECHANISM
THREE-DIMENSIONAL DRIVE MECHANISM
300
400
VERTICAL MOVEMENT DRIVE MECHANISM CONTROL UNIT
450
DRIVE CIRCUIT
MEASURING FORCE SIGNAL
430
PROBE COUNTER
440
441
442
410
SCANNING-MEASUREMENT CONTROL SECTION
411
MEASURING FORCE COMPARING SECTION
420
TOUCHING-MEASUREMENT CONTROL SECTION
CONTACT DETECTING SECTION
421
CONTROLLER
500
530
PROFILE ANALYZING SECTION
520
521
522
COUNTER UNIT
THREE-DIMENSIONAL COUNTER
LATCH COUNTER
510
SWITCHING CONTROL SECTION
444
540
CPU
THREE-DIMENSIONAL DRIVE MECHANISM CONTROL SECTION
SCANNING-SPECIFIED MEASURING FORCE

FIG. 6

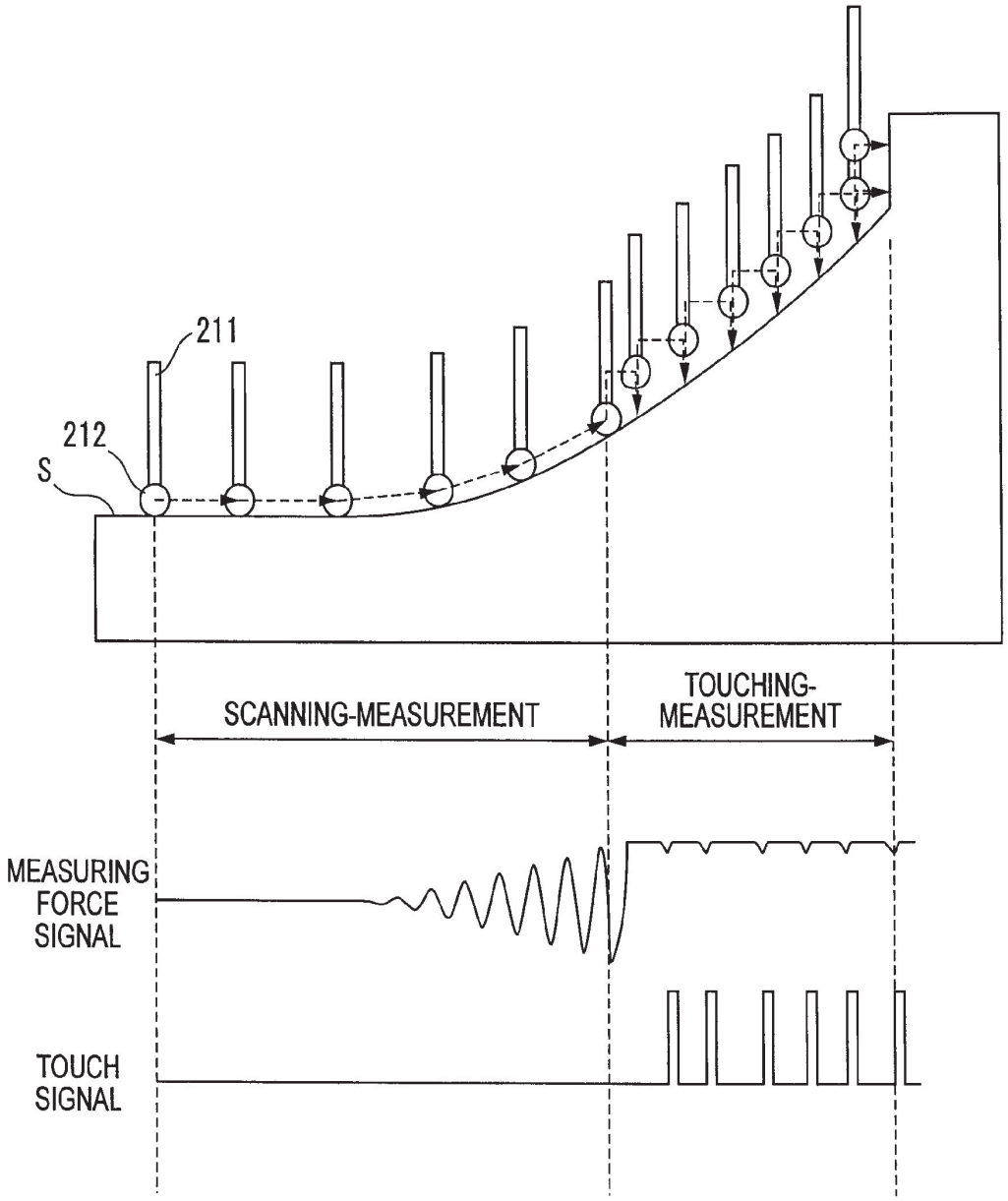

211
212
S
SCANNING-MEASUREMENT
TOUCHING-MEASUREMENT
MEASURING FORCE SIGNAL
TOUCH SIGNAL

FIG. 7

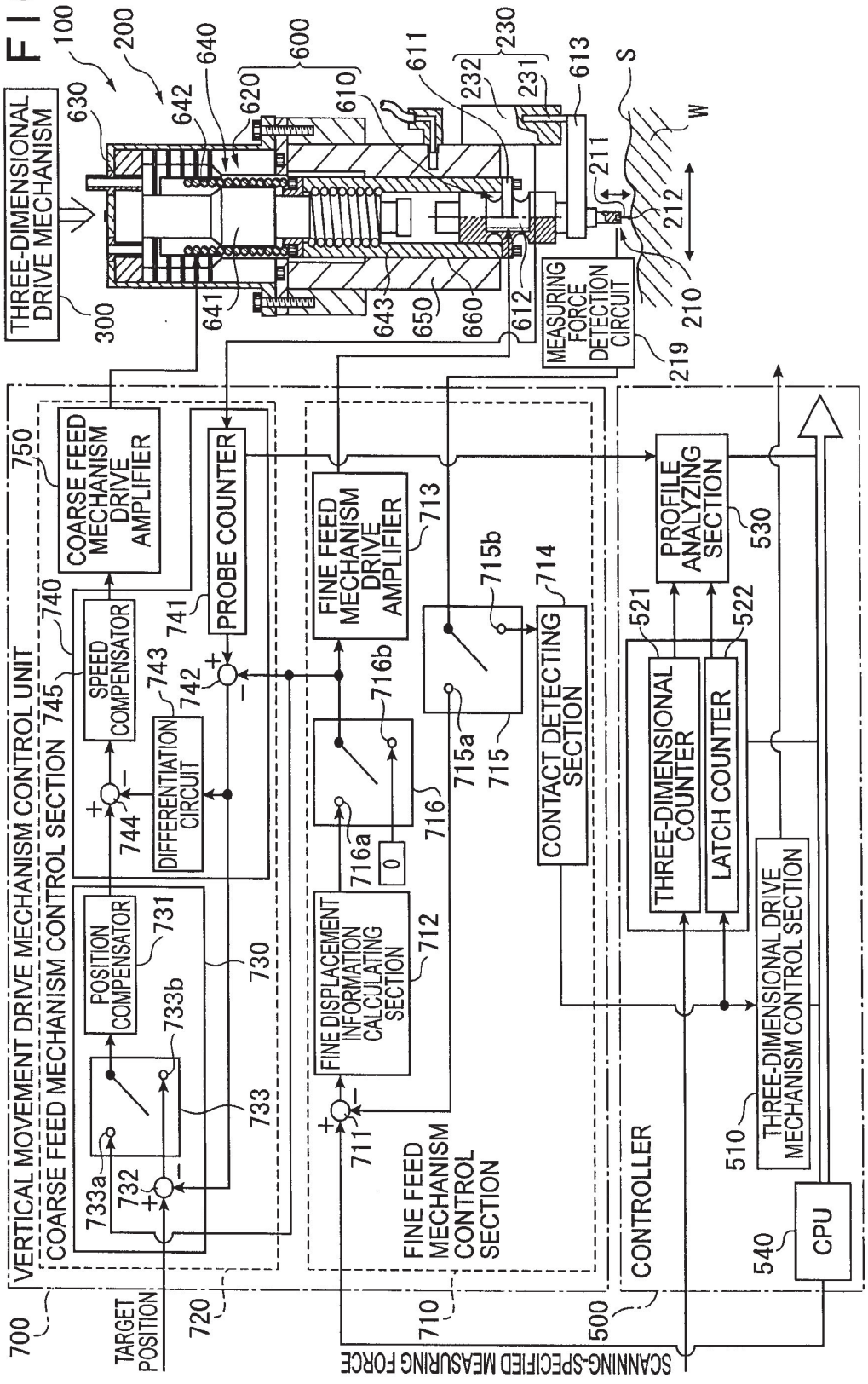

THREE-DIMENSIONAL DRIVE MECHANISM
300
100
200
630
642
640
620
600
610
611
232
231
230
613
S
W
211
212
641
643
650
660
612
MEASURING FORCE DETECTION CIRCUIT
219
210
VERTICAL MOVEMENT DRIVE MECHANISM CONTROL UNIT
750
COARSE FEED MECHANISM CONTROL SECTION
745
COARSE FEED MECHANISM DRIVE AMPLIFIER
740
SPEED COMPENSATOR
743
742
741
PROBE COUNTER
744
DIFFERENTIATION CIRCUIT
POSITION COMPENSATOR
731
733b
730
733a
732
733
FINE FEED MECHANISM DRIVE AMPLIFIER
713
716b
716a
0
716
FINE DISPLACEMENT INFORMATION CALCULATING SECTION
712
711
FINE FEED MECHANISM CONTROL SECTION
715b
715a
715
714
CONTACT DETECTING SECTION
PROFILE ANALYZING SECTION
530
521
522
THREE-DIMENSIONAL COUNTER
LATCH COUNTER
510
THREE-DIMENSIONAL DRIVE MECHANISM CONTROL SECTION
540
CPU
CONTROLLER
500
700
TARGET POSITION
720
710
SCANNING-SPECIFIED MEASURING FORCE

