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(54) **PUMP DEVICE**

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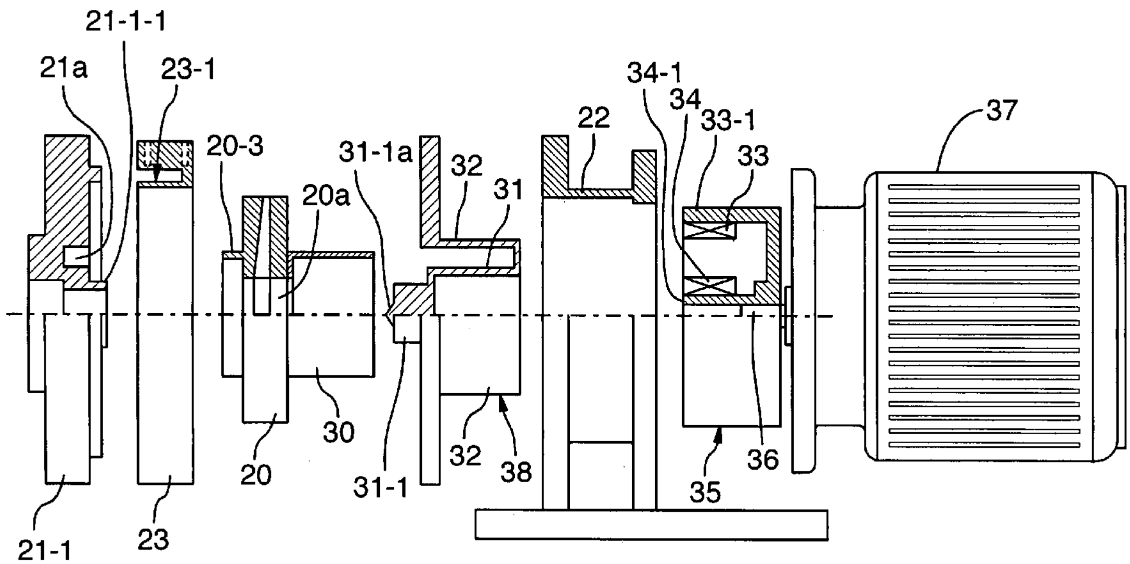
(57) **ABSTRACT**

A centrifugal pump for use with a liquid forms one aspect of the invention. This pump comprises a housing and a rotor. The housing has an interior surface defining an interior cavity, an axis intersecting the cavity, an intake port for receiving liquid and communicating same to said cavity, and a discharge port in communication with said cavity. The rotor has an impeller, is positioned in said cavity and is rotatable in said cavity about said axis in spaced relation to the interior surface. The impeller is adapted to force said liquid to flow through said discharge port upon said rotation in use. The pump further comprises means for balancing the pressure in said cavity, adapted so as to avoid the creation of pressure differentials in said cavity that would otherwise in use tend to cause translation of said rotor in said cavity. The pump further comprises a rotating magnetic field generation device adapted to drive rotation of said rotor about said axis in use.



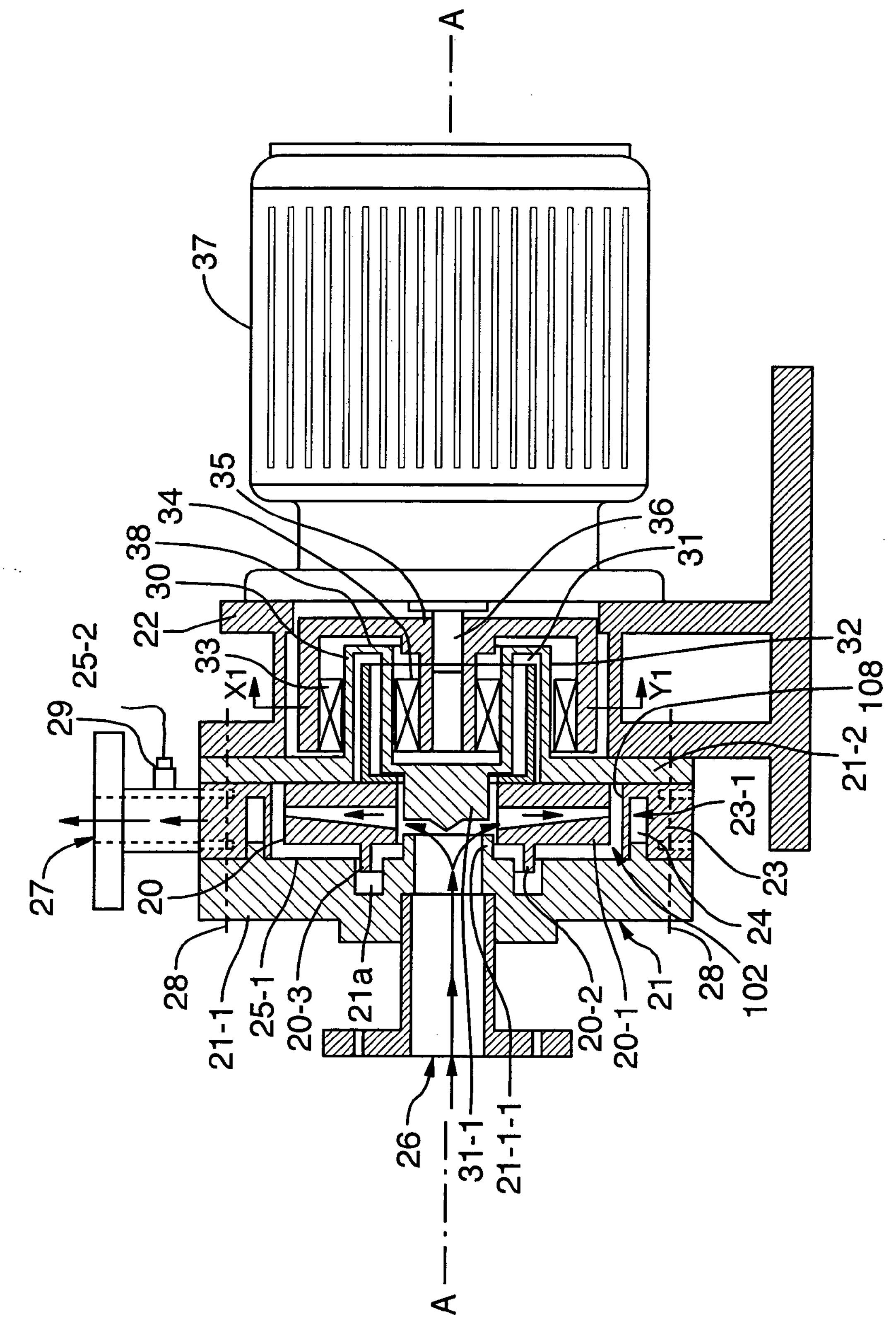
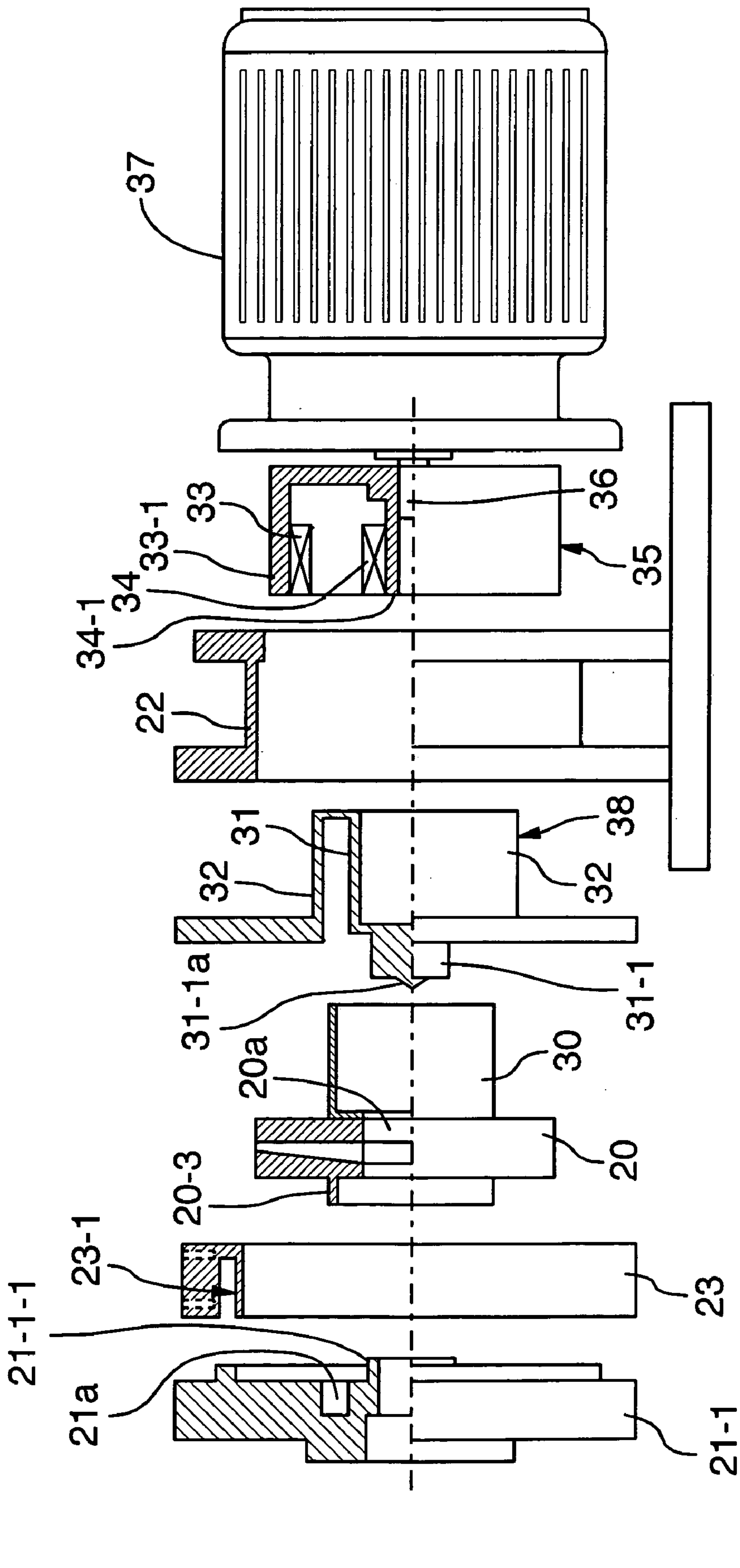

