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(54) **ROTARY PUMP WITH ELECTROMAGNETIC LCR BEARING**

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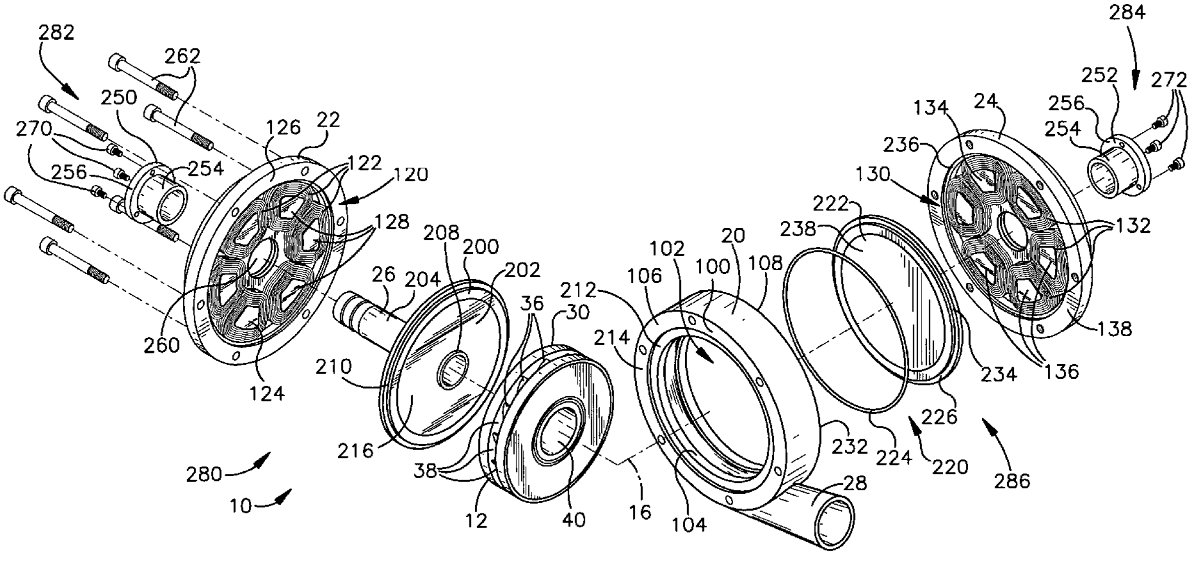
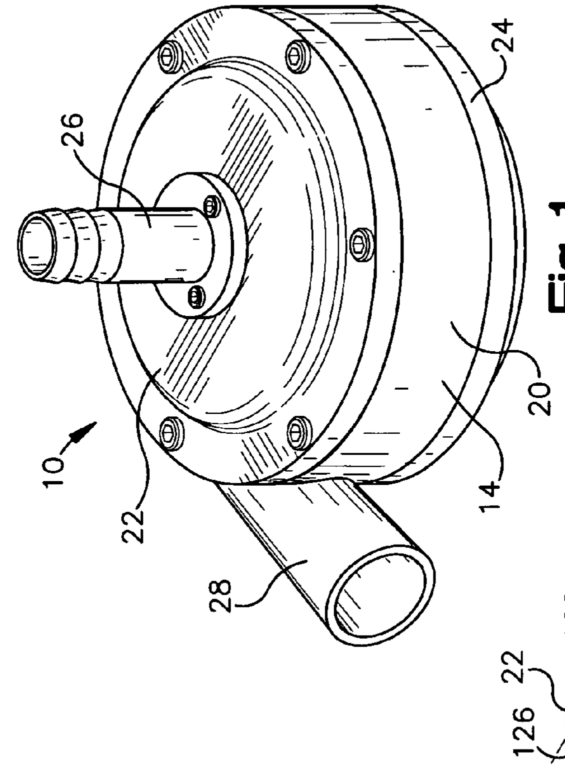
(57) **ABSTRACT**

A pump (**10**) includes a housing (**14**) having a fluid inlet (**26**) and a fluid outlet (**28**). A rotor (**12**) is disposed within the housing (**14**) and rotatable about an axis (**16**) to move fluid from the fluid inlet (**26**) to the fluid outlet (**28**). A magnetic axial bearing (**286**) for supporting the rotor (**12**) includes an axial bearing target (**70**) disposed on the rotor and an axial bearing stator (**130**) disposed on the housing, the axial bearing stator including multiple stator poles (**132***a*, **132***b*, **132***c*) each including a first coil portion wound in a first direction and a second coil portion wound in a second direction opposite the first direction.