FIG. 8

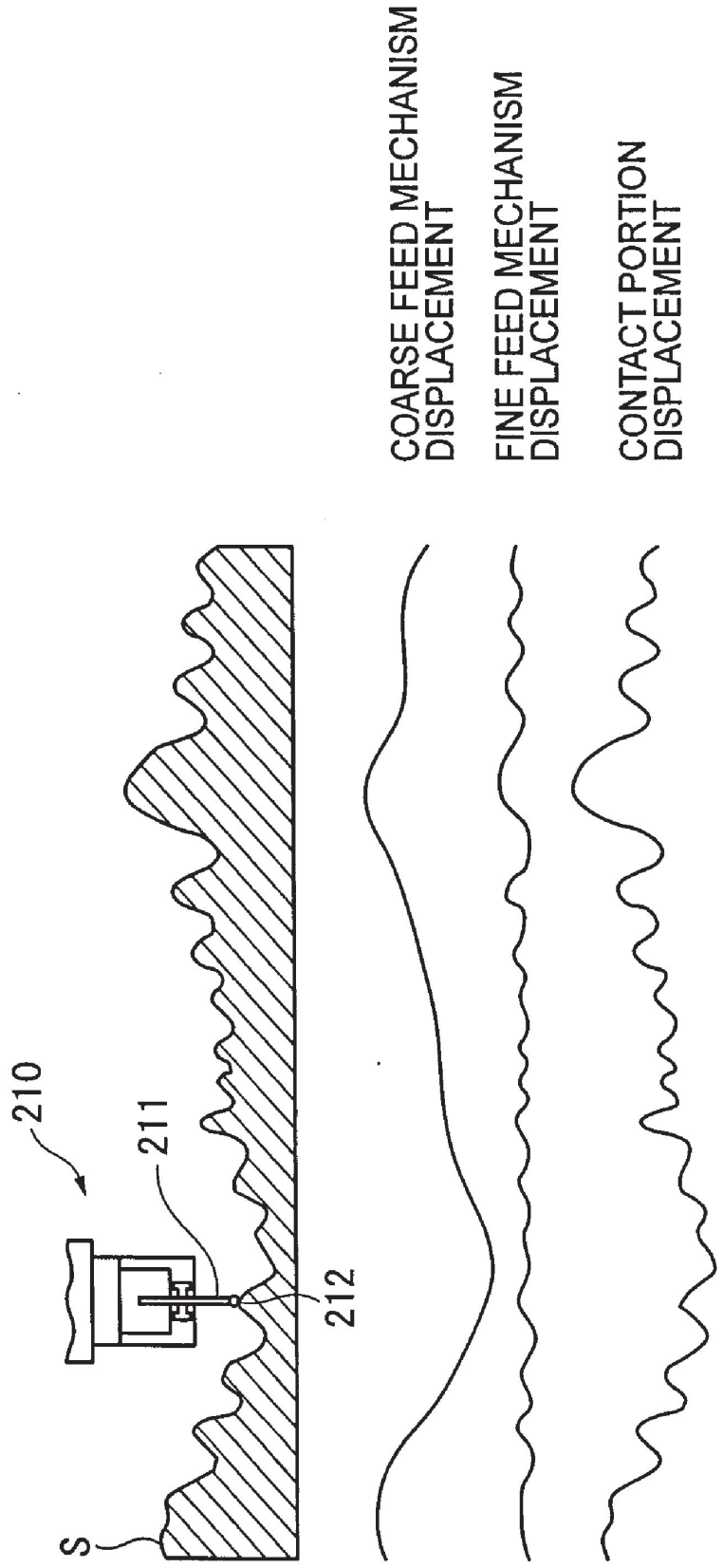

210
211
212
S
COARSE FEED MECHANISM DISPLACEMENT
FINE FEED MECHANISM DISPLACEMENT
CONTACT PORTION DISPLACEMENT

FIG. 9

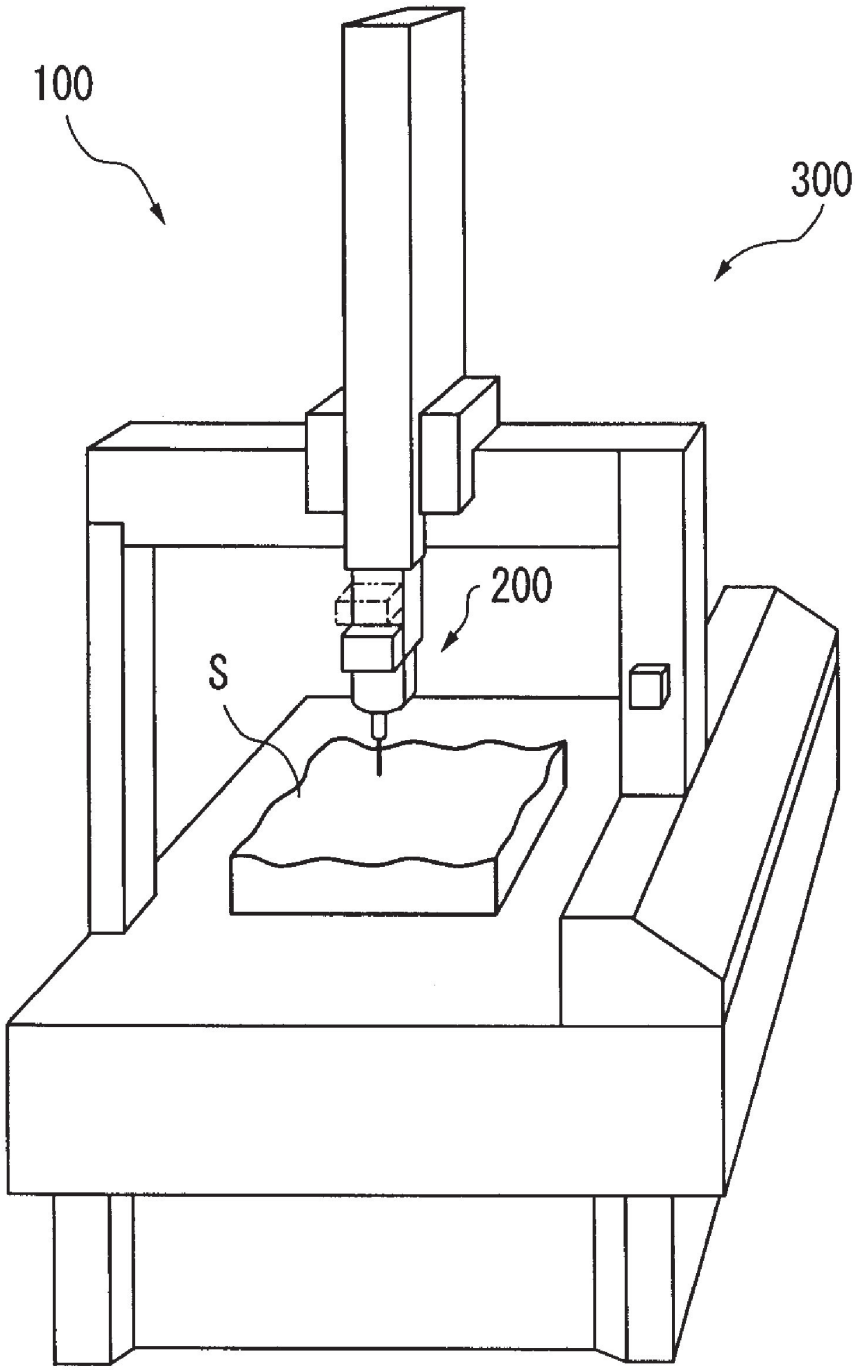


FIG. 10

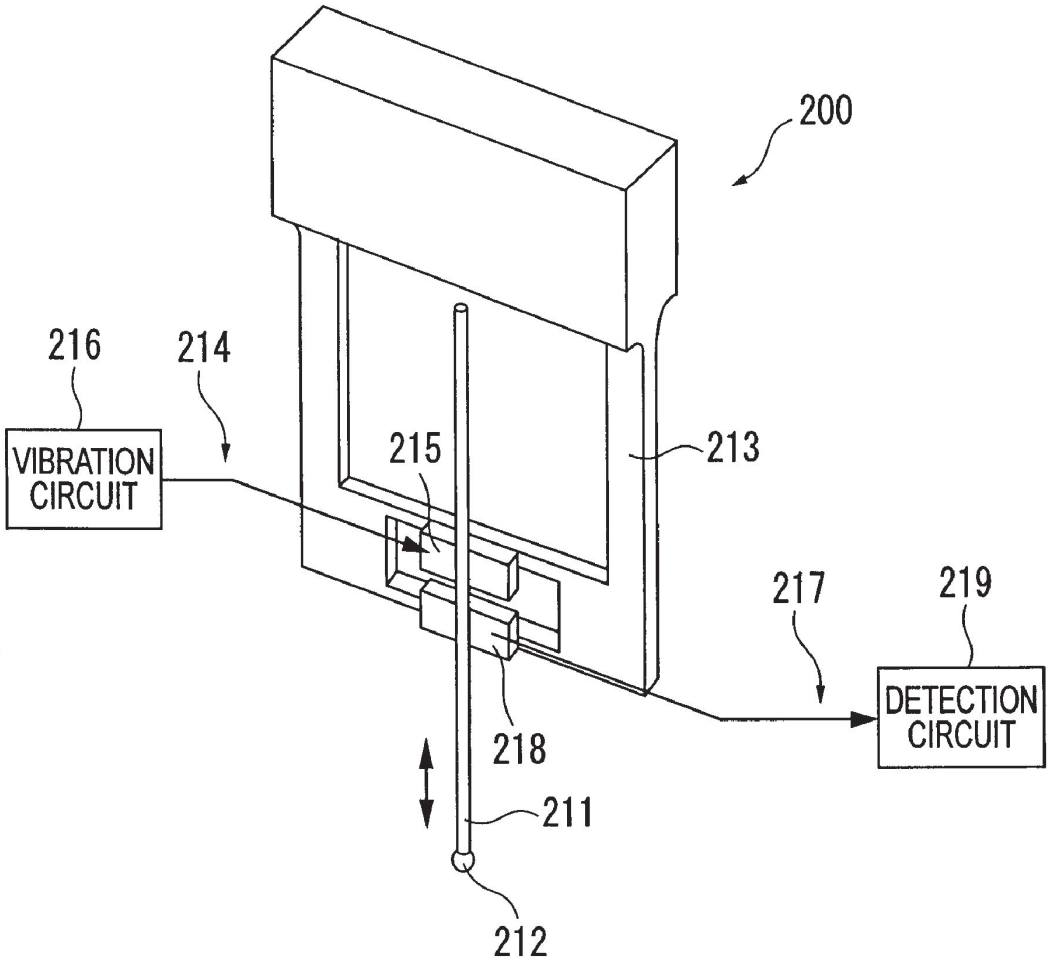

200
216
214
VIBRATION CIRCUIT
215
213
217
219
DETECTION CIRCUIT
218
211
212

FIG. 11

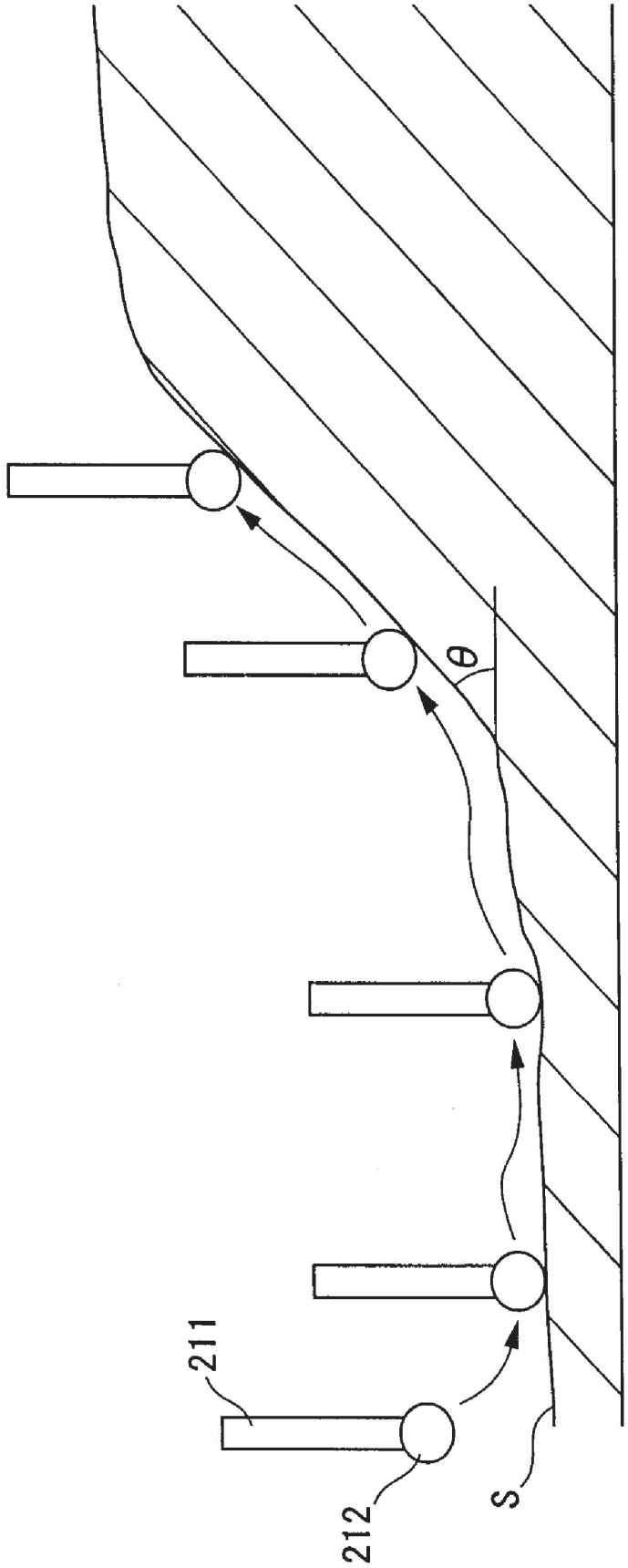
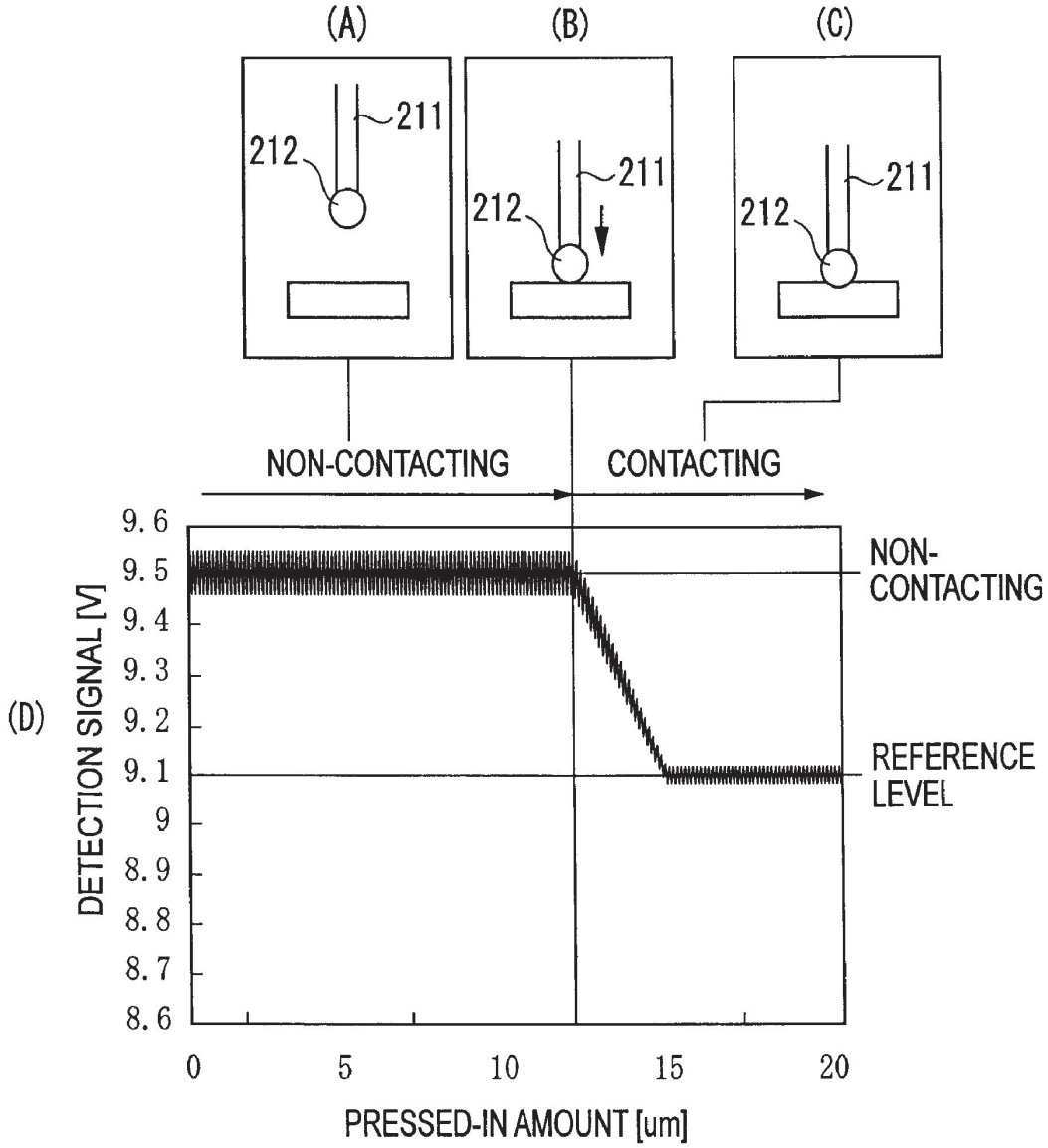


FIG. 12


(A)
(B)
(C)
211
212
NON-CONTACTING
CONTACTING
(D)
DETECTION SIGNAL [V]
9.6
9.5
9.4
9.3
9.2
9.1
9
8.9
8.8
8.7
8.6
NON-CONTACTING
REFERENCE LEVEL
0
5
10
15
20
PRESSED-IN AMOUNT [um]

SURFACE PROFILE MEASURING INSTRUMENT

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a surface profile measuring instrument.

[0003] For example, the invention relates to a surface profile measuring instrument that detects a workpiece surface using a contact-type probe to measure the profile of the workpiece surface.

[0004] 2. Description of Related Art

[0005] There has been known a measuring instrument that scans the workpiece surface to measure a surface texture and a three-dimensional profile of the workpiece such as a roughness tester, a contour measuring machine, a roundness measuring machine and a coordinate measuring machine.

[0006] For such a measuring instrument, a probe is used as a displacement sensor that detects the workpiece surface based on small displacements of a contact portion that is in contact with the workpiece surface (Document: JP-A-2004-61322).

[0007] FIG. **9** shows a profile measuring instrument **100** using a probe.

[0008] The profile measuring instrument **100** includes: a probe **200**; and a three-dimensional drive mechanism **300** as a movement mechanism that moves the probe **200** in the three dimensions along a workpiece surface S.

[0009] As shown in FIG. **10**, the probe **200** is a vibrating contact-type probe that includes: a stylus **211** having a contact portion **212** at a tip end thereof; a stylus holder **213** that supports the stylus **211**; a vibrator **214** provided for the stylus holder **213**, the vibrator constantly vibrating the stylus **211** at a natural frequency in an axial direction of the stylus **211**; and a detector **217** that detects a change in the vibration of the stylus **211** to output a detection signal.

[0010] The vibrator **214** includes: a piezoelectric element **215** provided to the stylus holder **213** to vibrate the stylus **211**; and a vibration circuit **216** that applies to the piezoelectric element **215** an output signal (such as a pulse and a sinusoidal wave signal) at a predetermined frequency.

[0011] The detector **217** includes: a piezoelectric element **218** that converts the vibration of the stylus **211** to voltage; and a detection circuit **219** that detects the voltage from the piezoelectric element **218** to output a detection signal.

[0012] The three-dimensional drive mechanism **300** is a three-dimensional drive mechanism that includes an X, Y and Z direction slide mechanism generally used in coordinate measuring machines.

[0013] Each of the axes of the three-dimensional drive mechanism **300** is provided with a linear encoder that detects a drive amount.

[0014] In the arrangement described above, when the contact portion **212** is moved along the workpiece surface S as shown in FIG. **11**, the detection signal changes as shown in FIG. **12** (D) by the positional relationship between the contact portion **212** and the workpiece surface S. From a state where the contact portion **212** is free (FIG. **12** (A)), the contact portion **212** is brought into contact with the workpiece surface S (FIG. **12** (B)). When the contact portion **212** contacts to the workpiece surface S at a predetermined measuring force (FIG. **12** (C)), the vibration of the contact portion **212** is suppressed, so that the detection signal reaches a predetermined reference level.

[0015] The reference level is set in advance as a level obtained by subtracting from a detection signal value detected in the free state (the non-contacting state) of the contact portion **212** a change amount in signal generated when the contacting portion **212** is pressed at the predetermined measuring force.

[0016] Note that the measuring force is a force at which the contact portion **212** is pressed to the workpiece surface S when the contact portion **212** is brought into contact with the workpiece surface S for detection of the workpiece surface S.

[0017] The contact portion **212** is moved for scanning along the workpiece surface S while being pressed to the workpiece surface S such that the detection signal value is at the reference level. When the detection signal reaches the reference level, positional information of the probe **200** is sampled from slide amounts of the X, Y and Z axes of the three-dimensional drive mechanism **300**. A contact point between the contact portion **212** and the workpiece surface S is calculated from the sampled position information of the probe **200**, whereby the profile of the workpiece surface S is illustrated.

[0018] The detection signal is damped differently depending on an angle at which the contact portion **212** contacts the workpiece surface S.

