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Schima et al.(54) **ROTARY PUMP COMPRISING A
HYDRAULICALLY MOUNTED ROTOR**(30) **Foreign Application Priority Data**

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Raderer, Wien (AT)****Publication Classification**(51) **Int. Cl.⁷** **F04B 17/00**(52) **U.S. Cl.** **417/420; 415/900; 417/423.1;
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RIVERDALE (BRONX), NY 10471-0900 (US)**(57) **ABSTRACT**

The invention relates to a pump for moving blood and other shear-sensitive with a rotor journaled hydraulically and, if necessary, magnetically in a housing and where the rotor (1) has flow-control surfaces (2, 4, 35, 33, 37, 41) for producing centrifugal flow components (3) and flow components (4) directed against the housing (30), the centrifugal flow components (3) serving mainly for producing the externally effective throughput and the flow components (5) directed against the housing serving mainly for contact-free journaling and stabilizing of the rotor in the housing.

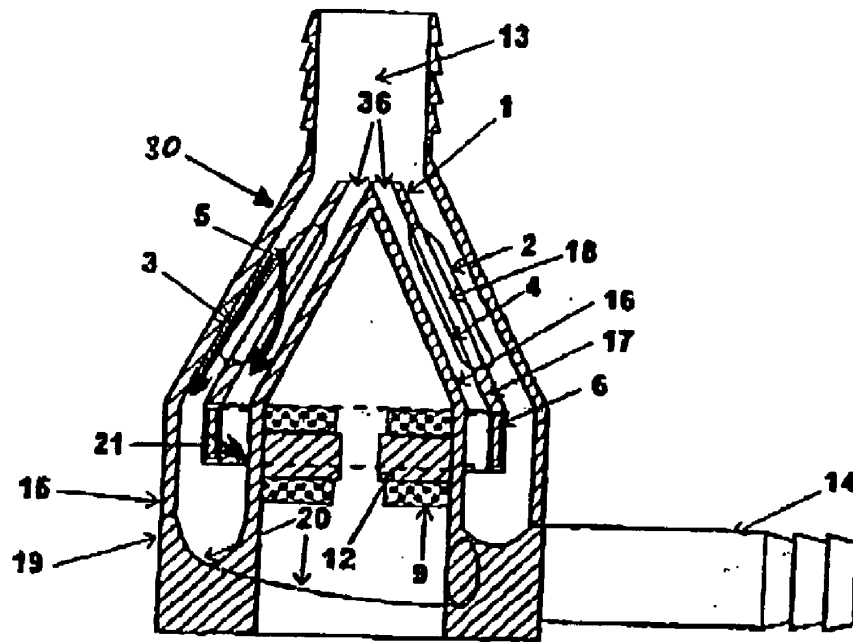
(21) Appl. No.: **10/239,602**(22) PCT Filed: **Mar. 22, 2001**(86) PCT No.: **PCT/AT01/00086**