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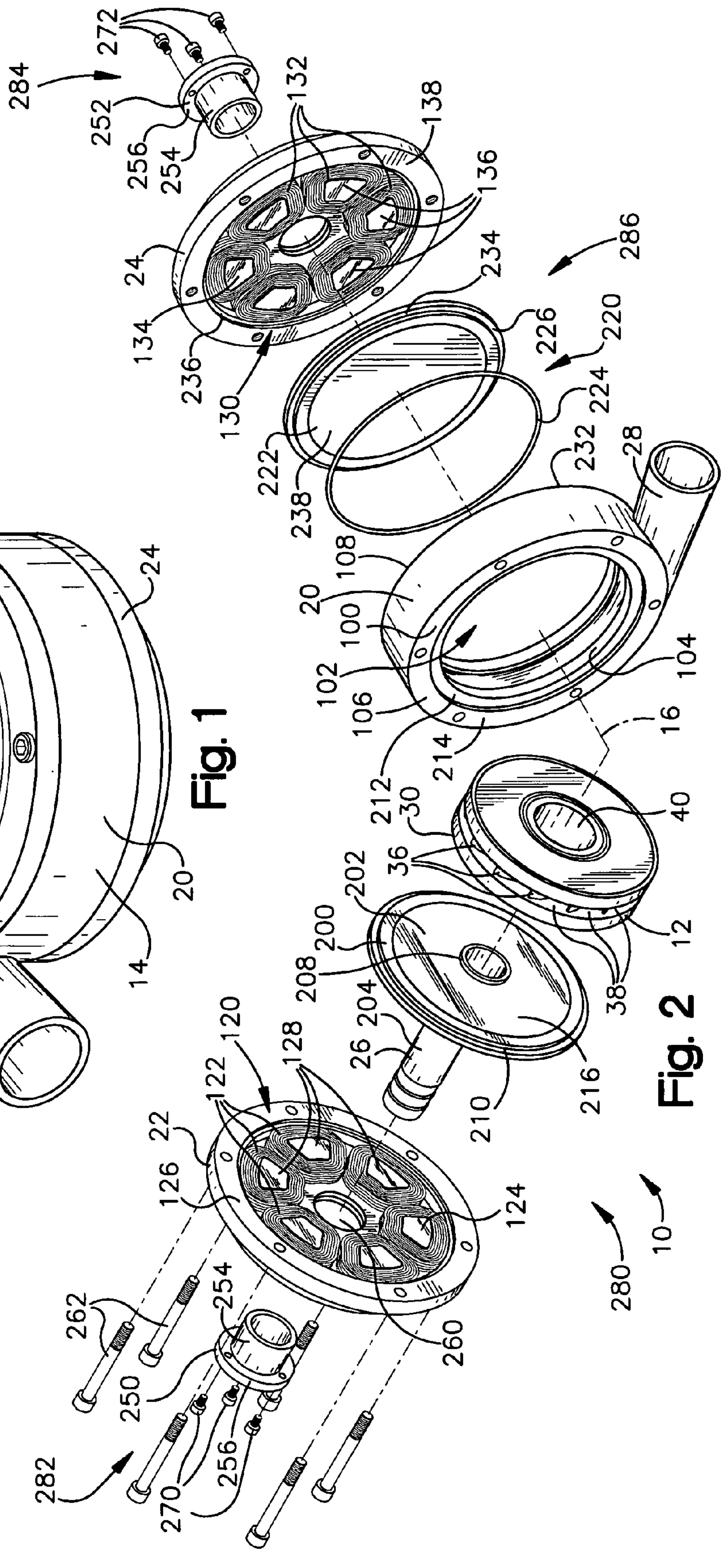
24
26

Fig. 1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212
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36
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12
38
202
200
208
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10