A
37
35
34
38
30
22
33
X1
25-2
29
27
20
28
21-1
25-1
20-3
21a
26
31-1
21-1-1
20-2
20-1
21
28
102
24
23
23-1
21-2
108
Y1
32
31
36
A

FIG.1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36
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33
33-1
34
34-1
22
31
38
32
32
31-1a
31-1
20a
30
20-3
20
23-1
23
21-1-1
21a
21-1

FIG.2

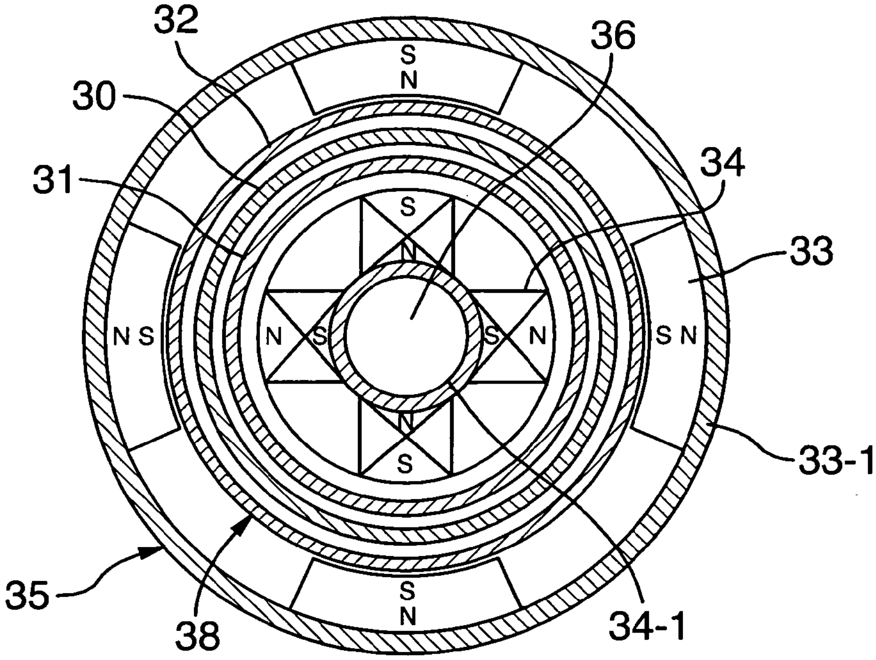

FIG.3

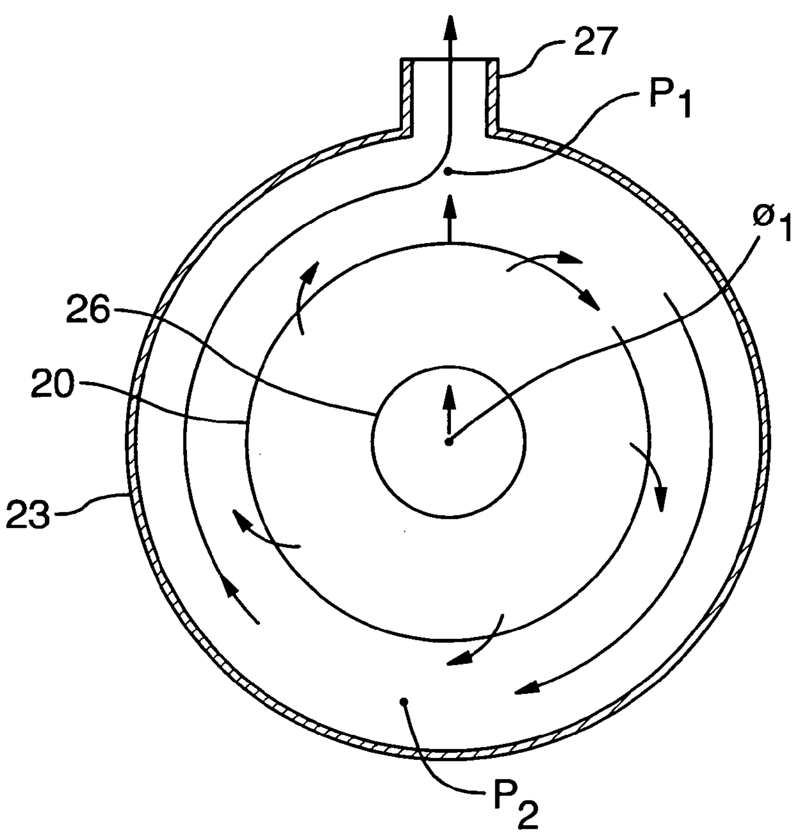

FIG.4

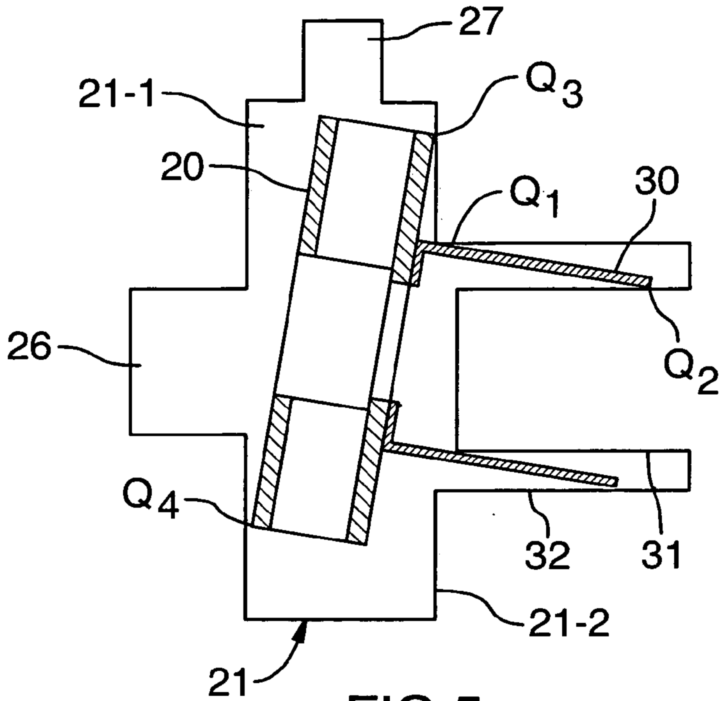
27
21-1
Q_3
20
Q_1
30
26
Q_2
Q_4
32
31
21-2
21