[0019] Specifically, since the stylus **211** is vibrated in the axial direction thereof, the vibration of the stylus **211** is suppressed to different extents depending on whether the contact portion **212** abuts on the workpiece surface S in the axial direction of the stylus **211** or in a direction deviated from the axial direction of the stylus **211**.

[0020] Accordingly, for the vibrating contact-type probe **200**, the reference level of the detection signal is set on the premise that the contact portion **212** contacts the workpiece in the axial direction of the stylus **211**.

[0021] Hence, in the case where the contact portion **212** contacts the workpiece surface S in the axial direction of the stylus **211**, the vibrating contact-type probe **200** can be moved for scanning such that the detection signal becomes the reference level in order to scan the workpiece surface S at a constant measuring force.

[0022] However, depending on how the workpiece surface S is slant, the contact portion **212** may abut on the workpiece surface S not in the axial direction of the stylus but in a direction deviated from the axial direction of the stylus **211**.

[0023] In this case, only a force component (in the axial direction of the stylus) out of the force acting from the workpiece surface S to the probe **200** can exert an influence on the detection signal change. Accordingly, the contact portion **212** is pressed too strongly to the workpiece in controlling the defect signal to the reference level, so that the measuring force cannot be maintained constant.

[0024] Thus, when the measuring force cannot be maintained constant, the workpiece surface S may be damaged

due to the too strong pressing and the stylus **211** may bend, preventing an accurate detection of the workpiece surface S. Therefore, the workpiece of which workpiece surface S can be measured by the vibrating contact-type probe **200** has been limited to a workpiece having a substantially flat surface.

SUMMARY OF THE INVENTION

[**0025**] An object of the present invention is to provide a surface profile measuring instrument which measures a profile of a workpiece surface, the surface including a slant portion, by using a contact-type probe.

[**0026**] A surface profile measuring instrument according to an aspect of the present invention includes: a measuring section including a stylus having a contact portion to contact a workpiece surface at a tip end and a measuring force detecting unit which detects a measuring force when the contact portion abuts on the workpiece surface; a moving unit which moves the measuring section relative to the workpiece surface; and a drive control unit which controls the moving unit based on the magnitude of the measuring force detected by the measuring force detecting unit. The contact portion is brought into contact with the workpiece surface to measure the workpiece surface. The drive control unit includes: a scanning-measurement control section that controls the moving unit such that the moving unit conducts a scanning-measurement in which the measuring force is a preset designated scanning measuring force and the contact portion is moved for scanning along the workpiece surface; and a touching-measurement control section that controls the moving unit such that the moving unit repeatedly conducts touching-measurements on the workpiece surface. In the touching measurements, the contact portion is brought into and then out of contact with the workpiece surface and the contact portion contacts the workpiece surface at a touch detecting measuring force set smaller than the designated scanning measuring force. The measuring force detecting unit has a predetermined measuring force detecting direction. The measuring force detecting unit detects the measuring force acting in the direction. When the contact portion contacts the workpiece surface in a direction along the measuring force detecting direction, the scanning-measurement control section conducts the scanning-measurement. When the contact portion contacts the workpiece surface in a direction deviated from the measuring force detecting direction, the touching-measurement control section conducts the touching-measurement.

[**0027**] In the above-described arrangement, the contact portion is adapted to contact the workpiece surface by the moving unit in order to measure the workpiece surface. Herein, the measurement is conducted while switching a measuring mode between the scanning-measurement in which the contact portion is moved to scan the workpiece surface and the touching-measurement in which the contact portion is moved to and from the workpiece surface to detect the workpiece surface. Specifically, when the workpiece surface is substantially perpendicular to the measuring force detecting direction and the contact portion contacts the workpiece surface in the measuring force detecting direction, the scanning-measurement is conducted. When the workpiece surface is deviated from a direction substantially perpendicular to the measuring force detecting direction and the contact portion contacts the workpiece surface in the direction deviated from the measuring force detecting direction, the touching-measurement is conducted.

[**0028**] In the scanning-measurement, to maintain the deformation amounts of the stylus and the workpiece constant in order to ensure the measuring accuracy, the contact portion needs to be moved along the workpiece surface such that the measuring force between the contact portion and the workpiece surface becomes constant at the preset designated scanning measuring force.