Fig. 2

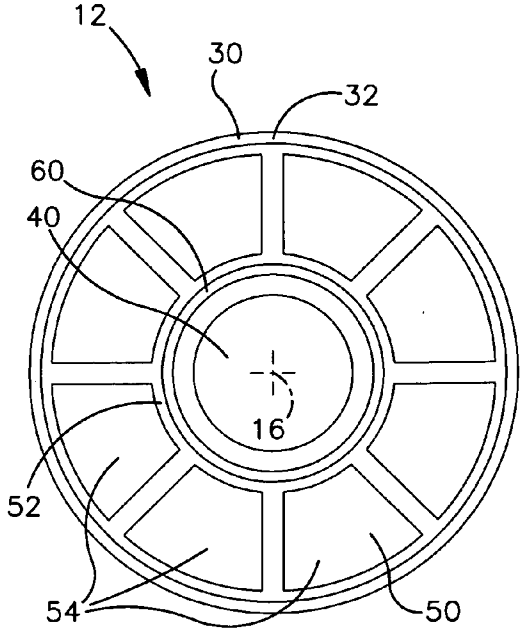


Fig. 3A

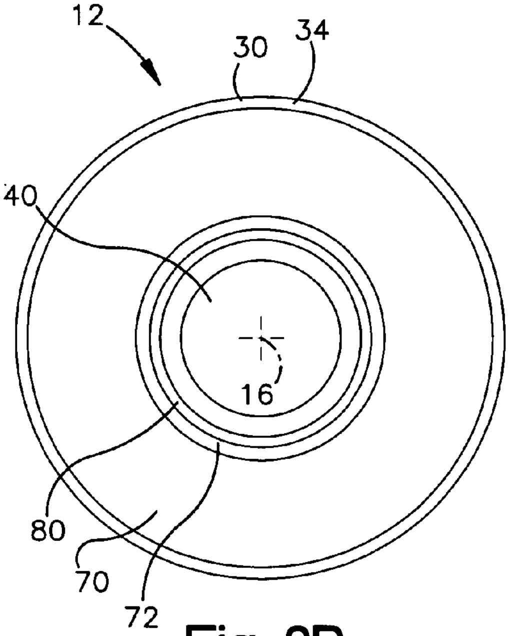


Fig. 3B

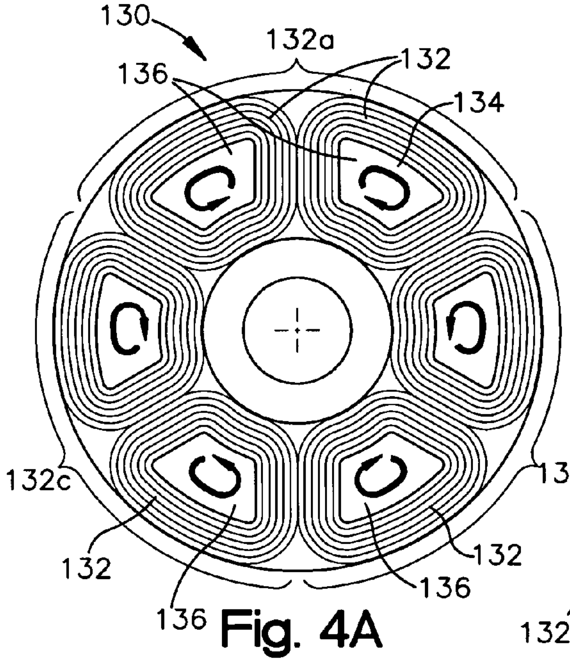


Fig. 4A

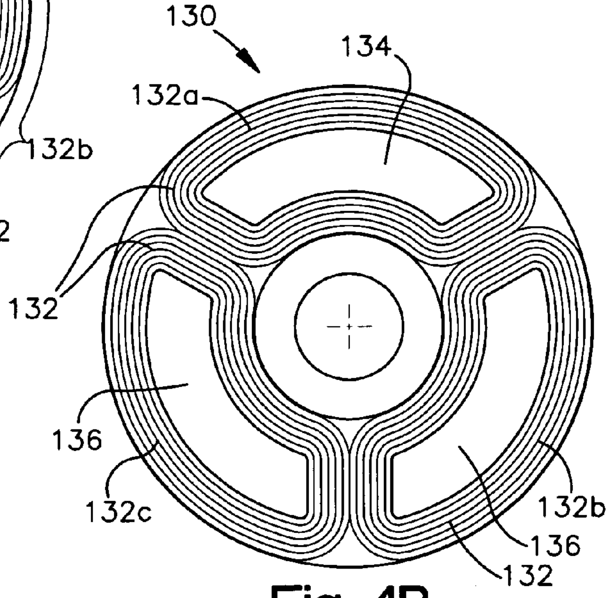