FIG.5

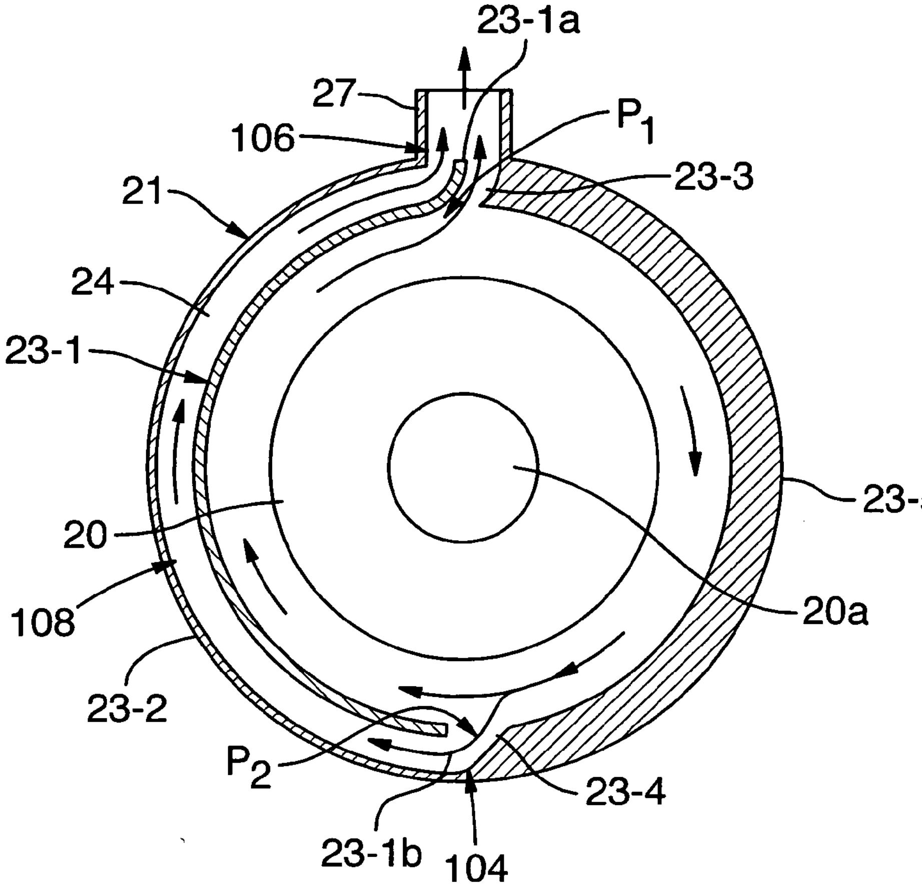
23-1a
27
P_1
106
21
23-3
24
23-1
23-5
20
20a
108
23-2
P_2
23-4
23-1b
104

FIG.6

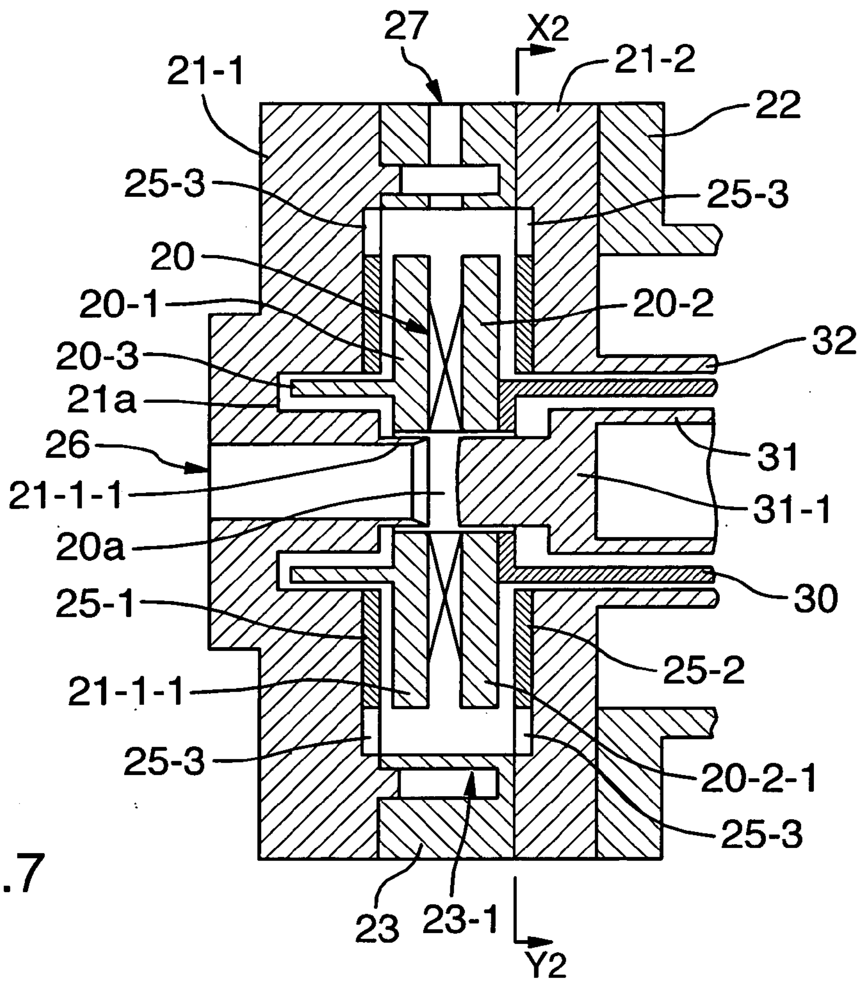
27
X2
21-1
21-2
22
25-3
25-3
20
20-1
20-2
32
20-3
21a
31
26
21-1-1
31-1
20a
30
25-1
25-2
21-1-1
25-3
20-2-1
25-3
23
23-1
Y2

FIG.7

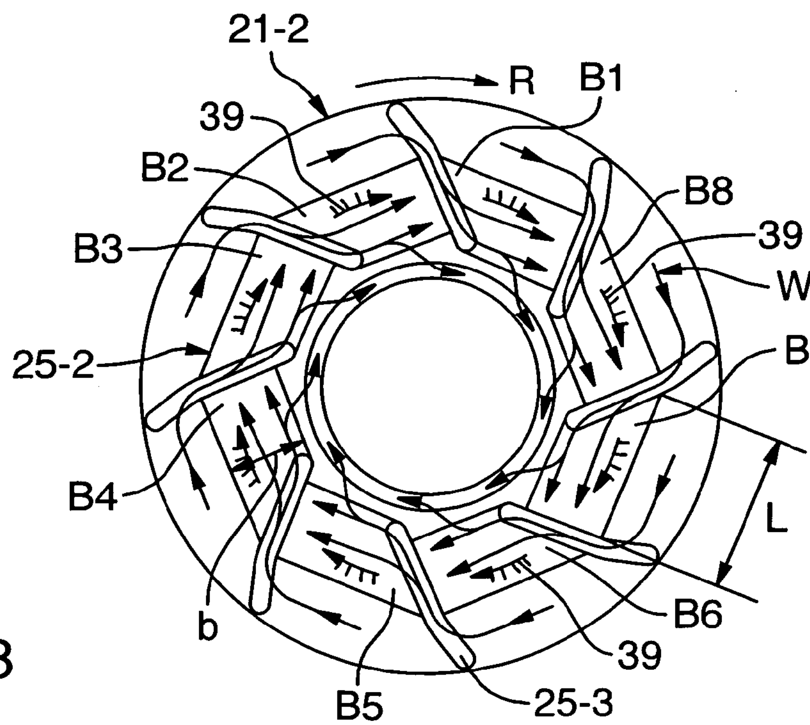
21-2
R
B1
39
B2
B8
B3
39
W
25-2
B7
B4
L
b
B6
39
B5
25-3