FIG.
Abb. 1

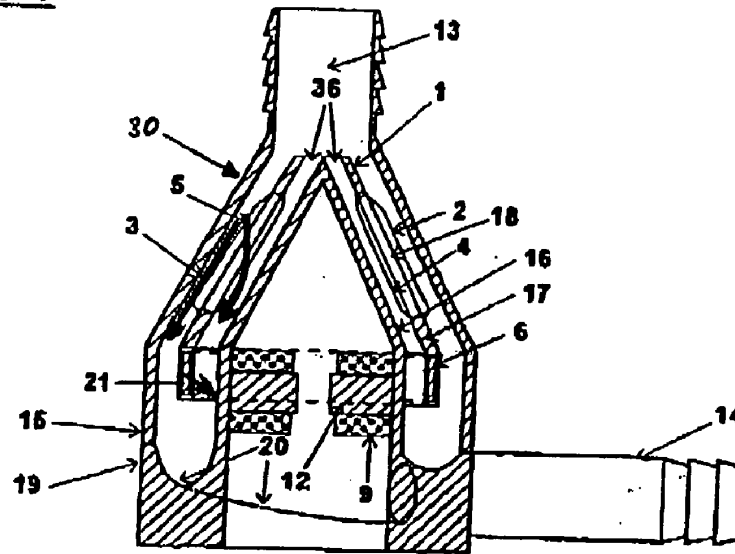


FIG.
Abb. 2

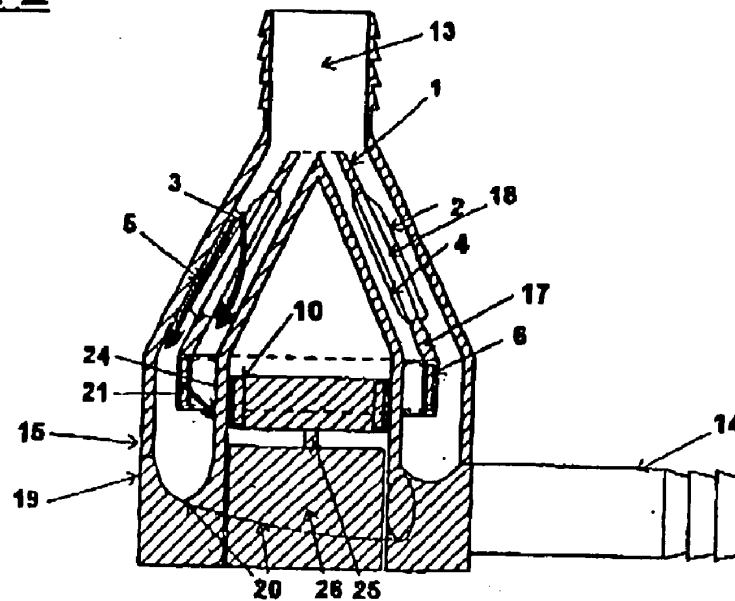


Fig
Abb. 3