Fig. 4B

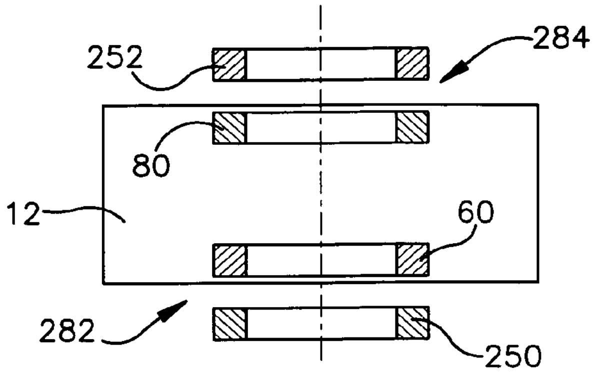


Fig. 5A

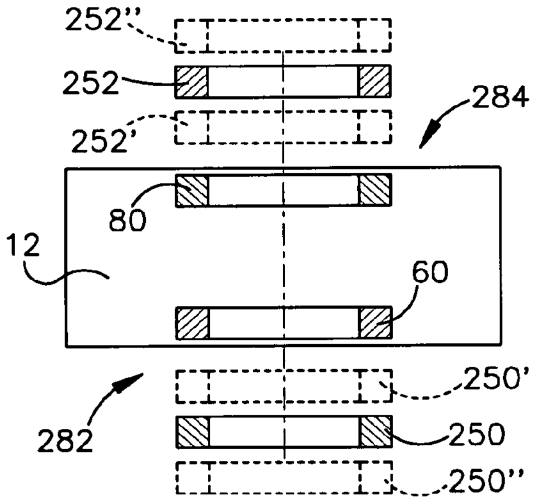


Fig. 5B

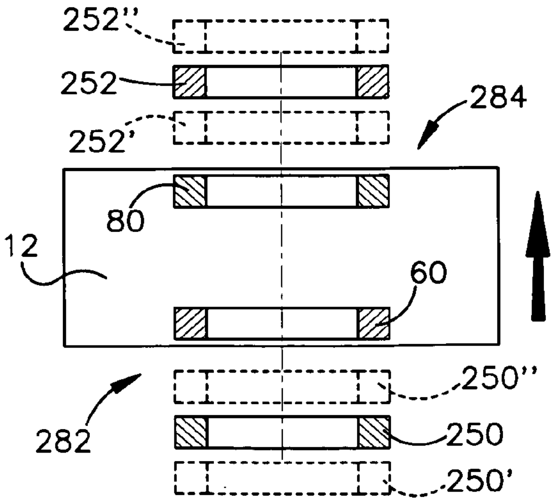
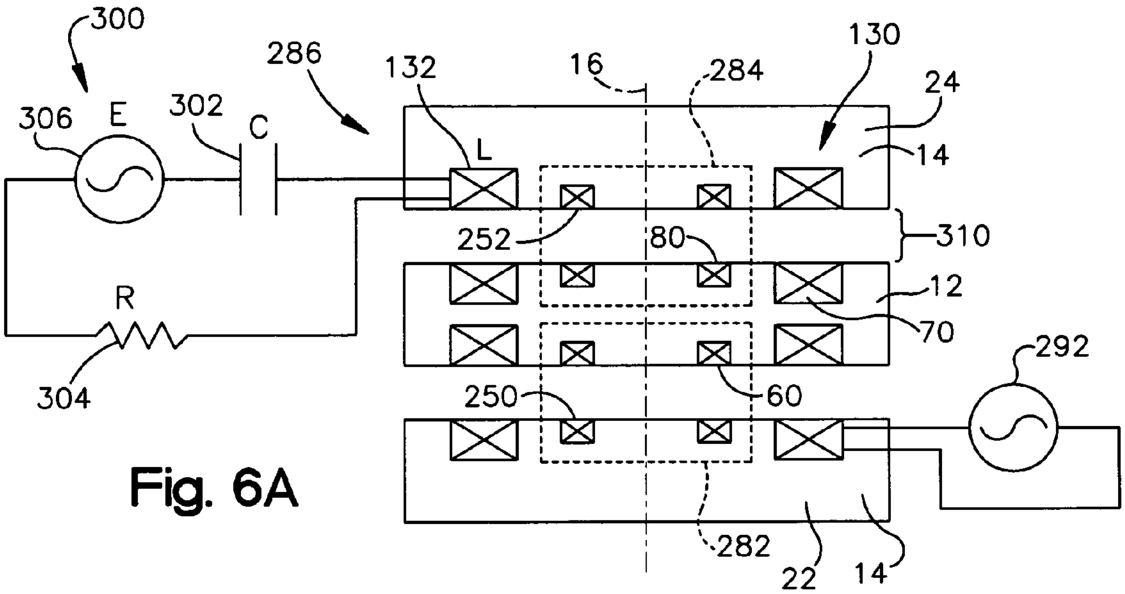