FIG.8

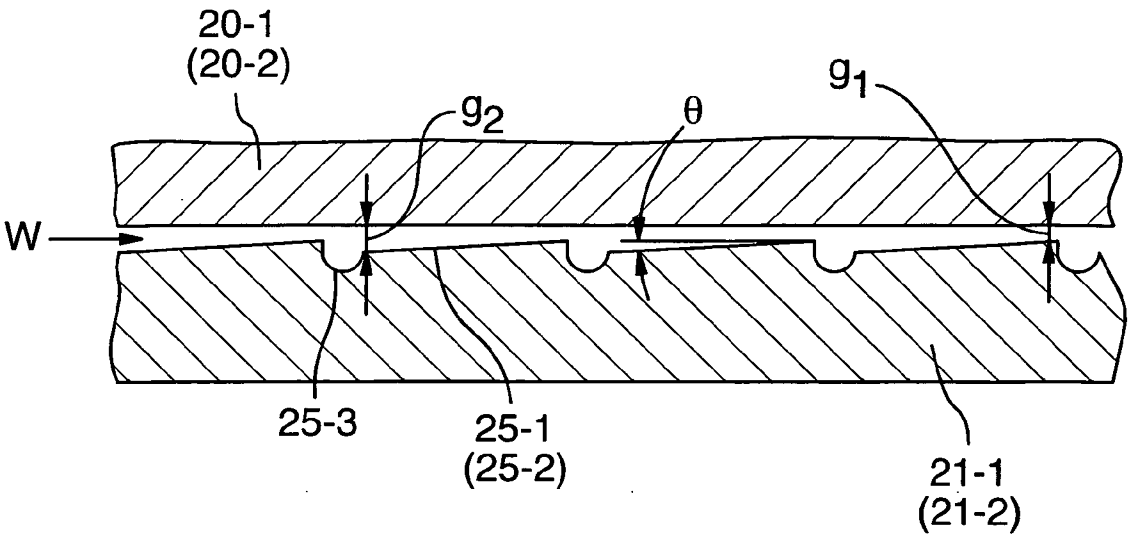

FIG.9

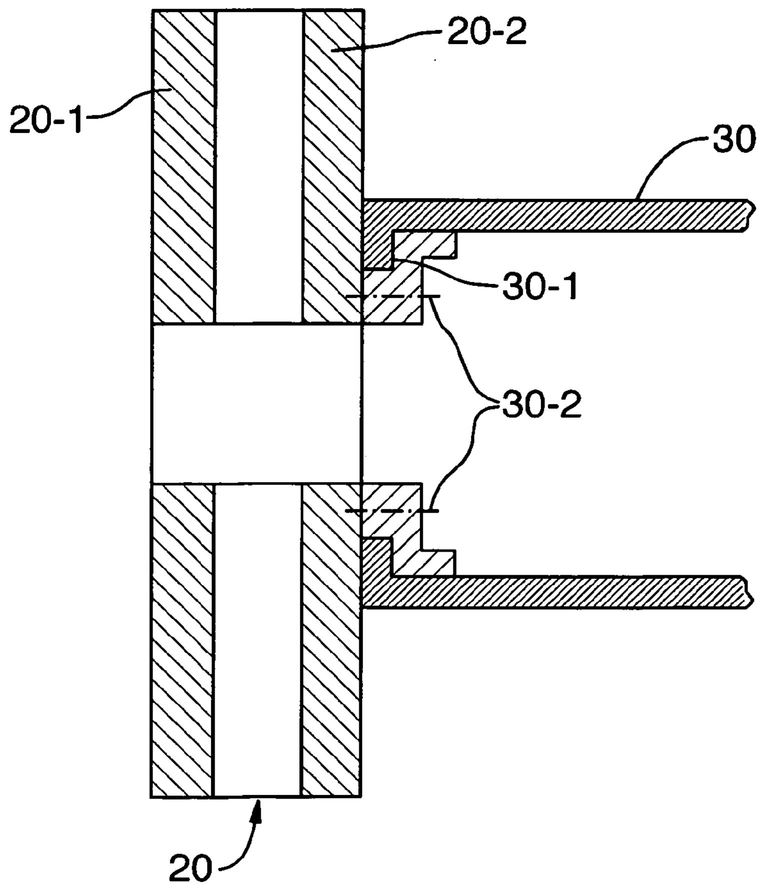

FIG.10

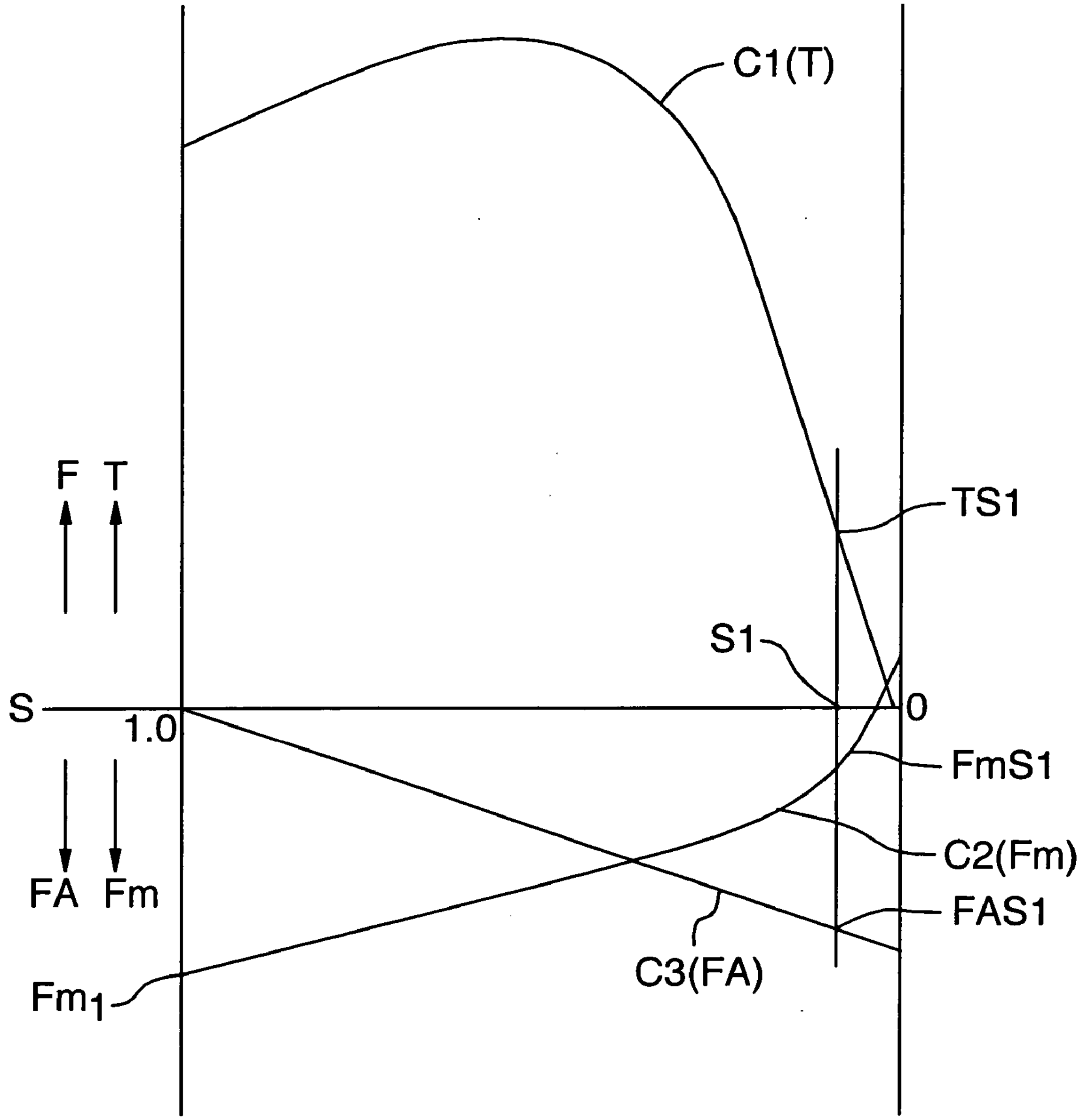

FIG.11

PUMP DEVICE

FIELD OF THE INVENTION

[0001] This invention relates to the field of centrifugal pumps.

BACKGROUND OF THE INVENTION

[0002] In the field of liquid transfer, it is common to provide power to the impeller of a centrifugal pump by means of a shaft coupled to an external motor. This necessitates that a form of dynamic seal be provided around the shaft, to minimize egress of liquid, which seals have associated maintenance issues. Dynamic shaft seals also add a frictional resistance load to the pump, which is not desired. Other pumps have been constructed wherein the impeller is rotated by an externally-created magnetic field. This type of pump avoids the maintenance and frictional resistance issues associated with dynamic shaft seals. However, in order to ensure that the impeller is properly indexed for rotation in the pump, submerged bearings are generally employed, which bearings have their own associated maintenance and frictional-resistance issues. It has also been known to attempt to create pumps lacking both submerged bearings and dynamic shaft seals, by providing magnets which serve both to rotate the impeller and support same in spaced relation from the housing. However, known prior art pumps of this type are not completely successful in avoiding rubbing contact between the impeller and housing; among other things, wear continues to be an issue.

SUMMARY OF THE INVENTION

[0003] A centrifugal pump for use with a liquid forms one aspect of the invention. This pump comprises a housing and a rotor. The housing has an interior surface defining an interior cavity, an axis intersecting the cavity, an intake port for receiving liquid and communicating same to said cavity, and a discharge port in communication with said cavity. The rotor has an impeller, is positioned in said cavity and is rotatable in said cavity about said axis in spaced relation to the interior surface. The impeller is adapted to force said liquid to flow through said discharge port upon said rotation in use. The pump further comprises means for balancing the pressure in said cavity, adapted so as to avoid the creation of pressure differentials in said cavity that would otherwise in use tend to cause translation of said rotor in said cavity. The pump further comprises a rotating magnetic field generation device adapted to drive rotation of said rotor about said axis in use.

[0004] According to another aspect of the invention, the means for balancing the pressure in said cavity may be a liquid conduit.

[0005] According to another aspect of the invention, in use, the discharge port may be disposed above the impeller and the liquid conduit may extend between a first terminus in the cavity above the impeller and a second terminus in the cavity below the impeller.