[**0029**] Note that the measuring force detecting unit that detects the measuring force between the contact portion and the workpiece surface can only detect the measuring force in a certain direction. When the contact portion abuts on the workpiece surface in the direction that the measuring force is detectable, the measuring force detecting unit can reliably detect the measuring force acting on the contact portion. Accordingly, the scanning-measurement in which the measuring force can be maintained constant at the designated scanning measuring force can be conducted based on the detected measuring force.

[**0030**] However, when the workpiece surface has a slant portion, it becomes impossible to cause the contact portion to contact the workpiece surface in the measuring force detecting direction.

[**0031**] In this case, only a force component in the measuring force detecting direction out of the measuring force generated between the workpiece surface and the contact portion is detectable. Accordingly, if the detected measuring force is adjusted to be the designated scanning measuring force, the contact portion is pressed too strongly into the workpiece surface, which prevents the scanning-measurement that requires the constant measuring force. Up to now, in the case in which the direction in which the contact portion contacts the workpiece surface is deviated from the measuring force detecting direction, the surface profile cannot be measured with high accuracy, thereby limiting a measurable surface profile of the workpiece.

[**0032**] In contrast, according to the aspect of the invention, when the direction in which the contact portion contacts the workpiece surface is deviated from the measuring force detecting direction due to the slant portion of the workpiece surface, the measuring mode is switched from the scanning-measurement to the touching-measurement. In the touching-measurement, the touch detecting measuring force is set to be a value smaller than the designated scanning measuring force, so that it is possible to detect the contact of the contact portion to the workpiece surface by detecting the small measuring force. When the direction in which the contact portion contacts the workpiece surface is deviated from the measuring force detection force, only the force component in the measuring force detecting direction out of the total measuring force can be detected by the measuring force detecting unit. However, the touch of the contact portion to the workpiece surface can be detected when the force component reaches the touch detecting measuring force that is set as the small value, thereby preventing the contact portion from being pressed too strongly into the workpiece surface. In the touching-measurement, since the contact portion and the workpiece surface are not abutted to each other too strongly, deformations of the contact portion and the workpiece can be quite small, so that the workpiece surface can be accurately detected.

[0033] As described above, the aspect of the invention ensures not only the scanning-measurement of the workpiece surface but also the touching-measurement of the workpiece surface including a portion immeasurable in the scanning-measurement with high accuracy.

[0034] Note that the measuring force detecting unit may vibrate the stylus in the axial direction of the stylus at a natural frequency and may detect the measuring force based on the change in the vibration level generated at the time when the contact portion abuts on the workpiece surface. In this case, the measuring force detecting direction becomes parallel to the axial direction of the stylus. Alternatively, the measuring force detecting unit may include a strain gauge for detecting distortion of the stylus and may detect the measuring force based on the detected distortion amount by the strain gauge. In this case, the measuring force detecting direction becomes the direction in which the strain gauge detects the distortion.

[0035] According to an aspect of the invention, the surface profile measuring instrument may preferably further includes: a displacement detector which detects a displacement of the contact portion to output a displacement detection signal. The touching-measurement control section may preferably include a contact detecting section which outputs a touch detection signal when the measuring force reaches the touch detecting measuring force. The drive control unit may preferably include: a counter which counts the displacement detection signal to calculate a position of the contact portion; a latch counter which receives the touch detection signal and latches the position of the contact portion which is counted by the counter; and a profile analyzing section which calculates a surface profile of the workpiece based on the position of the contact portion calculated by the counter and the position of the contact portion latched by the latch counter.

[0036] In the above-described arrangement, the displacement of the measuring section is detected by the displacement detector and the counter counts the displacement detection signal from the displacement detector to obtain the actual position of the measuring section. In the touching-measurement of the workpiece surface, the contact portion is brought from a position apart from the workpiece surface toward the workpiece surface into contact with the workpiece surface and when the measuring force detected by the measuring force detecting unit reaches the touch detecting measuring force, the contact detecting section outputs the touch detection signal. And, when the latch counter receives the touch detection signal, the latch counter latches the count value by the counter.

[0037] In such an arrangement, since the position of the contact portion at the time when the touch detecting measuring force is detected by the contact of the contact portion to the workpiece surface, the surface profile of the workpiece can be obtained based on the latched data.

[0038] According to an aspect of the invention, in the surface profile measuring instrument, the drive control unit may preferably include a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated. The switching section may preferably be switched in accordance with a selection by a user depending on the profile of the workpiece surface.

[0039] In the above-described arrangement, the user selects which portion of the workpiece surface is to receive the scanning-measurement and which portion thereof is to receive the touching-measurement by judging from the tilt angle and the curvature of the workpiece surface. In addition, the user can select the measuring mode by arbitrarily switching the switching section. Hence, as compared with, for example, a case in which the profile measuring instrument is adapted to repeat the scanning-measurement and the touching-measurement to automatically select the most suitable measuring mode, the measuring mode can be selected more speedily and appropriately, thereby ensuring an effective measurement.

[0040] According to an aspect of the invention, in the surface profile measuring instrument, the drive control unit may preferably include: a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated; and a switching control section which controls the switching of the switching section. The switching control section may preferably switch and control the switching section based on a change in the measuring force detected by the measuring force detecting unit.

[0041] Herein, the measuring force detecting unit may be adapted, for example, to vibrate the stylus in the axial direction thereof and to detect the measuring force between the contact portion and the workpiece surface in accordance with change in vibration level in the axial direction of the stylus.

[0042] In the above-described arrangement, when the contact portion contacts the workpiece surface and the vibration of the stylus is suppressed, the vibration level becomes small. Due to the difference in the vibration, the measuring force acting to the contact portion from the workpiece surface can be detected. Note that since the stylus is vibrated in the axial direction thereof, when the contact portion contacts the workpiece surface in the axial direction of the stylus, the vibration of the stylus is suppressed by the force acting to the contact portion from the workpiece surface. However, when the contact portion contacts the workpiece in a direction deviated from the axial direction of the stylus, only a force component in the axial direction of the stylus out of the force acting to the contact portion from the workpiece surface contributes the suppression of the vibration of the stylus.

[0043] Accordingly, when the contact portion contacts the workpiece surface in a direction deviated from the axial direction of the stylus, the measuring force between the contact portion and the workpiece surface cannot be accurately detected and the detected vibration level of the stylus becomes weak. Hence, when the contact portion contacts the workpiece surface in the axial direction of the stylus, where the measuring force can be accurately detected, the scanning-measurement can be conducted. While, when the contact portion contacts the workpiece surface in a direction deviated from the axial direction of the stylus, the scanning-measurement cannot be conducted, so that the touching-measurement needs to be alternatively employed.

[0044] In contrast, according to the aspect of the invention, since the switching control section controls the switching section based on the measuring force detected by the measuring force detecting unit, it is not necessary for the

user to judge and switch, which simplifies the measurement. Owing to the automatic switching, even when the surface profile cannot be measured in the scanning-measurement, the profile measurement can be automatically conducted in the touching-measurement.

[0045] According to an aspect of the invention, in the surface profile measuring instrument, the drive control unit may preferably include: a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated; and a switching control section which controls the switching of the switching section. The switching control section may preferably switch and control the switching section based on the surface profile of the workpiece.

[0046] Herein, controlling of the switching section based on the surface profile of the workpiece by the switching control section may be, for example, a switching between the scanning-measurement and the touching-measurement which is made based on the curvature of the workpiece surface and the angle between the workpiece surface and the measuring force detecting direction both obtained through the calculation of the surface profile of the workpiece based on the already-measured measuring data. Alternatively, the curvature and the tilt angle of the workpiece surface may be obtained from the design data, specifically by obtaining the surface profile of the workpiece from the design data of the workpiece.

[0047] In the above-described arrangement, when the surface profile of the workpiece includes a large curvature or a large tilt angle, it means that the contact portion contacts the workpiece surface in the direction deviated from the axial direction of the stylus. Accordingly, the measuring force acting between the contact portion and the workpiece surface cannot be accurately detected by the measuring force detection unit, so that the scanning-measurement cannot be conducted with the measuring force maintained constant at the designated scanning measuring force.

[0048] In contrast, according to the aspect of the invention, since the surface profile of the workpiece is analyzed to switch to the touching-measurement based on, for example, the curvatures or the tilt angles of the workpiece, it is not necessary for the user to judge and switch, thereby simplifying the measurement. Owing to the automatic switching, even when the surface profile cannot be measured in the scanning-measurement, the profile measurement can be automatically conducted in the touching-measurement.

[0049] According to an aspect of the invention, in the surface profile measuring instrument, the scanning-measurement control section may preferably change the designated scanning measuring force in accordance with an angle formed by the workpiece surface and the measuring force detecting direction.

[0050] In the above-described arrangement, the designated scanning measuring force in the scanning-measurement is changed in accordance with the angle between the workpiece surface and the measuring force detecting direction. For example, when the contact portion contacts the workpiece surface in the direction deviated from the measuring force detecting direction, the designated scanning measuring force is changed to take a smaller value. When the contact portion contacts the workpiece in the direction deviated from the measuring force detecting direction, the force component in the measuring force detecting direction out of the force acting to the contact portion from the workpiece surface can be detected as the measuring force. Hence, if the pressing amount of the probe is controlled such that the force component in the measuring force detecting direction becomes the designated scanning measuring force, the force acting between the contact portion and the workpiece surface becomes larger than the designated scanning measuring force, so that the scanning-measurement that requires a constant measuring force cannot be conducted.

[0051] In contrast, according to the aspect of the invention, the designated scanning measuring force is changed in accordance with the angle between the workpiece surface and the measuring force detecting direction, so that the measuring force acting between the contact portion and the workpiece surface is maintained constant, thereby ensuring a scanning-measurement in which the measuring force is accurately maintained constant.

[0052] According to an aspect of the invention and based on the same principle as described above, the touching-measurement control section may preferably change the touch detecting measuring force in accordance with the angle formed by the workpiece surface and the measuring force detecting direction.

[0053] According to an aspect of the invention, the moving unit includes: a fine feed mechanism which finely moves the measuring section; and a coarse feed mechanism which moves the fine feed mechanism and the measuring section more coarsely than the fine feed mechanism.

[0054] Herein, the fine feed mechanism may be preferably a feed mechanism that has high response speed. For example, the fine feed mechanism may be a piezoelectric actuator using a piezoelectric element.

[0055] The coarse feed mechanism may be an electromagnetic actuator.

[0056] In the above-describe arrangement, since the fine feed mechanism and the coarse feed mechanism are provided, in the scanning-measurement, the fine feed mechanism, of which response speed is high, can finely move the contact portion for small ridges and valleys of the workpiece surface, and the coarse feed mechanism, which can process a large change, can process a large profile change of the workpiece surface (such as an undulation). Hence, the contact portion can be moved for scanning along the workpiece surface accurately and speedily.

BRIEF DESCRIPTION OF THE DRAWINGS

[0057] FIG. **1** shows an arrangement of a first embodiment of a surface profile measuring instrument according to the present invention;

[0058] FIG. **2** shows change in vibration level in a scanning measurement according to the first embodiment;

[0059] FIG. **3** shows change in vibration level and output timings of touch detection signals in a touching-measurement according to the first embodiment;

[0060] FIG. **4** shows a process of a measurement of a workpiece surface according to the first embodiment;

[0061] FIG. **5** shows an arrangement of a modification 1 of the invention;

[0062] FIG. **6** shows a relationship between a measuring force signal and a switching of a measuring mode according to the modification 1;

[0063] FIG. **7** shows an arrangement of a second embodiment of the invention;

[0064] FIG. **8** shows a scanning on the workpiece surface using a fine feed mechanism and a coarse feed mechanism;

[0065] FIG. **9** shows an arrangement of a profile measuring instrument using a probe;

[0066] FIG. **10** shows an arrangement of a vibrating contact-type probe;

[0067] FIG. **11** shows a process of a scanning-measurement of the workpiece surface using the probe; and

[0068] FIG. **12** explains change in detection signal when the probe is in contact with the workpiece surface.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT(S)

[0069] Embodiments of the present invention, which are illustrated in the figures, will be described below with reference to numerals assigned to components in the figures.

First Embodiment

[0070] A first embodiment of a surface profile measuring instrument of the invention will be explained.

[0071] FIG. **1** shows an arrangement of the first embodiment of a surface profile measuring instrument **100** of the invention.