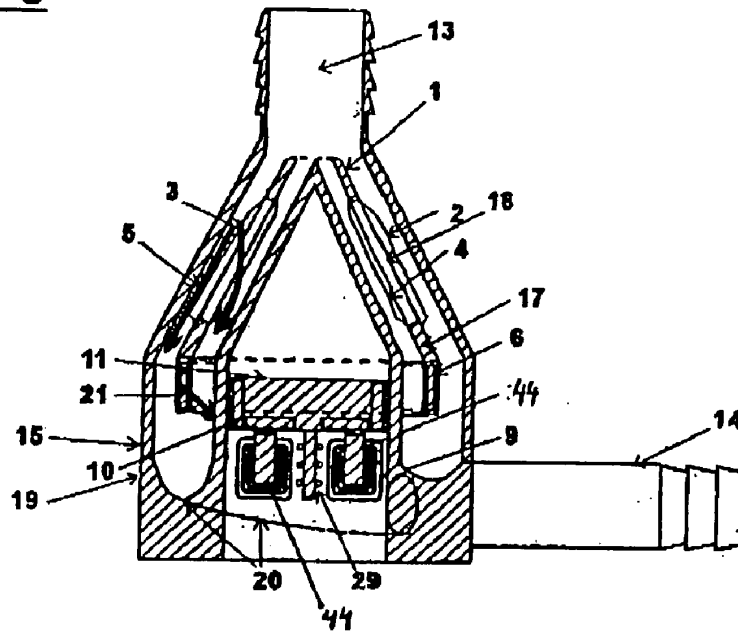
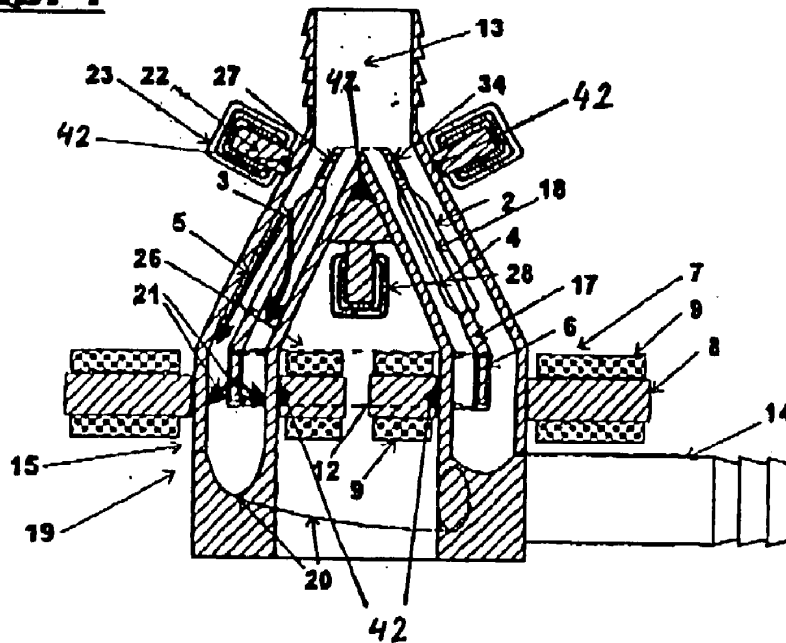
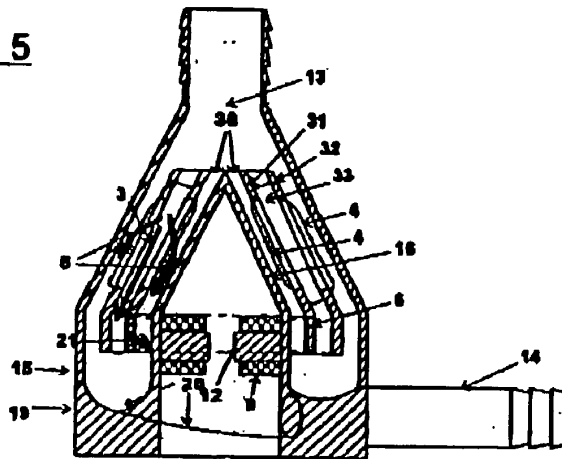