[0006] According to another aspect of the invention, the liquid conduit may be defined at least in part by an arc-shaped barrier.

[0007] According to another aspect of the invention, the rotor may include a drive member to which is coupled the impeller, for rotation therewith, the rotating magnetic field generation device being adapted to drive rotation of said rotor about said axis in use by driving rotation of said drive member.

[0008] According to another aspect of the invention, the impeller may be a closed impeller having axially-spaced sides and the drive member may comprise a metal tube extending axially from one of the sides of the impeller and arranged coaxial with the axis.

[0009] According to another aspect of the invention, the rotor and housing may be adapted such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface.

[0010] According to another aspect of the invention, said adaptation of the rotor and housing, such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface, may comprise: a balance tube extending from the other of the sides of the impeller in a direction coaxial with and opposite to the drive member; and a circular groove forming part of said cavity in which a rim of the balance tube revolves in use.

[0011] According to another aspect of the invention, said adaptation of the rotor and housing, such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface, may comprise, for each side of the impeller, a plurality of protrusions defined by the interior surface such that the space between the rotor and the housing, in use, measured axially, undulates in magnitude around the impeller for stabilizing the rotor against axial movement.

[0012] According to another aspect of the invention, measured axially, in the direction of rotation of the rotor, in each undulation the space between the rotor and the housing may gradually decrease and then quickly increase.

[0013] According to another aspect of the invention, each plurality of protrusions may have associated therewith a series of radial grooves forming part of the cavity, the grooves separating the protrusions from one another.

[0014] According to another aspect of the invention, each protrusion may comprise a wedge-shaped slope inclined in the direction of rotation of the rotor.

[0015] According to another aspect of the invention, the impeller may have defined therethrough, coaxial with the axis, an intake hole, and the housing may comprise an inflow regulation boss projecting into the cavity that extends, coaxially with the axis, into the intake hole.

[0016] According to another aspect of the invention, the inflow regulation boss may be shaped to direct flow impinging thereupon into the impeller.

[0017] According to another aspect of the invention, the inflow regulation boss may have a conical tip to direct flow impinging thereupon into the impeller.

[0018] According to another aspect of the invention, the pump may further comprise a tubular intake portion attached to the rim of the intake port and extending, coaxially with the axis, into the intake hole and towards the inflow regulation boss, to direct flow thereupon.

[0019] According to another aspect of the invention, the impeller may have defined therethrough, coaxial with the axis, an intake hole, and the pump may further comprise a tubular intake portion attached to the rim of the intake port and that extends, coaxially with the axis, into the intake hole.

[0020] According to another aspect of the invention, the impeller may have axially-spaced sides and the pump may further comprise extension plates attached around the perimeter of the impeller to increase the area of the impeller sides.

[0021] According to another aspect of the invention, the pump may further comprise a liquid detection sensor, capable of detecting the existence of liquid within the cavity and producing a liquid detection signal, and a controller that uses the liquid detection signal from said liquid detection sensor to control the pump during startup.

[0022] A centrifugal pump for use with a liquid forms another aspect of the invention. This pump comprises a housing, a rotor, a liquid conduit and a rotating magnetic field generating device. The housing has an interior surface defining an interior cavity, an axis intersecting the cavity, an intake port for receiving liquid and communicating same to said cavity, and a discharge port in communication with said cavity. The rotor has an impeller, is positioned in said cavity and is rotatable in said cavity about said axis in spaced relation to the interior surface. The impeller is adapted to force said liquid to flow through said discharge port upon said rotation in use. The liquid conduit is for balancing the pressure in said cavity so as to avoid the creation of pressure differentials in said cavity that would otherwise in use tend to cause translation of said rotor in said cavity towards said discharge port. The magnetic field generation device is adapted to drive rotation of said rotor about said axis in use.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1** is a cross sectional diagram of a pump constructed according to a preferred embodiment of the invention

[0024] FIG. **2** is an exploded, partially cut-away diagram of the pump shown in FIG. **1**

[0025] FIG. **3** is an X1-Y1 direction cross-sectional diagram of FIG. **1**

[0026] FIG. **4** is a side cross-sectional view of the liquid flow path inside the casing of a pump without a barrier inside the housing

[0027] FIG. **5** is a front cross-sectional view of the pump shown in FIG. **4**, showing a contact condition of the impeller, drive member, housing and can

[0028] FIG. **6** is a view similar to FIG. **4**, showing the liquid flow path inside the housing of the pump shown in FIG. **1**

[0029] FIG. **7** is a cross-sectional diagram of part of the pump of FIG. **1**

[0030] FIG. **8** is an X2-Y2 direction cross-sectional diagram of FIG. **7**

[0031] FIG. **9** is a view showing the position relationship between the impeller and wedge surface of the pump shown in FIG. **1**

[0032] FIG. **10** is a cross-sectional diagram of the structure of an alternative embodiment of the rotor

[0033] FIG. **11** is a behavior characteristic diagram for the drive member in the pump device shown in FIG. **1**

DETAILED DESCRIPTION.

[0034] A pump constructed according to a preferred embodiment of the invention is described hereinafter with reference to FIGS. **1**-**3**, **6**-**9** and **11**. FIG. **1** is a cross-sectional diagram of the pump. FIG. **2** is a partial cut-away disassembly diagram of FIG. **1**. FIG. **3** is a X1-Y1 cross-sectional diagram of FIG. **1**. FIG. **4** is a diagram showing the behavior of liquid within the housing in a pump with no barrier in the housing. FIG. **5** is a diagram of a contact condition between the impeller, drive member, housing and can of the pump device in FIG. **4**. FIG. **6** depicts the behavior of liquid within the housing of the pump in FIG. **1**.

[0035] The specifications for the pump device in FIG. **1** are as below. The aperture of the external intake tube (the aperture of inflow mouth or intake port **26**) is 32 mm, the discharge aperture (the aperture of discharge mouth or port **27**) is 20 mm. The closed impeller **20** is made from PVC. The outer diameter of the impeller is 80 mm. The aperture of the intake hole **20*a*** is 32 mm, and it has 5 blades. The drive member **30** consists of a metal tube, specifically, an aluminum cylinder, 3 mm in thickness, the exposed surface of which is coated in 200 μm thick Teflon™. The impeller **20** and drive member **30** together form a rotor **20**,**30**. The can **38**, is a 2 mm thick dual layer cylindrical structure consisting of an inner can **31** and an outer can **32**. The gaps between the inner can **31**, and outer can **32**, and drive member **30**, are each 2 mm. The main casing **21** is a dual walled structure. The width of the liquid passage is 10 mm.

[0036] Both the outer magnets **33** and inner magnets **34**, that form part of the rotating magnetic field generation device, come in 4 pairs. These magnets are made of neodymium. The driving motor **37** is a 3-phase, 200V type, with an output of 0.4 kW. Inclined wedge-shaped surfaces B**1**-B**8** alternate with grooves **25**-**3**, that are used to introduce water onto the wedges, for a total of 8 faces. Each inclined wedge-shaped surface has an angle of inclination θ of 2°. Also, the pump has a discharge rate of 50 l/min, an 8 m discharge head, and a pump efficiency of 24%.

[0037] As seen in FIGS. **1**, **2**, the impeller casing **21** in the pump device is formed by sandwiching barrier **23**-**1** and the main casing plate **23** between intake side casing plate **21**-**1**, and the can-side casing plate **21**-**2**. These parts are fixed together by tightening bolts **28**.

[0038] The impeller **20** is installed within the impeller casing **21**. Affixed to one side of this impeller (the drive side), along the same rotary axis A-A as the impeller and casing **21**, is the aluminum drive member **30**. Accordingly, by loosening and removing the tightening bolts, it is easy to remove or re-install the impeller **20** and drive member **30**. As earlier indicated, the drive member **30** is a non-magnetic electrical conducting hollow aluminum cylinder, the exposed surface of which is coated in a Teflon™ resin.

[0039] The impeller **20** and drive member **30** (hereafter referred to individually as rotating parts or collectively as rotor) are installed such that they rotate freely in the casing **21** and the can **38** (inner can **31**, outer can **32**). The casing

21 and the can 38 together define a housing 21,38 having an interior surface 100 defining an interior cavity 102 in which the rotor 20,30 is positioned and rotatable about axis A-A in spaced relation to the interior surface 100.