[0072] Note that the first embodiment will be described by exemplifying a measurement in which a workpiece having a substantially flat surface is disposed substantially horizontally and a probe **200** is adapted to approach a workpiece surface S from the upper side of the workpiece surface S.

[0073] The surface profile measuring instrument **100** includes: the probe **200** that conducts a detection on the workpiece surface S while moving with a vertical movement drive mechanism **220** a measuring section **210** to abut on the workpiece surface S; a three-dimensional drive mechanism **300** that moves the probe **200** in the three dimensions; a vertical movement drive mechanism control unit **400** that drives the vertical movement drive mechanism **220**; and a controller **500** that controls the entire operation of the surface profile measuring instrument **100**.

[0074] The probe **200** includes: the measuring section **210** that contacts the workpiece surface S to detect a measuring force on the workpiece surface S; the vertical movement drive mechanism **220** that moves the measuring section **210** vertically in accordance with the profile of the workpiece surface S; and a displacement amount sensor **230** that detects a vertical displacement amount of the measuring section **210**.

[0075] The measuring section **210** herein is the aforesaid vibrating contact-type probe **200** that is described in "2. Description of Related Art." The measuring section **210** includes: a stylus **211** having a contact portion **212** at a tip end; a stylus holder **213** that supports the stylus **211**; a vibrator **214** that is provided to the stylus holder **213** and constantly vibrates the stylus **211** in an axial direction at a natural frequency; and a detector **217** that detects a change in vibration of the stylus **211** to output a detection signal.

[0076] The vibrator **214** includes: a piezoelectric element **215** that is provided to the stylus holder **213** and vibrates the stylus **211**; and a vibration circuit **216** that applies to the piezoelectric element **215** an output signal (such as a pulse and a sinusoidal wave signal) of a predetermined frequency.

[0077] The detector **217** includes: a piezoelectric element **218** that converts the vibration of the stylus **211** to voltage; and a measuring force detection circuit **219** that detects the voltage from the piezoelectric element **218** to output a detection signal.

[0078] The measuring force detection circuit **219**, which detects the voltage from the piezoelectric element **218**, outputs a difference between the voltages detected when the contact portion **212** is unaffectedly vibrated and when the contact portion **212** is in contact with the workpiece surface S in a suppressed manner as information on the measuring force that the contact portion **212** receives from the workpiece surface S. For example, referring to FIG. **2**, the measuring force detection circuit **219** detects the measuring force based on a value obtained by subtracting from a voltage level L**1** detected when the contact portion **212** is not in contact with the workpiece surface S a reference value L**2** that is a voltage level detected when the contact portion **212** is pressed into the workpiece surface S at a predetermined measuring force.

[0079] The vertical movement drive mechanism **220** is a mechanism for vertically moving the measuring section **210**. For example, the vertical movement drive mechanism **220** drives the measuring section **210** in vertical directions by expansion and contraction of the piezoelectric element or vertical movements of a movable coil of an electromagnetic actuator.

[0080] The vertical movement drive mechanism **220** is provided to the three-dimensional drive mechanism **300** that moves the probe **200** in the X, Y and Z directions.

[0081] The three-dimensional drive mechanism **300** and the vertical movement drive mechanism **220** form a moving unit.

[0082] The vibrator **214** and the detector **217** form a measuring force detecting unit.

[0083] The displacement amount sensor **230** is a linear encoder including: a scale **231** that is vertically moved together with the measuring section **210**; and a detector head **232** that detects a displacement of the scale **231**.

[0084] The three-dimensional drive mechanism **300** herein has the same arrangement as that of the three-dimensional drive mechanism described in "2. Description of Related Art" including the X, Y and Z direction slide mechanism.

[0085] The vertical movement drive mechanism control unit **400** includes a scanning-measurement control section **410**, a touching-measurement control section **420**, a probe counter **430**, a switching section **440** and a drive circuit **450**.

[0086] The scanning-measurement control section **410** controls the vertical movement drive mechanism **220** such that the workpiece surface S is scanning-measured while the contact portion **212** of the measuring section **210** is abutted on the workpiece surface S with a predetermined designated scanning measuring force that is set in advance.

[0087] The scanning-measurement control section **410** includes a measuring force comparing section **411**.

[0088] The measuring force comparing section **411** is input with a measuring force signal detected by the measuring force detection circuit **219** and a designated scanning measuring force signal from the outside. The measuring force comparing section **411** compares the measuring force signal from the measuring force detection circuit **219** with the designated scanning measuring force signal from the outside and outputs a drive signal to the drive circuit **450** such that the measuring force becomes constant at the designated scanning measuring force.

[0089] For example, when the detected measuring force is larger than the designated scanning measuring force, the measuring section **210** is moved upward to make the contact portion **212** be less pressed into the workpiece surface S, while when the detected measuring force is smaller than the designated scanning measuring force, the measuring section **210** is moved downward to press the contact portion **212** more strongly into the workpiece surface S, thereby adjusting the measuring force become constant at the designated scanning measuring force.

[0090] As shown in FIG. **2**, the designated scanning measuring force herein is set as a value obtained by subtracting from the voltage level L**1** detected when the contact portion **212** is not in contact with the workpiece surface S a first reference level L**2** that is the voltage level detected when the contact portion **212** is pressed into the workpiece surface S at a predetermined measuring force. Specifically, when the scanning measurement is conducted at the designated scanning measuring force, the voltage level from the piezoelectric element **218** is constant at the first reference level L**2**.

[0091] The touching-measurement control section **420** detects that the contact portion **212** contacts the workpiece surface S in a touching measurement in which the contact portion **212** is alternately brought into and out of contact (touch) with the workpiece surface S.

[0092] The touching-measurement control section **420** includes a contact detecting section **421**.

[0093] The contact detecting section **421** detects that the measuring section **210** contacts (touches) the workpiece surface S when the measuring force signal from the measuring force detection circuit **219** reaches a touch detecting measuring force, and the contact detecting section **421** outputs a touch detection signal.

[0094] As shown in FIG. **3**, the touch detecting measuring force herein is set as a value smaller than the designated scanning measuring force. Specifically, the touch detecting measuring force is set as a voltage (a second reference level L**3**) that is higher than the first reference level L**2**.

[0095] Note that the operation of such a touching-measurement, in which the contact portion **212** is alternately brought into and out of contact (touch) with the workpiece surface S, is conducted by the three-dimensional drive mechanism **300**. Specifically, during the touching-measurement, a drive signal to stop the operation of the vertical movement drive mechanism **220** is output to the drive circuit **450** from the touching-measurement control section **420**. Thereby, the drive signal input to the drive circuit **450** is fixed at a predetermined value, so that the vertical movement drive mechanism **220** is stopped at a predetermined position. Herein, the vertical movement drive mechanism **220** may be stopped at a predetermined position with a so-called servo lock by using the output of the displacement amount sensor **230** as a returned signal. In addition, a touch signal from the contact detecting section **421** is output to the controller **500** and the controller **500** drives the three-dimensional drive mechanism **300** such that the touching-measurement is conducted in accordance with the touch signal.

[0096] The probe counter **430** counts a signal from the displacement amount sensor **230** to count a Z-direction displacement amount of the measuring section **210** caused by the vertical movement drive mechanism **220**.

[0097] The switching section **440** switches between the scanning-measurement control section **410** and the touching-measurement control section **420**, to which the measuring force signal from the measuring force detection circuit **219** is output. The switching section **440** includes a scanning-measurement terminal **441** and a touching-measurement terminal **442**, between which a user manually switches with a switching section **443**.

[0098] The drive circuit **450** outputs a control signal for controlling a vertical movement of the vertical movement drive mechanism **220** in accordance with the drive signal.

[0099] For example, when the scanning-measurement control section **410** is activated, a control signal for conducting the scanning-measurement with the measuring force maintained at the designated scanning measuring force is output.

[0100] When the touching-measurement control section **420** is activated, a control signal for conducting the touching-measurement is output. Specifically, during the touching-measurement, the operation of the vertical movement drive mechanism **220** is stopped. Note that the probe is displaced only by the three-dimensional drive mechanism **300** in the touching-measurement.

[0101] The controller **500** includes a three-dimensional drive mechanism control section **510**, a counter unit **520**, a profile analyzing section **530** and a CPU (Central Processing Unit) **540**.

[0102] The three-dimensional drive mechanism control section **510** drives the three-dimensional drive mechanism **300** to move the probe in the X, Y and Z directions. For example, in the scanning-measurement, the probe **200** is moved in a predetermined scanning direction.

[0103] Note that it is only necessary that the three-dimensional drive mechanism **300** moves the probe **200** in the scanning direction, since small displacements of the contact portion **212** corresponding to small ridges and valleys of the workpiece surface S is conducted by the vertical movement drive mechanism **220**.

[0104] In the touching-measurement, the probe **200** is also moved alternately to and from the workpiece surface S.

[0105] Concretely, the contact portion **212** is moved so as to approach the workpiece surface S and is pressed thereinto until the touch signal from the contact detecting section **421** generated when the contact portion **212** contacts the workpiece surface S is received. When the touch signal is received, the contact portion **212** is moved away from the workpiece surface S. The contact portion **212** is moved again so as to approach the workpiece surface S at a next sampling point. Note that the next sampling point in the touching-measurement is estimated based on measurement data on a few already measured sampling points.

[0106] Herein, the vertical movement drive mechanism control unit **400** and the controller **500** form a drive control unit.

[0107] The counter unit **520** includes a three-dimensional counter **521** and a latch counter **522** (a latch counter).

[0108] The three-dimensional counter **521** counts the output of linear encoders (not shown) for detecting drive amounts of the three-dimensional drive mechanism **300** in the X, Y and Z directions.

[0109] The latch counter **522** receives the touch signal output from the contact detecting section **421** and latches a count value of the three-dimensional counter **521**. Specifically, the drive amount of the three-dimensional drive mechanism **300** at the time when the contact portion **212** contacts (touches) the workpiece surface S with the touch detecting measuring force is latched.

[0110] Herein, the displacement amount sensor **230** and the linear encoders that detect the drive amounts in the X, Y and Z directions form a displacement detector, and the three-dimensional counter **521** and the probe counter **430** form a counter.

[0111] The profile analyzing section **530** calculates a surface profile of the workpiece based on the displacements of the probe and the three-dimensional drive mechanism **300** which are respectively counted by the probe counter **430** and the counter unit **520**.

[0112] For example, in the scanning-measurement, a movement locus of the contact portion **212** is calculated by using the probe displacement counted by the probe counter **430** and the drive amount of the three-dimensional drive mechanism **300** counted by the three-dimensional counter **521**.

[0113] The movement locus of the contact portion **212** represents the surface profile of the workpiece.

[0114] In the touching-measurement, the profile of the workpiece surface S is analyzed by plotting positions on the workpiece surface S based on the displacement of the three-dimensional drive mechanism **300** which is latched by the latch counter **522**.

[0115] Note that either in the scanning-measurement or the touching-measurement, the profile analyzing section **530** estimates the surface profile of the workpiece at a next sampling point based on a few already measured points and outputs the estimation to the scanning-measurement control section **410** and the three-dimensional drive mechanism control section **510**.

[0116] Note that the CPU **540** controls the controller **500** and outputs a command on the designated scanning measuring force to the measuring force comparing section **411**.

[0117] The operation of the first embodiment having the above-explained arrangement will be described below by exemplifying a measurement of the profile of the workpiece surface S shown in FIG. **4**.

[0118] Herein, the measurement is conducted from left to right in FIG. **4**. At the start point of the measurement, the workpiece surface S is a horizontal surface orthogonal to the stylus **211**. Hence, the scanning-measurement is to be conducted herein.

[0119] For the scanning-measurement, the switching section **443** is manually operated to connect the switching section **440** to the scanning-measurement terminal **441**.

[0120] In the scanning-measurement, the probe **200** is moved by the three-dimensional drive mechanism **300** in a scanning direction (which is from left to right in FIG. **4**). When the contact portion **212** abuts on the workpiece surface S, the measuring force applied from the workpiece surface S to the contact portion **212** is detected by the measuring force detection circuit **219** and the detection result is input to the measuring force comparing section **411** of the scanning-measurement control section **410** via the switching section **440**.