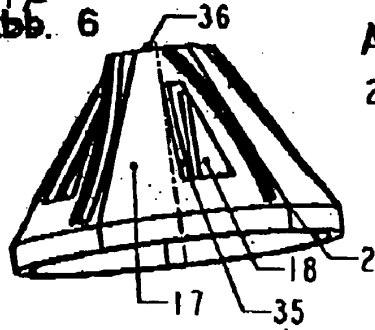
Fig
Abb. 4



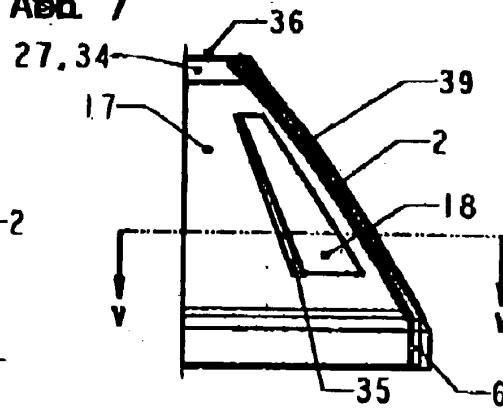
~~Fig~~
~~Abb. 5~~



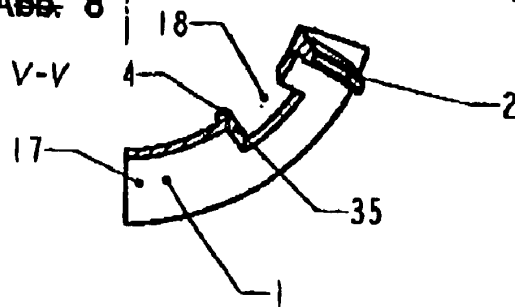
~~Fig~~
~~Abb. 6~~

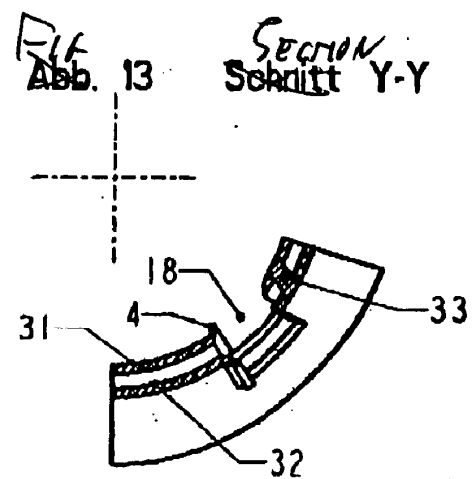
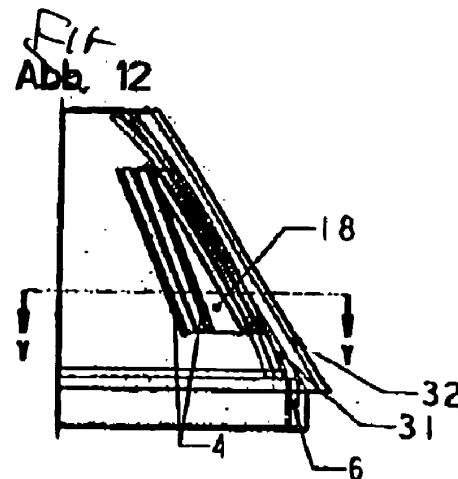
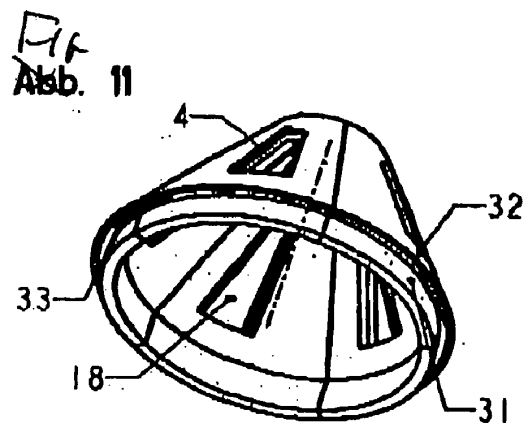
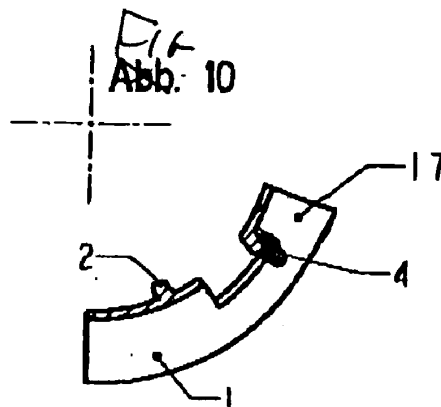
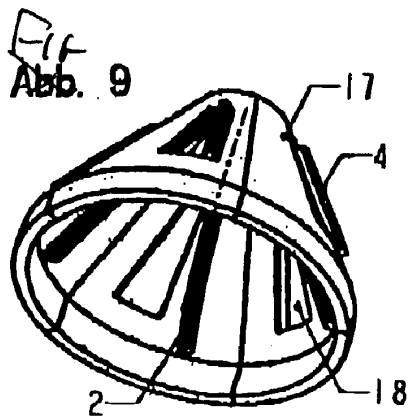