[0040] The can 38 (inner can 31, outer can 32) is a dual layer cylindrical structure made from a non-magnetic high electrical resistance material. The lower part of the inner can 31 (the part near the impeller 20) is closed, and the part at the other end (the part near the drive motor 37) has the inner can 31 joined up with outer can 32, creating a closed form. Arranged on the inside of the inner can 31 and the outside of outer can 32 is a gap. Installed into each gap are a grouping of several magnets, the inner magnets 34 and outer magnets 33, respectively. The outer magnets and inner magnets, respectively, are attached to outer magnet yoke 33-1 and inner magnet yoke 34-1, said yokes 33-1,34-1 being formed by a dual layer cylindrical magnet holder 35. This magnet holder 35 is connected to the output shaft (not shown) of the drive motor 37 at its axis A-A by a holder connective shaft 36.

[0041] As shown in FIG. 3, the corresponding surfaces of the inner magnets 34, which are attached to the inner magnet yoke 34-1, and the outer magnets 33, which are attached to the inner magnet yoke 33-1, are opposite in polarity. Regarding the inner magnets 34 and outer magnets 33, they are arranged such that each adjacent magnet is also of opposite polarity. These inner magnets 34 and outer magnets 33 are synchronously rotated by the drive motor 37, which drives the holder connective shaft 36, which in turn is fixed to the magnet holder 35.

[0042] By rotating the inner magnets 34 and outer magnets 33 together with the magnet holder 35 in this way, a rotating magnetic field is established in the space between the inner magnets 34 and outer magnets 33; the magnetic flux between the inner magnets 34 and the outer magnets 33 intersect the drive member 30, generating an induced current and generating a rotational force and repulsive force in the drive member 30. These rotational and repulsive forces serve as the rotational driving force for the impeller 20.

[0043] Since the drive member 30 is attached to the impeller 20 only on one surface (the drive side surface), the center of gravity of the rotating part or rotor composed by joining the impeller 20 and the drive member 30 is positioned in the part of impeller 20 close to the drive member 30, such that there is a possibility that the impeller could swing to the left and right. To minimize the likelihood of this outcome, attached to the intake surface of impeller side plate 20-1, which constitutes the side of the impeller positioned opposite the drive side surface (the surface to which the drive member 30 is attached) of impeller 20, is a cylindrical balance tube 20-3 that projects out to the side opposite the drive member 30. The balance tube 20-3 is positioned about the same rotational axis A-A as the impeller 20. The rim of the balance tube 20-3 fits into a circular groove 21*a* in the corresponding inner surface of the intake casing side plate 21-1. By placing a balance tube 20-3 and a groove 21*a* like this, a radial wedge effect, that occurs from the existence of liquid in the gap between the balance tube in 20-3 and 21*a*, causes the balance tube 20-3 to be forced away from the inner wall of groove 21*a* and to rotate in a suspended state inside groove 21*a*. Consequently, by coupling the wedge effect that occurs in the gap between the drive member 30 and can 38, and the wedge effect that occurs between the balance tube 20-3 and groove 21*a*, stability of the drive member 30 and the impeller 20 is provided in operation.

[0044] As a result, contact and rubbing between the impeller 20 and impeller casing 21, and the drive member 30 and can 38, is minimized, and it is possible to limit the chance of breakdown flowing from rubbing contact of these parts. In the case of the illustrated preferred embodiment, the inner diameter and outer diameter of the balance tube 20-3 are identical to the inner diameter and outer diameter of the drive member 30, providing exceptional stability to the drive member 30 and the impeller 20.

[0045] Also, as shown in FIG. 2, and later shown in FIG. 6, an intake hole 20*a* is established in the impeller 20 that penetrates through the center of impeller's rotary axis. Attached to the rim of the liquid intake mouth 26, on the impeller casing side plate 21-1 that corresponds intake surface of the impeller 20, is an auxiliary intake tube 21-1-1 that protrudes out into the intake hole 20*a*.

[0046] By attaching the auxiliary intake tube 21-1-1, it is possible to mitigate movement in the impeller 20's thrust direction due to liquid intake into the impeller 20 when the pump starts rotating, or during operation. As a result, it is possible to prevent rubbing and contact of the impeller 20 and impeller casing 21 during operation, or when the pump starts rotating.

[0047] Also, an inflow regulation 'boss'31-1 that protrudes out into the intake hole 20*a*, is attached onto inner surface in the center (the lower part of the inner can 31) of the impeller casing side plate 21 that faces the impeller 20 drive surface. By attaching this inflow regulation boss 31-1 as above, it is possible to mitigate movement in the impeller 20's thrust direction due to liquid intake into the impeller 20 when the pump starts rotating, or during operation. As a result, it is possible to prevent rubbing and contact of the impeller 20 and impeller casing 21 during operation, or when the pump starts rotating.

[0048] Furthermore, a tip of one end of the inflow regulation boss 31-1, the top of which is positioned into the center of the impeller 20's rotary axis, has attached to or formed thereon a conical protrusion 31-1*a*. By having this protrusion 31-1*a*, it becomes possible to evenly guide the dispersion of fluid flowing along the impeller 20 rotary shaft and into the inflow hole 20*a*, by radiating it along the perimeter of the protrusion 31-1*a*. This eases the movement of the impeller 20 thrust direction, and further increases the stability of the impeller 20 during startup and during operation.

[0049] FIG. 4 depicts a form of the pump device of FIG. 1 lacking an arc-shaped barrier and showing the relationship between the pump impeller 20 and the impeller casing 23, when the discharge 27 is vertical. If the center of the impeller 20 is set to θ1, the impeller 20 is rotating, and the liquid discharge out of the discharge 27 has started, then the pressure at position P1, facing towards the discharge 27 on the inside of the impeller casing 23 is less than the pressure at position P2, symmetrically opposite the intake 26. At this time, the impeller 20, which is still in a state of non-contact with the impeller casing 23, rises upwards towards the discharge port due to the pressure differential between P2 and P1, such that the drive member 30 touches the inner can

31 and outer **32**, and the impeller **20** and drive member **30** end up rotating at an incline, as shown in FIG. **5**. At this time, drive member **30** is touching the inner can **31** at point Q_1 and the outer can **32** at point Q_2, and the impeller **20** is touching the intake side impeller casing plate **21-1** at point Q_3 and the can side casing plate **21-2** at point Q_4.

[**0050**] The construction shown in FIG. **6** resolves this type of contact and rubbing phenomenon. As shown in FIG. **6**, an arc shaped barrier **23-1** is attached parallel to the impeller **20**'s rotary locus, on the impeller casing **21**, in the outer perimeter area inside the impeller casing **21**, and outside the impeller, such that it divides the impeller outer perimeter area into an inner area and outer area, with one end facing the inner opening of the discharge **27** that is within the impeller casing **21**, and the other end of the barrier **23-1** positioned opposite the discharge **27**.

[**0051**] By these means, the barrier **23-1** and the outer wall **23-2** form a dual-walled arc shape. Positioned opposite this dual wall is a closed arc-shaped wall **23-5**. Also, established between each end of the barrier **23-1**, at one end **23-1***a* and the other **23-1***b*, and the closed wall **23-5**, connecting each through to the impeller **20**'s outer perimeter, are discharge holes **23-3**, and **23-4**, whose widths are roughly identical. The liquid flow that passes thorough the lower facing discharge hole **23-4** flows along the liquid discharge pathway, between the outer wall **23-2** and the barrier **23-1**, and merges with the liquid flow that passes through the upward facing discharge hole **23-3** that faces the discharge **27**. To restate, the barrier in combination with the casing **21** defines a liquid flow conduit **108** that extends between a first terminus **106** in the cavity above the impeller and a second terminus **104** in the cavity below the impeller. By attaching arc shaped barrier **23-1** onto the impeller casing **21**, in the outer perimeter area inside the impeller casing **21**, and outside the impeller **20**, with one end **23-1***a* facing the inner opening of the discharge **27** and the other end of the barrier **23-1***b* positioned opposite the discharge **27**, the pressure at the discharge hole **23-3**, P1 is made to roughly equal P2, the pressure at discharge hole **23-4**. As a result, the impeller **20** is no longer urged towards the discharge, away from the axis of rotation, and can rotate in a stable position. Also, the rotating parts will not tilt, thus eliminating the phenomenon, due to tilting of the impeller, of rubbing and contact between the rotor **30** and the inner can **31** and outer can **32**, and of the impeller **20** rubbing and contacting the casing **21**, as shown in FIGS. **4** and **5**.

[**0052**] With this barrier in place, there exists a thrust force against the impeller **20** (the force along the axis of rotation= the force along the holder connective shaft **36**), whose magnitude depends on the pump discharge head, and discharge quantity. All things being equal, this thrust force would tend to force the impeller **20** to tilt to the left and right, which would result in wear.