[0121] The measuring force signal from the measuring force detection circuit **219** is compared with the designated scanning measuring force in the measuring force comparing section **411**. Based on the comparison result, the measuring force comparing section **411** outputs the drive signal to the drive circuit **450** such that the measuring force becomes constant at the designated scanning measuring force.

[0122] The vertical movement drive mechanism **220** is driven by the signal from the drive circuit **450** to vertically move the contact portion **212** so as to abut on the workpiece at the constant measuring force. Thereby, the scanning-measurement is conducted in accordance with ridges and valleys of the workpiece surface S. The vertical displacement of the measuring section **210** in the scanning-measurement is detected by the displacement amount sensor **230** and a sensor signal from the displacement amount sensor **230** is counted by the probe counter **430**, so that the displacement amount of the contact portion **212** caused by the vertical movement drive mechanism **220** is calculated.

[0123] The displacement of the probe **200** caused by the three-dimensional drive mechanism **300** is counted by the three-dimensional counter **521**. The displacement of the vertical movement drive mechanism **220** counted by the probe counter **430** and the displacement of the three-dimensional drive mechanism **300** counted by the three-dimensional counter **521** are used together by the profile analyzing section **530** to obtain the movement locus of the contact portion **212**, thereby obtaining the surface profile of the workpiece.

[0124] As the measurement of the workpiece surface S shown in FIG. **4** is proceeded from left to right, the workpiece surface S becomes slant from the horizontal line and the tilt angle gradually becomes larger.

[0125] When the tilt angle between the workpiece surface S and the horizontal line becomes larger than a predeter-

mined value, the direction in which the contact portion **212** contacts the workpiece surface S is deviated from the axial direction of the stylus (a measuring force detecting direction), whereby the measuring force cannot be accurately detected. In addition, when the tilt angle of the workpiece surface S becomes large, it is difficult to move the contact portion **212** along the workpiece surface S by making small displacements with the vertical movement drive mechanism **220**. Hence, when the tilt angle of the workpiece surface S is large, it is not suitable to continue the scanning-measurement.

[**0126**] When the user judges that it is not suitable to conduct the scanning-measurement, the user may manually operate the switching section **443** to connect the switching section **440** to the touching-measurement terminal **442**, thereby changing a measuring mode from the scanning-measurement to the touching-measurement.

[**0127**] In the touching-measurement, the drive of the vertical movement drive mechanism **220** is stopped and the touching-measurement is conducted with the contact portion **212** moved to and form the workpiece surface S by the three-dimensional drive mechanism **300**.

[**0128**] When the contact portion **212** is moved toward the workpiece surface S by the three-dimensional drive mechanism **300** into contact with the workpiece surface S, the measuring force applied from the workpiece surface S to the contact portion **212** is detected by the measuring force detection circuit **219**. The measuring force signal from the measuring force detection circuit **219** is input to the contact detecting section **421** and compared with the touch detecting measuring force in the contact detecting section **421**. The contact portion **212** is pressed into the workpiece surface S until the measuring force signal reaches the touch detecting measuring force, where the touch signal is output from the contact detecting section **421** (see FIG. **3**). Note that since the touch detecting measuring force has a smaller value as compared with the designated scanning measuring force, the touch signal is output when the contact portion **212** slightly contacts the workpiece surface S.

[**0129**] The touch signal is input to the three-dimensional drive mechanism control section **510**. When the touch signal is received by the three-dimensional drive mechanism control section **510**, the contact portion **212** is moved apart from the workpiece surface S. Subsequently, the contact portion **212** is moved to and from the workpiece surface S at a next sampling point. The touch signal is input to the latch counter **522**. The latch counter **522**, which receives the touch signal, latches the count value of the three-dimensional counter **521** and outputs it to the profile analyzing section **530**.

[**0130**] The profile analyzing section **530** plots the positions of the contact portion **212** at the times when the touch signals are output, whereby the surface profile of the workpiece is obtained.

[**0131**] The first embodiment described above can provide advantages below.

[**0132**] (1) When the contacting direction between the contact portion **212** and the workpiece surface S is deviated from the measuring force detecting direction due to the tilt angle of the workpiece surface S or the like, the measuring mode is switched from the scanning-measurement to the touching-measurement. In the touching-measurement, the touch detecting measuring force is set to be smaller than the designated scanning measuring force. Thereby, it is possible to detect that the contact portion **212** contacts the workpiece surface S by detecting a small measuring force. In the touching-measurement, it is possible to detect that the contact portion **212** touches the workpiece surface S at a time when the measuring force signal reaches the touch detecting measuring force having a small value, thereby preventing the contact portion **212** from being pressed too strongly into the workpiece surface S. Since the contact portion **212** and the workpiece surface S are not abutted to each other too strongly in the touching-measurement, deformations of the stylus **211** and the workpiece surface S can be quite small, so that the workpiece surface S can be accurately detected. In other words, even in a portion in which the scanning-measurement cannot be conducted, the workpiece surface S can be accurately measured by the touching-measurement.

[**0133**] (2) When the latch counter **522** receives the touch detection signal in the touching-measurement of the workpiece surface S, the latch counter **522** latches the count value of the three-dimensional counter **521**. Hence, the position of the contact portion **212** at the time when the contact portion **212** contacts the workpiece surface S and the touch detecting measuring force is detected can be latched. Based on the latched data, the surface profile of the workpiece can be obtained.

[**0134**] (3) The user can select which portion of the workpiece surface S is to be measured by the scanning-measurement or by the touching-measurement by judging from the tilt angle and curvature of the workpiece surface S to select the measuring mode through switching the switching section **440** using the switching section **443**. Hence, as compared with a case in which the profile measuring instrument is adapted to try the scanning-measurement and the touching-measurement and automatically select the most suitable measuring mode, the measuring mode can be selected speedily and appropriately, thereby ensuring an effective measurement.

[**0135**] [Modification 1]

[**0136**] A modification 1 of the invention will be described below with reference to FIG. **5**.

[**0137**] Although the basic arrangement of the modification 1 is the same as the first embodiment, the modification 1 includes a switching control section **444** that controls the switching section **440**, so that the switching can be automatically conducted based on the measuring force signal.

[**0138**] In FIG. **5**, the modification 1 includes the switching control section **444** in place for the switching section **443**.

[**0139**] The switching control section **444** is input with the measuring force signal from the measuring force detection circuit **219** and controls the switching section **440** in accordance with a change in the measuring force signal. In the scanning-measurement in which the contact portion **212** is pressed to the workpiece surface S such that the measuring force becomes constant at a predetermined designated scanning measuring force, the measuring force is detected in a direction along the axial direction of the stylus **211** by vibrating the contact portion **212** in the axial direction of the stylus **211**.

[**0140**] However, when the workpiece surface S is tilted from the horizontal line or from the direction substantially

orthogonal to the axial direction of the stylus, the contact portion **212** does not abut on the workpiece surface S in the axial direction of the stylus. Hence, the measuring force signal from the measuring force detection circuit **219** becomes disturbed.

[**0141**] For example, as shown in FIG. **6**, when the tilt angle of the workpiece surface S becomes large, the measuring force signal cannot be maintained at a constant value in the scanning-measurement, causing a large fluctuation in the measuring force signal. When the fluctuation in the measuring force signal exceeds a predetermined value, the switching section **440** is connected to the touching-measurement terminal **442**, thereby changing the measuring mode to the touching-measurement. The touching-measurement is then conducted while detecting the touch signal.

[**0142**] The modification 1 can provide advantages below.

[**0143**] (4) Since the switching control section **444** switches and controls the switching section **440** based on the measuring force detected by the measuring force detection circuit **219**, it is not necessary for the user to judge and switch, which simplifies the measurement. Owing to the automatic switching, even when the surface profile cannot be measured by the scanning-measurement, the profile measurement can be automatically conducted in the touching-measurement.

[**0144**] [Modification 2]

[**0145**] The modification 1 has been described above by exemplifying the case in which the switching control section **444** controls the switching section **440** based on the measuring force signal from the measuring force detection circuit **219**. However, the switching control section **444** may control the switching section **440** based on the profile of the workpiece surface S.

[**0146**] In the case in which the measuring mode is switched between the scanning-measurement and the touching-measurement based on the profile of the workpiece surface S, the measuring mode may be selected by estimating the workpiece surface S based on the measurement data on the last already measured sampling point. For example, the curvature or the tilt angle of the workpiece surface S may be calculated from the data on a plurality of last already measured points and compared with a predetermined threshold value to make a switch between the scanning-measurement and the touching-measurement. When the curvature of the workpiece surface S is small enough, the scanning-measurement can be conducted. On the other hand, when the curvature is large, the measuring mode is switched to the touching-measurement. When the tilt angle of the workpiece surface S is in a predetermined range from the horizontal line, the scanning-measurement can be conducted. On the other hand, when the tilt angle of the workpiece surface S is beyond the predetermined range, the measuring mode is switched to the touching-measurement.

[**0147**] An alternative way of measurement may be employed, in which the entire surface of the workpiece may be roughly measured in the touching-measurement; the curvatures and the tilt angles of points on the workpiece surface S are calculated from the data of the rough measurement; and the surface profile of the workpiece is measured again while making a switch between the scanning-measurement and the touching-measurement based on the data of the curvatures or the tilt angles.

[**0148**] As another way of measurement, the curvatures or the tilt angles of the workpiece surface S may be calculated in advance based on design data of the workpiece to make a switch between the scanning-measurement and the touching-measurement.

[**0149**] The modification 2 can provide advantages below.

[**0150**] (5) Since the surface profile of the workpiece is analyzed to switch to the touching-measurement based on, for example, the curvatures or the tilt angles of the workpiece, it is not necessary for the user to judge and switch, thereby simplifying the measurement. Owing to the automatic switching, even when the surface profile cannot be measured by the scanning-measurement, the profile measurement can be automatically conducted in the touching-measurement.

[**0151**] [Modification 3]

[**0152**] A modification 3 of the invention will be described below.

[**0153**] Although the basic arrangement of the modification 3 is the same as the first embodiment, the modification 3 is different in that the designated scanning measuring force is variable in the scanning-measurement.

[**0154**] When the curvature or the tilt angle of the workpiece surface S is within a predetermined range, the scanning-measurement is conducted. Herein, the designated scanning measuring force can be changed in accordance with the curvature or the tilt angle of the workpiece surface S. For example, in the scanning-measurement, when the curvature or the tilt angle of the workpiece surface S is large, the designated scanning measuring force is changed to a smaller value in accordance with the curvature or the tilt angle.

[**0155**] When the curvature or the tilt angle of the workpiece surface S is large, the direction in which the contact portion **212** contacts the workpiece surface S becomes deviated from the axial direction of the stylus **211** (the measuring force detecting direction). Herein, only the force component in the axial direction of the stylus out of the measuring force applied from the workpiece surface S to the contact portion **212** is detected by the measuring force detection circuit **219**. Hence, when the workpiece surface S is slant and the designated scanning measuring force is controlled based on the measuring force detected by the measuring force detection circuit **219**, the actual measuring force between the contact portion **212** and the workpiece surface S is not the designated scanning measuring force, so that the contact portion **212** is pressed too strongly onto the workpiece surface S.

[**0156**] Accordingly, changing the designated scanning measuring force in accordance with the curvature or the tilt angle of the workpiece surface S ensures a scanning-measurement in which the measuring force between the workpiece surface S and the contact portion **212** is accurately maintained constant.

Second Embodiment

[0157] A second embodiment of the invention will be described below with reference to FIG. **7**.

[0158] Although the basic arrangement of the second embodiment is the same as the first embodiment, the second embodiment is different in that a vertical movement drive mechanism **600** of the probe **200** includes a fine feed mechanism **610** that finely moves the measuring section **210** and a coarse feed mechanism **620** that coarsely moves the fine feed mechanism **610** and the measuring section **210**.