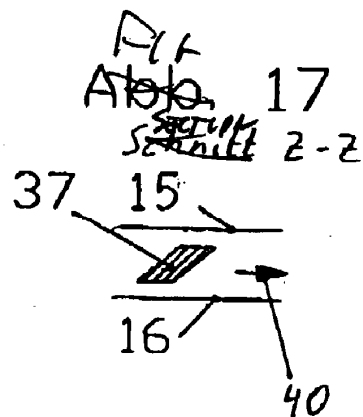
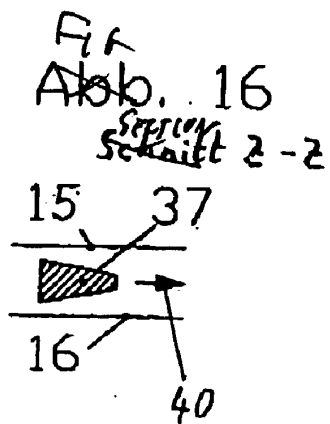
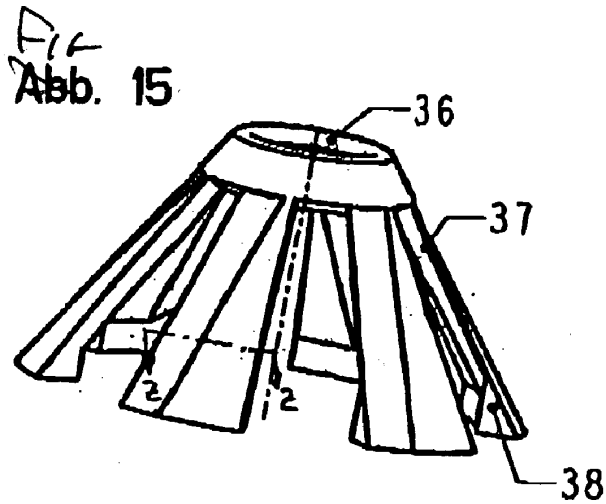
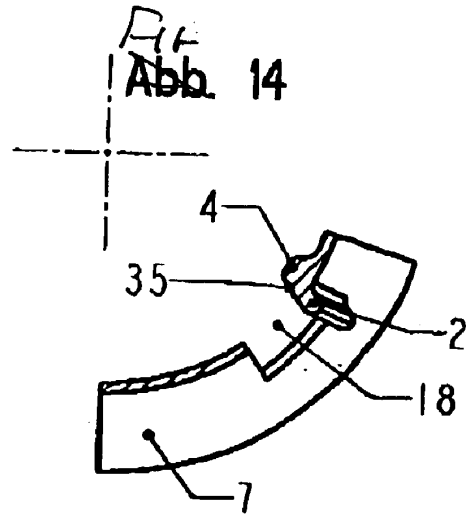
~~Fig~~
~~Abb. 7~~



~~Fig~~
~~Abb. 8~~







ROTARY PUMP COMPRISING A HYDRAULICALLY MOUNTED ROTOR

[0001] The present invention relates to a rotary pump for moving blood and other shear-sensitive liquids with a rotor journaled hydraulically and, if necessary, magnetically in a housing.

[0002] In order to pump blood and other shear-sensitive liquids, rotary pumps and the like are used. In order to minimize destruction of the blood, locally occurring speed differences should not be too great as otherwise the corpuscular portion of the blood is subjected to shear and as a result of the heat generated by friction there is chemical degradation. In addition low-flow and dead-water areas must be avoided in order to prevent deposits from forming. When pumping blood, this is referred to as thrombosis- or clot-forming.

[0003] This problem is particularly an issue in conventional axle-type pumps since the axle is mounted in a standard seal, for example in a needle bearing in the pump chamber, so as to produce regions of high shear, friction and also often of low flow velocity near the axle.

[0004] Therefore solutions have been suggested to provide pumps without axles or mechanical bearings. Thus Akamatsu et al (see e.g. *Artificial Organs* 1997, Vol. 21, No. 7, pp. 645-638) proposes a pump where the rotor of a centrifugal pump is driven from one side by a standard motor and is stabilized by a controlled electromagnet. This pump above all is of complex construction and there is a small gap between the rotor and the housing for proper electrical operation.

[0005] Kung and Hart (*Artificial Organs* 1997, Vol. 21, No. 7, pp. 645-650) suggest a pump where the journaling is done purely hydraulically by a geometric distribution of gaps above and below the pump that are enlarged and decreased by axial movements of the pump and the changes created thereby in pressure between the rotor and the housing are used for stabilizing the pump. This system functions only with a relatively narrow gap and can be made unstable even if small amounts of blood form deposits.

[0006] Furthermore, Allaire et al (see e.g. *Artificial Organs* 1996, Vol. 20, No. 7, pp. 582-690) suggest a centrifugal pump where the rotor is journaled by a relatively expensive system of electromagnets. In this system there are also small gaps and control is complex.

[0007] Golding (U.S. Pat. Nos. 5,324,177 and 5,370,509) has in addition suggested floating a conical rotor with helical arms on a cone and centering of the rotor by support forces between a flatly shaped rotor inner wall and a cone of the housing end wall. This method requires above all the formation of very small gaps and thus high shear forces, at the same times fluid tends to sit for quite some time in the gap and the centering forces are very modest.