[**0053**] Arresting this, as seen in FIG. **1**, defined by each of the inner surfaces of the impeller casing plate **21-1**, **21-2**, opposite impeller side plates **20-1**, **20-2**, are a set of wedge faces **25-1**, **25-2** respectively. As shown in FIG. **8**, wedge faces **25-1** and **25-2** are formed and separated from one another by series of 8 radial grooves **25-3** arranged about the impeller **20**'s rotary axis, and a series of wedge shaped slopes B1-B**8** or protrusions that are set within each of the **8** areas divided by the grooves **25-3**, which are inclined in the direction of rotation of the impeller R. Through this arrangement, the space between the rotor and the housing, measured axially, undulates in magnitude around the impeller. More specifically, in the direction of rotation of the rotor, in each undulation, the space between the rotor and the housing gradually decreases and then quickly increases, due to the wedge shapes.

[**0054**] By placing these kinds of wedge faces **25-1**, **25-2**, when the impeller **20** approaches the casing side plate **21-1** or **21-2** due to the aforementioned thrust force, the wedge effect due to the flow of liquid through the gap between the impeller **20** and the wedge face **25-1**, **25-2** will force the impeller sides and housing away from one another.

[**0055**] Without intending to be bound by theory, here follows a detailed explanation of the wedge effect referenced in FIGS. **7-9**. FIG. **7** is a partial cross-sectional diagram of part of the pump device. FIG. **8** is an X2-Y2 directional diagram, and FIG. **9** shows the relationship between the impeller side plate **20-1** (**20-2**) and the wedge face **25-1** (**25-2**). As shown in FIG. **8**, the wedge face **25-2** in casing side plate **21-2**, is divided into several wedge-shaped slopes B1-B8 by a series of groves **25-3**. In FIG. **8** there are a series of arrows: arrow **39** indicates the direction of inclination of the wedge-shaped slopes B1-B**8**; arrow R indicates the direction of rotation of the impeller **20**; and arrow W indicates the flow direction for liquid that has entered wedge-shaped slopes B1-B**8**. In FIG. **9**, when R>0, θ is the angle of inclination of B1-B**8** and g_1, g_2 are the gaps between the wedge face **25-1** (**25-2**) of casing side plate **21-1** (**21-2**), and the impeller side plate **20-1** (**20-2**). The repulsive force FA that occurs due to wedge face **25-1** (**25-2**) is summarized below. If the liquid viscosity, and the speed of liquid entering the wedge face **25-1** (**25-2**) (it is assumed that this is proportional to the rpm of the impeller **20**), are fixed, then FA can be expressed by:

$$FA \propto (b^2 \times L \times n)/g_1^2$$

(b: wedge shaped slope width, L: wedge shaped slope length, n: number of wedge shaped slope)

[**0056**] Here, g_2 is the gap at the liquid entry side towards the wedge-shaped slopes B1-B8, g_1 is the gap at the discharge side, and g_2/g_1 normally has a value from 2-4. Therefore, L and θ can be determined.

[**0057**] From above, when the diameter of the impeller **20** is small, the corresponding area of the wedge face **25-1** (**25-2**) (b×L) becomes narrow and the wedge effect is decreased, and especially as the width b decreases, the wedge effect tends to decrease dramatically. To avoid suppression of the wedge effect when the outer diameter of the impeller is small, it may be preferable to provide for the area of the impeller and wedge faces to be larger than the area of the impeller. This can be done by increasing the impeller **20** side plate, and also expanding the corresponding wedge faces **25-1**, **25-2** of the casing side plate **21-1**, **21-2**. In other words, just as seen in FIG. **7**, by attaching the extension plates **20-1-1** and **20-2-1** to the perimeter of impeller side plates **20-1**, **20-2** which compose impeller **20**, and also expanding the corresponding wedge faces **25-1**, **25-2** of the casing side plate **21-1**, **21-2**, it is possible to provide a desired wedge effect even in the context of a relatively small diameter impeller.

[**0058**] The only liquid-contacting component of the illustrated pump that must utilize metal is the drive member **30**.

To prevent corrosion (including galvanic corrosion) of the drive member **30**, it is advantageous to apply a sufficient coating of a resin, etc., or apply a lining to surface in contact with liquid. However, when coatings and the like are applied to the drive member **30**, and it is attached to the impeller **20**, it becomes troublesome to directly attach them together by screws etc., and thus it may be preferable to indirectly attach them. In other words, just as shown in FIG. **10**, rather than attaching the drive member **30** directly to the impeller **20**, it can be advantageous to attach it via a resin auxiliary attachment plate **30-1**. This is because if there are screw holes in the drive member **30**, it is difficult to apply a coating completely inside the screw holes, and if the interior of the screw holes are improperly coated, galvanic corrosion can result.

[0059] FIG. **11** shows, from the time this pump embodiment starts operating until it achieves full operating speed, the characteristics of the applied torque and repulsive force to the drive member **30** from the rotating magnetic field generation device (outside magnets **33**, inside magnets **34**, magnet holder **35**), and the repulsive force due to liquid flow between the can **38** and the drive member **30** due to the wedge effect. In FIG. **11**, the graph shown is for R>2, the drive member **30**'s speed (slip S) is drawn along the horizontal axis, the vertical axis shows the characteristic of the applied rotor **30**'s torque T, the repulsive force Fm received by the magnetic field on the drive member **30**, and the repulsive force FA due to the wedge effect.

[0060] In FIG. **11**, curve C**1** shows the Torque T, curve C**2**, the repulsive force Fm due to the magnetic field, C**3**, and the repulsive force FA due to the wedge effect. If the rpm of the outside magnets **33** and inner magnets **34** are no, and the rpm of the rotor **30** n, then S=(no−n)/no. Since the applied torque T to the drive member **30** from the rotating magnetic field is approximated by the speed characteristic of a general purpose drive motor with an extremely large gap, it is roughly the same as C**1**.

[0061] The applied repulsive force Fm to the drive member **30** due to the rotating magnetic field is a repulsive force when S*Rm>1, and is an attractive force when S*Rm<1. Here, Rm, is a value determined by the magnetic gap between magnets **33**, **34** and the thickness and material of drive member **30**, etc. It is called the Magnetic Reynolds' number.

[0062] As can be understood from the graph shown in FIG. **11**, when S is at its maximum point, in other words when S=1 at startup, the repulsive force is at maximum. Conveniently therefore, substantial rubbing will not occur between the drive member **30** and the can **38** at startup.

[0063] On the other hand, as the rpm of the drive member **30** increases, in other words, the rpm of the impeller **20** increases, S=0, that repulsive force becomes 0. However, the repulsive force due to the wedge effect that occurs between the can **38** and the drive member **30** becomes proportionally larger as the rpm of the drive member **30** increases, so long as there is liquid. If S**1** is the slip when the drive member **30**, i.e. the impeller **20**, reaches normal rotation, the applied repulsive force to the drive member **30** becomes FmS**1**+FAS**1**, and the drive member **30** has risen and stabilized. However, if there is no liquid, FA=0, the rpm of the drive member **30** further increases, Fm becomes extremely small, and the repulsive force almost disappears. This fact shows that when there is no liquid, the repulsive force becomes extremely small, and rubbing occurs between the drive member **30** and the can. Accordingly, in this pump, an empty operation preventative counter-measure is advantageous, to prevent operation of the drive motor **37** when the inside of casing **21** is empty or liquid.

[0064] Therefore, in the illustrated preferred embodiment, as shown in the aforementioned FIG. **1**, a liquid sensor **29** capable of detecting the existence of liquid is placed close to the discharge **27**. The liquid detection signal from liquid sensor **29** acts as the startup condition for the pump device. In other words, it becomes impossible to operate the drive motor **37** when there is no liquid detection signal from the liquid sensor **29**. In this manner, it is possible to prevent dry operation of the pump. Also, as a method of preventing empty pump operation, it is also a way of ensuring there will be sufficient liquid in the pump casing at shutdown.

[0065] In the preferred embodiment, wedge effects provided by the balance tube/groove, drive member/can, impeller/protrusion, intake regulation boss/intake hole and intake portion/intake hole combinations support the rotor for rotation substantially about the axis in spaced relation to the interior surface of the housing. In testing, absolutely no trace of rubbing between the rotating parts (drive member **30**, impeller **20**) and the surrounding walls (casing **21**, can **38**) were observable, during startup, operation, and shutdown, for every condition starting with a completely open discharge valve to completely closed. Inspection for the existence of rubbing was conducted by coating the rotating parts in an inspection coating, and after operating the pump, inspecting the inspection coating for the existence of peeling. Also, in tests with fine slurries, and liquid limestone, no obstacles were observed. Also, by attaching a reflux valve (not shown) to the inflow tube (not shown) to the inflow **26**, it was possible to confirm the possibility of ordinary restart.

[0066] In the illustrated preferred embodiment, which has a no-seal construction, no submerged bearings, and rotating parts (drive member **30**, impeller **20**) that can rotate in an extremely stable floating state without contacting the surrounding walls (casing **21**, can **38**), in testing there was found to be no contamination due to rubbing, etc.