[0159] Specifically, the vertical movement drive mechanism **600** includes the fine feed mechanism **610** having a high response speed and the coarse feed mechanism **620** having a large stroke, whereby, in the scanning-measurement, the fine feed mechanism **610** speedily processes small ridges and valleys of the workpiece surface S and the coarse feed mechanism **620** processes a large change such as an undulation. Thus, the contact portion is accurately and speedily moved for scanning along the workpiece surface in the scanning-measurement.

[0160] An arrangement of the second embodiment will be described in detail.

[0161] In FIG. **7**, the surface profile measuring instrument **100** includes the probe **200**, the three-dimensional drive mechanism **300**, the vertical movement drive mechanism control unit **700** and the controller **500**.

[0162] The probe **200** includes the measuring section **210**, the vertical movement drive mechanism **600** and the displacement amount sensor **230**. The arrangements of the measuring section **210** and the displacement amount sensor **230** are the same as those of the first embodiment.

[0163] The vertical movement drive mechanism **600** includes the fine feed mechanism **610** that moves the measuring section **210** in a small range and the coarse feed mechanism **620** that coarsely moves the fine feed mechanism **610** and the measuring section **210**. The fine feed mechanism **610** includes: a fine feed fixing portion **611** fixed to a movable portion **643** of the coarse feed mechanism **620**; and a piezoelectric element **612** provided to the fine feed fixing portion **611**. The measuring section **210** is disposed on the lower side of the piezoelectric element **612**.

[0164] The coarse feed mechanism **620** includes: a permanent magnet **641** fixed in a housing **630** (a casing); and an electromagnetic actuator **640** having a movable coil **642** that vertically moves in the magnetic field of the permanent magnet **641**. At a lower end of the movable coil **642**, the movable portion **643** that integrally moves with the movable coil **642**. The movable portion **643** is held by an air bearing **660** in a manner smoothly movable to a coarse feed fixing portion **650** integrated with the housing **630**. The housing **630** is attached to the three-dimensional drive mechanism **300**, and the probe **200** is moved in the three dimensions by X, Y and Z drive axes.

[0165] The displacement amount sensor **230** is a linear encoder that includes the scale **231** and the detector head **232**. The scale **231** is held by a movable component **613** provided between the lower end of the fine feed mechanism **610** and the upper end of the measuring section **210**. The scale **231** moves in a direction parallel to the displacement direction of the fine feed mechanism **610** and the coarse feed mechanism **620**. The detector head **232** provided to the coarse feed fixing portion **650** detects the displacement amount of the scale **231**. The displacement amount sensor **230** detects the displacement amount of the measuring section **210** from the housing **630**. In other words, the displacement amount sensor **230** detects a combined displacement amount of the coarse feed mechanism **620** and the fine feed mechanism **610**. The detection result of the displacement amount sensor **230** is output as a displacement amount signal.

[0166] The vertical movement drive mechanism control unit **700** includes a fine feed mechanism control section **710** that drives the fine feed mechanism **610** and a coarse feed mechanism control section **720** that drives the coarse feed mechanism **620**.

[0167] The fine feed mechanism control section **710** includes a measuring force comparing section **711**, a fine displacement information calculating section **712**, a fine feed mechanism drive amplifier **713**, a contact detecting section **714**, a first switching section **715** and a second switching section **716**. The measuring force comparing section **711** compares the designated scanning measuring force that is set in advance with the measuring force signal from the measuring force detection circuit **219** to output the difference in the measuring force. The fine displacement information calculating section **712** calculates fine displacement information of the fine feed mechanism **610** based on the difference in the measuring force which is output by the measuring force comparing section **711**. The fine feed mechanism drive amplifier **713** drives the piezoelectric element **612** of the fine feed mechanism **610** based on the displacement amount information from the fine displacement information calculating section **712**. The contact detecting section **714** detects the contact of the measuring section **210** on the workpiece surface S by the measuring force signal from the measuring force detection circuit **219** to output the touch signal. The first switching section **715** makes a switch between the measuring force comparing section **711** and the contact detecting section **714** to which the measuring force signal is output from the measuring force detection circuit **219**. The second switching section **716** is disposed between the fine displacement information calculating section **712** and the fine feed mechanism drive amplifier **713**.

[0168] The measuring force comparing section **711** compares the designated scanning measuring force that is set in advance with the measuring force signal from the measuring force detection circuit **219** and calculates to output the difference between the measuring force that is actually being applied to the measuring section **210** and the designated scanning measuring force that is designated.

[0169] The fine displacement information calculating section **712** calculates the displacement amount of the fine feed mechanism **610** which is necessary to maintain the measuring force at the designated scanning measuring force and outputs it as the fine displacement information. The calculation is made based on the signal output by the measuring force comparing section **711** (the difference between the designated scanning measuring force and the measuring force signal). The fine displacement information calculated by the fine displacement information calculating section **712** is output via the second switching section **716** to the fine

feed mechanism drive amplifier **713** that drives the piezoelectric element **612** of the fine feed mechanism **610**.

[**0170**] The fine feed mechanism drive amplifier **713** is a drive amplifier for driving the piezoelectric element **612**. The fine feed mechanism drive amplifier **713** calculates a voltage to be applied to the piezoelectric element **612** based on the displacement amount commanded through the fine displacement information and applies the calculated voltage to the piezoelectric element **612**.

[**0171**] The contact detecting section **714** detects that the measuring section **210** contacts the workpiece surface S based on the measuring force signal from the measuring force detection circuit **219**.

[**0172**] Similarly to the first embodiment, the contact detecting section **714** of the second embodiment detects the contact by the touch detecting measuring force that is a measuring force smaller than the designated scanning measuring force and outputs the touch signal.

[**0173**] The first switching section **715** includes a scanning-measurement terminal **715***a* and a touching-measurement terminal **715***b*. The scanning-measurement terminal **715***a* is connected to the measuring force comparing section **711**. The touching-measurement terminal **715***b* is connected to the contact detecting section **714**.

[**0174**] The second switching section **716** includes a scanning-measurement terminal **716***a* and a touching-measurement terminal **716***b*. The scanning-measurement terminal **716***a* is connected to the fine displacement information calculating section **712**. The touching-measurement terminal **716***b* contains no signals. In other words, the fine feed mechanism **610** is in a fixed state in the touching-measurement.

[**0175**] The coarse feed mechanism control section **720** includes: a coarse displacement control section **730** that controls the displacement amount of the coarse feed mechanism **620**; a coarse feed speed control section **740** that controls drive speed of the coarse feed mechanism **620**; and a coarse feed mechanism drive amplifier **750** that controls a current amplitude value given to the coarse feed mechanism **620**.

[**0176**] The coarse displacement control section **730** includes: a position compensator **731** that generates a speed command value of the coarse feed mechanism **620**; a position comparator **732**; and a third switching section **733**.

[**0177**] The position compensator **731** generates the speed command value of the coarse feed mechanism **620** based on the signal input via the third switching section **733**. The position compensator **731** may include a phase compensator, a PI compensator, a filter or the like. The output from the position compensator **731** is sent to the subsequent coarse feed speed control section **740** as the speed command value of the coarse feed mechanism **620**.

[**0178**] The position comparator **732** is input with a command on a fixed position of the coarse feed mechanism **620** and the current displacement amount information of the coarse feed mechanism **620** in the touching-measurement. In the touching-measurement in which the coarse feed mechanism **620** is not driven but fixed at a predetermined position, the coarse feed mechanism **620** is fixed at a fixed command position. The position comparator **732** is input with a value obtained by subtracting the fine displacement information from the displacements of the coarse feed mechanism **620** and the fine feed mechanism **610** that are counted by a probe counter **741** (the displacement amount of the coarse feed mechanism **620**). The position comparator **732** outputs the difference between the fixed position command and the displacement amount of the coarse feed mechanism **620** to the touching-measurement terminal **733***b*.

[**0179**] The third switching section **733** switches the input signal for the position compensator **731** to a scanning-measurement terminal **733***a* or a touching-measurement terminal **733***b* depending on whether the measuring mode is the scanning-measurement or the touching-measurement. The scanning-measurement terminal **733***a* contains the fine displacement information calculated by the fine displacement information calculating section **712**.

[**0180**] The coarse feed speed control section **740** includes the probe counter **741**, a displacement comparator **742**, a differentiator **743**, a speed comparator **744**, and a speed compensator **745**. The displacement comparator **742** compares the displacement information by the probe counter **741** with the fine displacement information by the fine displacement information calculating section **712** to output the difference therebetween. The differentiator **743** differentiates the calculation result by the displacement comparator **742** to obtain speed information. The speed comparator **744** compares the speed information from the differentiator **743** with the coarse feed speed command value from the coarse displacement control section **730** to calculate the difference therebetween (a speed deviation). The speed compensator **745** generates a current amplitude command value from the signal value from the speed comparator **744**.

[**0181**] The displacement comparator **742** compares the fine displacement information calculated by the fine displacement information calculating section **712** with the displacement amount of the measuring section **210** calculated by the probe counter **741** to calculate the difference therebetween. The differentiator **743** calculates a differential value of the output value from the displacement comparator **742**. Herein, the differential value of the fine displacement information is the drive speed of the fine feed mechanism **610**. The differential value of the displacement amount of the measuring section **210** is the combined drive speed of the fine feed mechanism **610** and the coarse feed mechanism **620**. Accordingly, the output value from the differentiator **743** is the speed of the coarse feed mechanism **620**. The speed of the coarse feed mechanism **620** can be stabilized by providing a loop for the speed feedback.

[**0182**] The speed comparator **744** compares the coarse feed speed command value from the coarse displacement control section **730** with the speed information from the differentiator **743** to calculate the difference therebetween and outputs a signal on the drive speed to be added to the coarse feed mechanism **620**.

[**0183**] The speed compensator **745** performs a characteristic compensation on the signal from the speed comparator **744** and obtains the current amplitude value to be applied to the coarse feed mechanism **620** based on the signal (the speed information) from the speed comparator **744** in order to attain the speed obtained by the speed comparator **744**. The speed compensator **745** is for improving frequency characteristic and may include a phase compensator, a PI compensator, a filter or the like. The current amplitude command value obtained by the speed compensator **745** is sent to the coarse feed mechanism drive amplifier **750**.

[**0184**] The coarse feed mechanism drive amplifier **750** may include a coil amplifier that drives the electromagnetic

actuator **640** (the coarse feed mechanism **620**) and applies to the movable coil **642** a current suitable for the speed to be added to the coarse feed mechanism **620** based on the current command value from the speed compensator **745**.

[**0185**] The arrangement of the controller **500** is the same as the first embodiment. The controller **500** includes the counter unit **520** having the three-dimensional counter **521** and the latch counter **522**, the profile analyzing section **530**, the three-dimensional drive mechanism control section **510** and the CPU **540**.

[**0186**] The operation of the second embodiment having the above-explained arrangement will be described below

[**0187**] First, the scanning-measurement in the second embodiment will be described.

[**0188**] When the scanning-measurement is conducted, the first switching section **715**, the second switching section **716** and the third switching section **733** are respectively switched to the scanning-measurement terminals **715***a*, **716***a*, **733***a*. And the designated scanning measuring force is then input to the measuring force comparing section **711**. The vertical movement drive mechanism **600** (the fine feed mechanism **610**, the coarse feed mechanism **620**) is controlled by the vertical movement drive mechanism control unit **700** so as to have the designated scanning measuring force.

[**0189**] The contact portion **212** is brought into contact with the workpiece surface S, and the probe **200** is moved along the X and Y axes of the three-dimensional drive mechanism **300** to which the vertical movement drive mechanism **600** is attached (along the drive axes for moving the measuring section **210** to trace on the workpiece surface S). When the contact portion **212** abuts on the workpiece surface S, the measuring force applied from the workpiece surface S to the contact portion **212** is detected by the measuring force detection circuit **219** and the detection result is input to the measuring force comparing section **711** via the first switching section **715**. The measuring force comparing section **711** compares the designated scanning measuring force with the measuring force signal to calculate the difference therebetween (a measuring force deviation) to output it to the fine displacement information calculating section **712**.

[**0190**] The fine displacement information calculating section **712** calculates a movement amount of the contact portion **212** which is necessary to eliminate the deviation between the designated scanning measuring force and the detected measuring force and outputs it as the fine displacement information.