[0008] Finally Woodward et al (WO 00/12587) proposes a pump whose rotor is hydrodynamically journaled, the rotation body having several cylindrical elements whose angled ends form tapered gaps together with the housing upper surface. The pressures that build up therein or the liquid trapped between the tapering surfaces serves to center the rotor. At the same time the conical shape of the housing upper wall ensures radial centering. This invention relates to

a preferred system of stabilizing forces, but is disadvantageous in that a small gap in the range of less than 0.3 mm is used which creates considerable shear and which can lead to substantial changes in the flow parameters if there is any deposition of solids. In addition the rotor shapes suggested there create a multiplicity of dead spots and stagnant zones.

[0009] The present invention therefore has the object of overcoming these disadvantages. Mechanical depositions, dead-water zones or zones of reduced flow velocity and small gaps are to be avoided. The number of parts should be small and the construction simple.

[0010] The invention is characterized in that the rotor has flow-control surfaces for producing centrifugal flow components and flow components directed against the housing, the centrifugal flow components serving mainly for producing the externally effective throughput and the flow components directed against the housing serving mainly for contact-free journaling and stabilizing of the rotor in the housing. Further preferred features are that the housing has a conical central part and/or a hollow conical upper part and that the rotor arranged between them is conical. Furthermore the flow-control surfaces are formed as vanes on a conical inner and/or outer surface of the rotor. Preferably the rotor has flow-through rotor holes on which the flow-control surfaces are mounted. Further features can be seen in the claims, the description, and the drawing.

[0011] The invention is described in the following with reference to seventeen figures. FIGS. 1 to 5 show cross sections through various embodiments of the pump and FIG. 6 an oblique view of a rotor. FIG. 7 is a section through the rotor and FIG. 8 an angle view of the section according to line V-V of FIG. 7. FIGS. 9 and 11 show rotors in an oblique view and FIGS. 12, 12, 13, and 14 the respective sections. FIGS. 15 shows a further embodiment of the rotor and FIGS. 16 and 17 show possible cross sections through the rotor vane. All figures are schematic.

[0012] FIG. 1 shows a section through the pump. The rotor 1 has as flow surfaces 2 and 4 vanes that produce centrifugal flow components 3 and flow components 5 directed against the housing. To this end these flow surfaces 2 and 4 are formed on a conical base 17 which has rotor openings 18 for flow to the inner vanes 4. This hollow conical rotor 1 rotates in a pump housing 30 comprised of a housing lower part 19 with a conical middle part 16 and a hollow conical upper part 15, centering of the hollow conical rotor in the middle part 16 of the housing lower part 19 being effected by the flow components 5 directed against the housing, this flow being preferably axially against the conical upper surface of the middle part 16. This centering can however also be wholly or additionally effected by flow components (5) directed against the housing or centrifugally (3) against the hollow conical upper part 15. A spiral-shaped outlet passage 20 in the lower housing part 19 leads to an outlet 14. The rotor holds rotor magnets 6 that preferably transfer rotation energy and that can be individual or formed by a continuous magnetic ring. These rotor magnets work as shown in FIG. 1 with a stator 12 inside the housing lower part 19 having coils 9 creating a rotating magnetic field. An axial offset of the rotor magnets 6 and stator 8 causes the coupling force 21 to be effective at an angle and provide an axial component for additional stabilizing of the rotor 1, the direction of this axial component being upward or down-

ward by appropriate offset of the stator 12 upward or downward. The rotor 1 has at an inlet 13 an inlet opening 36 that distributes the incoming liquid to both sides of the rotor and against the point of the cone-shaped middle part 16.

[0013] As shown in FIG. 2, the drive can also be an electric motor 26 which drives a rotating disk 24 with magnets 10 by means of a shaft 25. This embodiment has the advantage that no electrical energy is used to journal the rotor and as a result the axial offset of the disk 24 ensures an axial component for the magnetic force 21.

[0014] FIG. 3 shows that the drive can be a disk-rotor motor where the disk 11 with imbedded magnets 10 or a similar multipolar magnetization with a journaled axle 29 simultaneously serves as rotor for the motor-stator 44 and for transmitting magnetic energy 5 to the rotor 1.