Fig. 5C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130
24
306
E
302
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310
R
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250
60
282
22
14

Fig. 6A

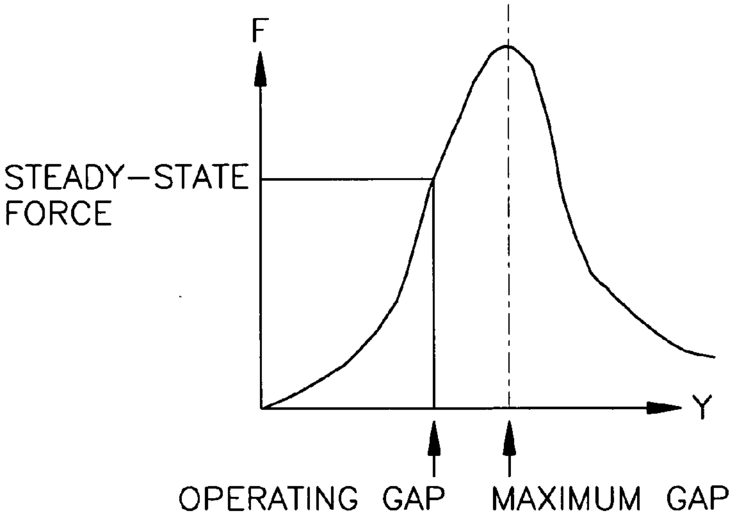
F
STEADY-STATE FORCE
Y
OPERATING GAP
MAXIMUM GAP

Fig. 6B

ROTARY PUMP WITH ELECTROMAGNETIC LCR BEARING

RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application No. 60/508,618, which was filed on Oct. 2, 2003 and is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to a rotary pump with an electromagnetic LCR bearing for supporting the pump rotor.

BACKGROUND OF THE INVENTION

[0003] Heart disease is the leading cause of death and disability in the United States. Some approaches to the treatment of heart disease employ the use of pumping systems that are used to assist the heart in its pumping function, bypass the heart, or replace the heart. Such pumping systems may include pumps that are implantable or pumps that remain external to the patient. One example of a pumping system is a post-cardiotomy assist system. Another example of a pumping system is a bridge-to-transplant system for assisting or replacing a patient's heart while awaiting a transplant. A further example of a pumping system is a bridge-to-recovery system, such as a ventricular assist device (VAD), that assists the patient's heart in order to promote myocardial recovery, either spontaneously, with drugs, or with gene therapy.

SUMMARY OF THE INVENTION

[0004] The present invention relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the fluid inlet to the fluid outlet. A magnetic axial bearing supports the rotor. The axial bearing includes an axial bearing target disposed on the rotor and an axial bearing stator disposed on the housing. The axial bearing stator includes multiple stator poles, each of the stator poles including a first coil portion wound in a first direction and a second coil portion wound in a second direction opposite the first direction.

[0005] The present invention also relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the fluid inlet to the fluid outlet. A magnetic first radial bearing exerts a force on the rotor in a first direction along the axis and a magnetic second radial bearing exerts a force on the rotor in a second direction along the axis opposite the first direction. The first and second radial bearings are adjustable to allow for independently adjusting the net axial force exerted on the rotor by the radial bearings and the radial stiffness of the radial bearings.