[**0191**] The fine displacement information output from the fine displacement information calculating section **712** is branched: a portion thereof is sent to the fine feed mechanism drive amplifier **713** to drive the fine feed mechanism **610**; the other is sent to the coarse feed mechanism control section **720** to drive and control the coarse feed mechanism **620**. The fine feed mechanism drive amplifier **713** applies to the piezoelectric element **612** of the fine feed mechanism **610** a voltage value that is necessary to drive the fine feed mechanism **610** by the displacement amount commanded by the fine displacement information. Thereby, the measuring section **210** is displaced such that the measuring force becomes constant at the designated scanning measuring force.

[**0192**] The fine displacement information calculated by the fine displacement information calculating section **712** is further branched in the coarse feed mechanism control section **720**: a portion thereof is sent to the position comparator **732** to form a loop for control of the displacement amount of the coarse feed mechanism **620**; the other is sent to the displacement comparator **742** to form a loop for speed control of the coarse feed mechanism **620**.

[**0193**] The fine displacement information is sent to the position compensator **731** via the scanning-measurement terminal **715***a* of the first switching section **715** and is output to the speed comparator **744** as a speed command that is necessary to compensate the displacement of the fine feed mechanism **610** and bring the displacement of the fine feed mechanism **610** within a predetermined fine range.

[**0194**] The displacement of the contact portion **212** is detected by a displacement detecting sensor and sent to the probe counter **741** as the displacement amount signal. The displacement amount signal is counted by the probe counter **741**, and the displacement of the contact portion **212** (the combined displacement of the coarse feed mechanism **620** and the fine feed mechanism **610**) is calculated. The displacement amount of the contact portion **212** which is counted by the probe counter **741** is sent to the displacement comparator **742**. Meanwhile, the actual displacement amount of the contact portion **212** from the probe counter **741** is sent to the profile analyzing section **530** to be the measurement data therein.

[**0195**] The fine displacement information and the displacement information output from the probe counter **741** are compared with each other by the displacement comparator **742** and the difference therebetween is calculated. The output from the displacement comparator **742** is sent to the differentiator **743** and differentiated to be output to the speed comparator **744** as the speed information.

[**0196**] In the speed comparator **744**, the output value from the position compensator **731** and the speed information from the differentiator **743** are compared with each other and the difference therebetween is calculated. The calculation result is the speed to be further added to the coarse feed mechanism **620** and is converted by the speed compensator **745** into the current amplitude value to be further added to the coarse feed mechanism **620**. The output from the speed compensator **745** is the current amplitude value to be further added to the coarse feed mechanism **620** and is output to the coarse feed mechanism drive amplifier **750**. The coarse feed mechanism drive amplifier **750** applies a voltage to the movable coil **642** of the coarse feed mechanism **620** based on the current amplitude value input from the speed compensator **745**. Accordingly, the movable coil **642** is displaced in the magnetic field of the permanent magnet **641**, and the coarse feed mechanism **620** is driven. The displacement of the movable coil **642** causes the displacement of the movable portion **643**, thereby causing the displacement of the fine feed mechanism **610** and the measuring section **210**.

[**0197**] Thus, the fine feed mechanism **610** and the coarse feed mechanism **620** move the measuring section **210**.

[**0198**] The displacement amount of the contact portion **212** is output from the probe counter **741** to the profile analyzing section **530**. The displacement amount of the contact portion **212** counted by the probe counter **741** and the drive amount of the three-dimensional drive mechanism **300** are processed into the measurement data of the workpiece surface S.

[0199] Next, the touching-measurement in the second embodiment will be described.

[0200] When the touching-measurement is conducted, the first switching section **715**, the second switching section **716** and the third switching section **733** are respectively connected to the touching-measurement terminals **715***b*, **716***b*, **733***b*. And the information on the fixed position of the coarse feed mechanism **620** is input to the position comparator **732**. The difference between the displacement of the contact portion counted by the probe counter **741** and the fine displacement information from the fine displacement information calculating section **712** is output from the displacement comparator **742** to be input to the position comparator **732** of the third switching section **733**. The position comparator **732** outputs a signal to move the coarse feed mechanism **620** to the fixed position and a predetermined voltage is applied from the touching-measurement terminal **733***b* via the coarse feed speed control section **740** and the coarse feed mechanism drive amplifier **750** to the movable coil **642** such that the movable coil **642** of the coarse feed mechanism **620** is controlled to the fixed position. Accordingly, the coarse feed mechanism **620** is fixed at the fixed position. When the second switching section **716** is switched to the touching-measurement terminal **716***b*, the touching-measurement terminal **716***b* is input with a signal, for example, "0", the fine feed mechanism **610** is not driven and the piezoelectric element **612** is in an unaffected state having a normal length. Herein, the piezoelectric element **612** may be positioned at a predetermined position by adding a predetermined signal to the touching-measurement terminal **716***b*.

[0201] In the aforesaid state, the probe **200** is moved by the three-dimensional drive mechanism **300** to conduct the touching-measurement. More specifically, the contact portion **212** is moved toward the workpiece surface S by the three-dimensional drive mechanism **300**, and when the contact portion **212** contacts the workpiece surface S, the measuring force applied from the workpiece surface S to the contact portion **212** is detected by the measuring force detection circuit **219**. The measuring force signal from the measuring force detection circuit **219** is input via the first switching section **715** to the contact detecting section **714** and is compared therein with the touch detecting measuring force. The contact portion **212** is pressed into the workpiece surface S until the measuring force signal reaches the touch detecting measuring force, where the touch signal is output from the contact detecting section **714**.

[0202] The touch signal is input to the three-dimensional drive mechanism control section **510**. When the touch signal is received by the three-dimensional drive mechanism control section **510**, the contact portion **212** is moved apart from the workpiece surface S. Subsequently, the contact portion **212** is moved to and from the workpiece surface S at a next sampling point. The touch signal is input to the latch counter **522**. The latch counter **522**, which receives the touch signal, latches the count value of the three-dimensional counter **521** and outputs it to the profile analyzing section **530**. The profile analyzing section **530** plots the positions of the contact portion **212** at the times when the touch signals are output, whereby the profile of the workpiece surface S is obtained.

[0203] The second embodiment having the above-described arrangement can provide advantages below.

[0204] Since the fine feed mechanism **610** and the coarse feed mechanism **620** are provided, in the scanning-measurement, the fine feed mechanism **610**, which response speed is high, can finely move the contact portion **212** for small ridges and valleys of the workpiece surface S, and the coarse feed mechanism **620**, which can process a large change, can process a large profile change of the workpiece surface S (such as an undulation) (see FIG. **8**).

[0205] [Modification 4]

[0206] A modification 4 of the invention will be described below.

[0207] When the workpiece surface S is slant, the contact portion **212** abuts on the workpiece surface S in a direction deviated from the axial direction of the stylus. At this time, the stylus **211** receives a force in a direction crossing the axial direction thereof, so that the stylus **211** is flexed. When the stylus has the flexure, the abutting position between the contact portion **212** and the workpiece surface S becomes deviated by the amount of the flexure. To deal with this, the profile analyzing section **530** is set with compensation parameters for the X, Y and Z directions, which are determined from the tilt angle of the workpiece surface S and the measuring force in the measurement, and the detected measurement data is compensated using the compensation parameters. According to the arrangement, even when the workpiece surface S has a slant portion, the profile of the workpiece surface S can be obtained accurately.

[0208] Note that the scope of the present invention is not restricted to the above-described embodiments, but includes modifications and improvements as long as an object of the present invention can be achieved.

[0209] For example, although the measuring force detecting unit includes the vibrator and the detector in the aforesaid embodiments, a strain gauge may be used for detecting the measuring force.

[0210] Although the switching operation of the first switching section **715**, the second switching section **716** and the third switching section **733** according to the second embodiment is not described above, the switching may be operated manually like in the first embodiment or automatically like the modifications **1** and **2**.

[0211] In the aforesaid embodiments, the latch counter **522** has been described as the latch counter that latches the three-dimensional counter **521**. However, the arrangement is not limited thereto but a probe latch counter that latches the probe counter **430** may be provided such that the latch counter **522** and the probe latch counter form the latch counter. The profile of the workpiece surface may be calculated based on the position of the contact portion **212** which is latched by these two latch counters. It is preferable that such probe latch counter is also used in order to ensure an accurate measurement, since when the vertical movement drive mechanism **220** is stopped at a predetermined position by the servo lock or the like, the measuring section **210** may be finely moved (or finely moved due to temperature drift) in the touching-measurement.

[0212] In the aforesaid embodiments, the linear encoder has been described as one example of the displacement detector, but the displacement detector is not limited thereto. An analog-type detector or a non-contact type detector such as an interferometer may be used. The counter may be a counter that outputs the output of the analog-type detector in an A/D converted digital amount or in an analog amount.

[0213] The priority application Number JP2005-254016 upon which this patent application is based is hereby incorporated by reference.

What is claimed is:

1. A surface profile measuring instrument, comprising:

a measuring section including a stylus having a contact portion to contact a workpiece surface at a tip end and a measuring force detecting unit which detects a measuring force when the contact portion abuts on the workpiece surface;

a moving unit which moves the measuring section relative to the workpiece surface; and

a drive control unit which controls the moving unit based on the magnitude of the measuring force detected by the measuring force detecting unit, the contact portion being brought into contact with the workpiece surface to measure the workpiece surface, wherein

the drive control unit includes: a scanning-measurement control section which controls the moving unit such that the moving unit conducts a scanning-measurement in which the measuring force is a preset designated scanning measuring force and the contact portion is moved for scanning along the workpiece surface; and a touching-measurement control section which controls the moving unit such that the moving unit repeatedly conducts touching-measurements on the workpiece surface, in the touching measurements the contact portion being brought into and then out of contact with the workpiece surface, the contact portion contacting the workpiece surface at a touch detecting measuring force set smaller than the designated scanning measuring force,

the measuring force detecting unit has a predetermined measuring force detecting direction, the measuring force detecting unit detecting the measuring force acting in the direction,

when the contact portion contacts the workpiece surface in a direction along the measuring force detecting direction, the scanning-measurement control section conducts the scanning-measurement, and

when the contact portion contacts the workpiece surface in a direction deviated from the measuring force detecting direction, the touching-measurement control section conducts the touching-measurement.

2. The surface profile measuring instrument according to claim 1, further comprising:

a displacement detector which detects a displacement of the contact portion to output a displacement detection signal, wherein

the touching-measurement control section includes a contact detecting section which outputs a touch detection signal when the measuring force reaches the touch detecting measuring force, and

the drive control unit includes: a counter which counts the displacement detection signal to calculate a position of the contact portion; a latch counter which receives the touch detection signal and latches the position of the contact portion which is counted by the counter; and a profile analyzing section which calculates a surface profile of the workpiece based on the position of the contact portion calculated by the counter and the position of the contact portion latched by the latch counter.

3. The surface profile measuring instrument according to claim 1, wherein

the drive control unit includes a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated, and

the switching section is switched in accordance with a selection by a user depending on the profile of the workpiece surface.

4. The surface profile measuring instrument according to claim 1, wherein

the drive control unit includes: a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated; and a switching control section which controls the switching of the switching section, and

the switching control section switches and controls the switching section based on a change in the measuring force detected by the measuring force detecting unit.

5. The surface profile measuring instrument according to claim 1, wherein

the drive control unit includes: a switching section for selecting the scanning-measurement control section or the touching-measurement control section as the one to be operated; and a switching control section which controls the switching of the switching section, and

the switching control section switches and controls the switching section based on the surface profile of the workpiece.

6. The surface profile measuring instrument according to claim 1, wherein

the scanning-measurement control section changes the designated scanning measuring force in accordance with an angle formed by the workpiece surface and the measuring force detecting direction.

7. The surface profile measuring instrument according to claim 1, wherein

the touching-measurement control section changes the touch detecting measuring force in accordance with the angle formed by the workpiece surface and the measuring force detecting direction.

8. The surface profile measuring instrument according to claim 1, wherein

the moving unit includes: a fine feed mechanism which finely moves the measuring section; and a coarse feed mechanism which moves the fine feed mechanism and the measuring section more coarsely than the fine feed mechanism.

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