[0015] As shown in FIG. 4 the drive 7 can be an externally effective stator 8 that is used instead of or in addition to an internal stator 12. In addition for hydraulic stabilization of the rotor 1 all embodiments of the drive also have a magnetic stabilizer near the inlet 13, a ferromagnetic or permanent-magnet ring 27 imbedded in the rotor 1 being provide internally and/or externally with permanent or electromagnets 22 and 28 with coils 23 so as to compensate for any instability caused by flow past the rotor. The ferromagnetic ring 27 can be provided externally with an electrically very conductive layer 34 in order to facilitate the formation of electrical eddy currents which create magnetically centering forces.

[0016] In addition a combination of inside and outside drive systems (stators 8 and 19) is possible on the lower edge of the rotor 1, one of which preferably serves for transmitting rotation energy and the other for stabilization purposes.

[0017] The position (running characteristic) of the rotor can for example be determined by appropriate position sensors as shown schematically in FIG. 4 at 42 in various positions. For example Hall-type sensors can be used. In order to determine position however induced voltages or the effect of high-frequency feed voltages in the coils can be measured and evaluated, eliminating the need of any further sensors.

[0018] Various embodiments are described in FIGS. 5 to 15.

[0019] FIG. 5 shows an embodiment of the pump with a rotor 1 that is formed of two superposed conical sleeves 31 and 32 that are connected together by centrifugal vanes or flow surfaces 33. Rotor openings 18 and the outer vanes 4 serve to produce the flow component 5 against the upper part 15 of the housing as well as against the conical middle part 16 of the lower housing part 19. In this manner the rotor is hydrodynamically stabilized in the housing.

[0020] FIGS. 6 to 8 show in oblique view, top view, and section the basic shape of a rotor 1 in an embodiment with a conical base part 17 on whose outside are mounted vanes serving as flow surfaces 2 for preferably producing centrifugal flow components. These vanes can have an arched portion 39 known in centrifugal blood pumps and that allows the vanes to be oriented against the rotation direction 40. The base body 17 has at the inlet side the inlet opening 36 that makes possible direct flow into the point of the conical central part 16 of the housing lower part 19. The base

body is further formed with rotor holes 18 through which the liquid can be move by the vanes 4 against the housing middle part 16. The effect of the vanes 2 and 4 can be increased by an angling 35 of the opening 18 or when the conical body 17 is thick enough even replaced, in which latter case the vanes 2 and 4 can be eliminated. The flow surfaces are thus only formed by an angling of the edges of the rotor openings 18.

[0021] FIGS. 9 and 10 show in angled view and section the also possible variant whereby the vanes 4 for producing the flow component 5 against the housing are on the outer side of the conical base body 17 and the vanes 2 for preferably producing centrifugal flow components 3 are on the inside of the base body 17.

[0022] These two described opposite rotor constructions are made possible by as described above an upward or downward axial offset of the rotor magnets 6 and the drive magnets 8, 12, or 24 and the thereby achieved equally selective upwardly or downwardly directed axial components of the magnetic forces 21, see FIGS. 1 to 5.

[0023] FIGS. 11 to 13 show a rotor with two nested conical sleeves. It makes possible flow against both housing walls 16 and 19. It is shown in cross section in FIG. 5 and is shown in detail in angled view in FIG. 11, in FIG. 12 in top view, and in FIG. 13 in a section transverse to the axis of the pump. Here the inner conical sleeve 31 and the outer conical sleeve 32 are connected together by struts 33 that are also effective as flow-control vanes. The rotor holes 18 have edge bevels or vanes (4) that produce the flow component directed against the housing.

[0024] In addition this arrangement of the two flow-control surfaces (2 and 4) in combination with the angling 35 of the rotor hole 18 in the conical sleeve can be formed together to a single vane formation as shown in FIG. 14. This formation is also possible with superposed conical sleeves.

[0025] Finally the pump according to FIG. 15 also has a rotor where the individual vanes 37 are freestanding without a continuous conical base body. These vanes are either of a wedge-shaped profile (see FIG. 16) or have an angled shape (see FIG. 17), a substantial beveling 37 forming flow-control surfaces. The rotor holes 18 extend to the lower edge 41 of the rotor 1. This lower edge can also extend at an angle to the flow direction so that it serves as a flow-control surface for reducing the drive component or a flow component for the liquid flow. The ends of the vanes can carry magnets 38 for the drive and additional magnetic journaling.