[0067] Also, since it is possible to manufacture the liquid-contacting parts but for the drive member entirely from plastic, resin coating, or ceramic materials, there is no necessity to use metal materials in the liquid-contacting surfaces. This fact shows that it is possible to eliminate or minimize the elution of metal ions into the transported liquid. Also, the fact that there are no rubbing parts in operation provides a relatively maintenance-free pump having a relatively long lifespan and a relatively low breakdown risk.

[0068] The pump in this invention has a wide variety of possible uses, in various fields, transporting, drawing, etc., all kinds of liquids, in addition to pure liquids and corrosive liquids, fine slurries, mixed liquids, etc.

[0069] The various parts of the pump described are listed below.

Parts List

[0070] **20** Impeller

[0071] **20***a* Inflow hole

[0072] **20-1**, **20-2** Impeller side plate

[0073] **20-1-1**, **20-2-1** Extension side plate

[0074] **20-3** Balance tube

[0075] **21** Impeller casing

[0076] **21***a*, **25-3** Groove

[0077] **21-1**, **21-2** Casing Side plate

[0078] **21-1-1** Auxiliary inflow tube

[0079] **22** Drive Casing

[0080] **23** Casing main plate

[0081] **23-1** Barrier

[0082] **23-2** Outer wall

[0083] **23-1***a* Discharge end of the barrier

[0084] **23-1***b* Opposite end of the barrier

[0085] **23-3** Upward discharge hole

[0086] **23-4** Downward discharge hole

[0087] **23-5** Closed Wall

[0088] **24** Liquid discharge path

[0089] **25-1**, **25-2** Wedge Faces

[0090] **26** Inflow

[0091] **27** Discharge

[0092] **28** Tightening bolt

[0093] **29** Liquid detection sensor

[0094] **30** Rotor

[0095] **30-1** Auxiliary attachment plate

[0096] **30-2** Screw

[0097] **31** Inner Can

[0098] **31-1** Inflow regulation boss

[0099] **31-1***a* Protrusion on the inflow regulation boss

[0100] **32** Outer Can

[0101] **33** Outer magnets

[0102] **33-1** Outer magnetic yoke

[0103] **34** Inner magnets

[0104] **34-1** Inner magnetic yoke

[0105] **35** Magnet holder

[0106] **36** Holder connective shaft

[0107] **37** Drive motor

[0108] **38** Can

[0109] **39** Directional arrow

[0110] **100** interior surface

[0111] **102** cavity

[0112] **104** second terminus of flow conduit

[0113] **106** first terminus of flow conduit

[0114] **108** flow conduit

[0115] A-A axis

[0116] P_1, P_2 Pressure

[0117] ϕ_1 Center of the impeller

[0118] Q_1 Point of contact between the rotor and can

[0119] Q_2 Point of contact between the rotor and can

[0120] Q_3 Point of contact between the impeller and casing

[0121] Q_4 Point of contact between the impeller and casing

[0122] B**1**~B**8** wedge shaped slope

[0123] R Direction of rotation for the impeller

[0124] W Direction of liquid flow

[0125] θ Angle of inclination for wedge-shaped slope

[0126] g_1, g_2 The gap between the impeller side plate and the wedge-shaped slope

[0127] b Width of the wedge-shaped slope

[0128] L Length of the wedge-shaped slope

[0129] S Slip

[0130] T Torque

[0131] F Attractive force

[0132] Fm Repulsive force

[0133] FA Repulsive force due to the wedge effect

[0134] C**1** T-S characteristic curve

[0135] C**2** Fm-S characteristic curve

[0136] C**3** FA-S characteristic curve

[0137] S**1** Slip during normal operation

[0138] Finally, it is to be understood that while but a single preferred embodiment of the pump, and a single alternative embodiment of the rotor, have been herein shown and described, it will be understood that various changes in size and shape of parts may be made. These modifications, and others which may be routine to persons of ordinary skill in the art, may be made without departing from the spirit or scope of the invention, which is accordingly limited only by the claims appended hereto, purposively construed.

1. A centrifugal pump for use with a liquid, said pump comprising:

a housing having an interior surface defining an interior cavity, an axis intersecting the cavity, an intake port for receiving liquid and communicating same to said cavity, and a discharge port in communication with said cavity;

a rotor having an impeller, said rotor being positioned in said cavity and rotatable in said cavity about said axis in spaced relation to the interior surface, the impeller being adapted to force said liquid to flow through said discharge port upon said rotation in use;

means for balancing the pressure in said cavity, adapted so as to avoid the creation of pressure differentials in said cavity that would otherwise in use tend to cause translation of said rotor in said cavity; and a rotating magnetic field generation device adapted to drive rotation of said rotor about said axis in use.

2. A pump according to claim 1, wherein the means for balancing the pressure in said cavity is a liquid conduit.

3. A pump according to claim 2, wherein, in use, the discharge port is disposed above the impeller and the liquid conduit extends between a first terminus in the cavity above the impeller and a second terminus in the cavity below the impeller.

4. A pump according to claim 3, wherein the liquid conduit is defined at least in part by an arc-shaped barrier.

5. A pump according to claim 1, wherein the rotor includes a drive member to which is coupled the impeller, for rotation therewith, and wherein the rotating magnetic field generation device is adapted to drive rotation of said rotor about said axis in use by driving rotation of said drive member.

6. A pump according to claim 5, wherein the impeller is a closed impeller having axially-spaced sides and wherein the drive member comprises a metal tube extending axially from one of the sides of the impeller and arranged coaxial with the axis.

7. A pump according to claim 1, wherein the rotor and housing are adapted such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface.

8. A pump according to claim 6, wherein the rotor and housing are adapted such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface.

9. A pump according to claim 8, wherein said adaptation of the rotor and housing, such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface, comprises:

a balance tube extending from the other of the sides of the impeller in a direction coaxial with and opposite to the drive member, and

a circular groove forming part of said cavity in which a rim of the balance tube revolves in use.

10. A pump according to claim 8, wherein said adaptation of the rotor and housing, such that, in use, said liquid supports said rotor for rotation substantially about said axis in spaced relation to said interior surface, comprises:

for each side of the impeller, a plurality of protrusions defined by the interior surface such that the space between the rotor and the housing, in use, measured axially, undulates in magnitude around the impeller for stabilizing the rotor against axial movement.

11. A pump according to claim 10, wherein, measured axially, in the direction of rotation of the rotor, in each protrusion the space between the rotor and the housing gradually decreases and then quickly increases.

12. A pump according to claim 10, wherein each plurality of protrusions has associated therewith a series of radial grooves forming part of the cavity, the grooves separating the protrusions from one another.

13. A pump according to claim 10, wherein each protrusion comprises a wedge-shaped slope inclined in the direction of rotation of the rotor.

14. A pump according to claim 1, wherein the impeller has defined therethrough, coaxial with the axis, an intake hole, and wherein the housing comprises an inflow regulation boss projecting into the cavity that extends, coaxially with the axis, into the intake hole.

15. A pump according to claim 14, wherein the inflow regulation boss is shaped to direct flow impinging thereupon into the impeller.

16. A pump according to claim 14, wherein the inflow regulation boss has a conical tip to direct flow impinging thereupon into the impeller.

17. A pump according to claim 15, further comprising a tubular intake portion attached to the rim of the intake port and that extends, coaxially with the axis, into the intake hole and towards the inflow regulation boss, to direct flow thereupon.

18. A pump according to claim 1, wherein the impeller has defined therethrough, coaxial with the axis, an intake hole, and further comprising a tubular intake portion attached to the rim of the intake port and that extends, coaxially with the axis, into the intake hole.

19. A pump according to claim 1, wherein the impeller has axially-spaced sides and further comprising extension plates attached around the perimeter of the impeller to increase the area of the impeller sides.

20. A pump according to claim 1, further comprising a liquid detection sensor, capable of detecting the existence of liquid within the cavity and producing a liquid detection signal, and a controller that uses the liquid detection signal from said liquid detection sensor to control the pump during startup.

21. A centrifugal pump for use with a liquid, said pump comprising:

a housing having an interior surface defining an interior cavity, an axis intersecting the cavity, an intake port for receiving liquid and communicating same to said cavity, and a discharge port in communication with said cavity;

a rotor having an impeller, said rotor being positioned in said cavity and rotatable in said cavity about said axis in spaced relation to the interior surface, the impeller being adapted to force said liquid to flow through said discharge port upon said rotation in use;

a liquid conduit for balancing the pressure in said cavity so as to avoid the creation of pressure differentials in said cavity that would otherwise in use tend to cause translation of said rotor in said cavity towards said discharge port; and

a rotating magnetic field generation device adapted to drive rotation of said rotor about said axis in use.

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