[0026] In FIGS. 1 to 5 the outlet is always underneath the lower edge 41. When the outlet 14 should be set higher, generally in the plane of the lower edge 41 of the rotor 1, it can be advantageous to provide two symmetrically opposite outlets or one outlet with two parts, in order to stabilize flow of the liquid.

1. A rotary pump for moving blood and other shear-sensitive liquids and having a rotor journaled hydraulically and if necessary magnetically in a housing, characterized in that the rotor (1) has flow-control surfaces (2, 4, 35, 33, 37, 41) for producing centrifugal flow components (3) and flow components (4) directed against the housing (30), the centrifugal flow components (3) serving mainly for producing the externally effective throughput and the flow components

(5) directed against the housing serving mainly for contact free journaling and stabilizing of the rotor in the housing.

2. The pump according to claim 1, characterized in that the housing (30) has a conical central part (16) and/or a hollow conical upper part (15) and that the rotor (1) arranged between them is conical.

3. The pump according to claim 1 or 2, characterized in that the flow-control surfaces are formed as vanes (2 and 4) on a conical inner and/or outer surface of the rotor.

4. The pump according to one of claims 1 to 3, characterized in that the rotor (1) has flow-through rotor holes (18) on which the flow-control surfaces (2, 4, 35, 33, 37, 41) are mounted.

5. The pump according to one of claims 1 to 4, characterized in that edges of the rotor holes (18) are beveled to form flow-control surfaces (35 and 37).

6. The pump according to one of claims 1 to 5, characterized in that the rotor holes (18) extend to a lower edge (41) of the conical sleeve and the lower edge (41) if necessary is formed as flow-control surfaces for producing a drive component.

7. The pump according to one of claims 1 to 6, characterized in that the rotor (1) is formed of two nested conical sleeves (31 and 32) between which extend vanes serving as flow-control surfaces (33) for producing the centrifugal flow components (3) and that the two conical sleeves (31 and 32) have rotor openings (18) and selectively vanes (4) for producing the flow components (5) directed against the housing.

8. The pump according to one of claims 1 to 7, characterized in that the rotor (1) has at an inlet (13) and inlet opening (36) in order to direct a portion of the incoming liquid against a point of the conical central part (16) of the housing (30).

9. The pump according to one of the preceding claims, characterized in that in the region of the lower edge (41) the rotor (1) is provided with a plurality of rotor magnets (6) or a magnetic ring that cooperates with magnets (10, 12) in the housing (30) and/or with a magnetic drive.

10. The pump according to claim 9, characterized in that the magnetic drive is formed by a stator (8, 12) with a surrounding magnetic field.

11. The pump according to claim 9, characterized in that the magnetic drive is formed by a disk rotor, a stator (38) being provided with a rotating disk (24) with imbedded magnets (10) or multiple magnetized regions.

12. The pump according to one of claims 1 to 11, characterized in that the rotor magnets (6) and the magnetic-force producing portions of the drive motor (8, 11, 12) are offset axially such that the produce on the rotor (1) in addition to rotation energy a force component effective axially and serving to journal and/or stabilize the rotor (1).

13. The pump according to one of claims 1 to 12, characterized in that in addition to the drive a ring (27) of ferromagnetic iron or permanent-magnet material is provided around the inlet (13) and in the adjacent housing parts permanent or electromagnets (22, 23, 28) are provided for additional magnetic stabilization, and that preferably to control this magnets additional sensors (42) are provided for determining the exact position of the rotor (1) (FIG. 4).

14. The pump according to one of claims 1 to 13, characterized in that the ring (27) of ferromagnetic iron around the inlet (13) has a highly conductive surface coating (34), so that eddy currents and magnetic fields therein center the rotor (1).

15. The pump according to one of claims 1 to 14, characterized in that in order to rotate and stabilize the rotor (1) a peripheral external stator (8) and an internal either stator (12) or motor (26) or a disk-rotor motor (24, 29) with a magnetic disk (11, 24) is provided, the internal components (12, 26, 29, 11, 24) preferably being effective to produce the rotation energy and the external stator for stabilizing the rotor (1).

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