[0006] The present invention also relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the inlet to the outlet. The rotor includes permanent magnets arranged on a first side of the rotor and a magnetically conductive disk arranged on a second side of the rotor opposite the first side of the rotor. A motor stator is arranged on the housing to interact with the permanent magnets on the rotor. At least one electromagnet is arranged on the housing to interact with the magnetically conductive disk on the rotor. At least one ring magnet is arranged on at least one of the first and second sides of the rotor. At least one ring magnet is arranged on the housing to magnetically interact with the at least one ring magnet on the rotor.

[0007] The present invention also relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the inlet to the outlet. A motor is arranged to cause rotation of the rotor. At least one electromagnet is arranged to interact magnetically with material in the rotor. The electromagnet includes a stator formed from a spiral wound lamination material.

[0008] The present invention also relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the inlet to the outlet. A motor is arranged to cause rotation of the rotor. At least one electromagnet is arranged to interact magnetically with material in the rotor. The electromagnet includes an even number of poles, adjacent poles being wound in opposite directions.

[0009] The present invention also relates to a pump including a housing having a fluid inlet and a fluid outlet. A rotor is disposed within the housing and is rotatable about an axis to move fluid from the inlet to the outlet. A motor is arranged to cause rotation of the rotor. At least one electromagnet is arranged to interact magnetically with material in the rotor. The material includes a disk of spiral wound magnetic alloy material.

[0010] The present invention also relates to a method for magnetically supporting a pump rotor in a housing for rotation about an axis. The method includes the step of providing an axial bearing target on the rotor. The method also includes the step of providing an axial bearing stator on the housing, the axial bearing stator including multiple stator poles, each including a first coil portion and a second coil portion. The method also includes the steps of winding the first coil portion in a first direction and winding the second coil portion in a second direction opposite the first direction.

[0011] The present invention further relates to a method for magnetically supporting a pump rotor in a housing for rotation about an axis. The method includes the step of providing a magnetic first radial bearing for exerting a force on the rotor in a first direction along the axis. The method also includes the step of providing a magnetic second radial bearing for exerting a force on the rotor in a second direction along the axis opposite the first direction. The method further includes the step of adjusting the axial positions of the first and second radial bearings to independently adjust the net axial force exerted on the rotor by the radial bearings and the radial stiffness of the radial bearings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The foregoing and other features of the present invention will become apparent to those skilled in the art to which the present invention relates upon reading the following description with reference to the accompanying drawings, in which:

[0013] **FIG. 1** is a perspective view of a pump apparatus according to the present invention;

[0014] **FIG. 2** is an exploded view of the apparatus of **FIG. 1**;

[0015] **FIGS. 3A and 3B** are side views illustrating a portion of the apparatus of **FIGS. 1 and 2**;

[0016] **FIGS. 4A and 4B** are side views illustrating alternative configurations of a portion of the apparatus of **FIGS. 1 and 2**;

[0017] **FIGS. 5A-5C** are schematic illustrations depicting the operation of a portion of the apparatus of **FIGS. 1 and 2**;

[0018] **FIG. 6A** is a schematic illustration depicting the operation of a portion of the apparatus of **FIGS. 1 and 2**; and

[0019] **FIG. 6B** is a graph illustrating certain operating parameters of the apparatus of **FIGS. 1 and 2**.

DESCRIPTION OF EMBODIMENTS

[0020] The present invention relates to a rotary pump that includes magnetic bearings for supporting the pump rotor by magnetically levitating the rotor. In one embodiment, the pump may comprise a blood pump for incorporation in a system for pumping blood in a patient. For example, the pump may be a cardiac assist pump or a cardiac replacement pump. The present invention, however, is not necessarily limited to blood pumps and could have alternative implementations or uses in which the pump is used to pump alternative fluids.

[0021] **FIGS. 1 and 2** illustrate an example configuration of an apparatus in the form of a pump **10** for pumping fluids. The pump **10** may, for example, be a blood pump. In the embodiment of the invention illustrated in **FIGS. 1 and 2**, the pump **10** is a rotary pump in which a rotor assembly or rotor **12** is supported in a housing **14** for rotation about an axis **16**. The housing **14** includes a central volute housing part **20**, a motor stator housing part **22**, and an inherently controlled bearing (ICB) stator housing part **24**. The motor stator housing **22** and ICB housing **24** are connectable to the volute housing **20** on opposite sides of the volute housing, thus forming the assembled condition of the housing **14** shown in **FIG. 1**. The pump **10** includes an inlet **26**, associated with the motor stator housing **22**, through which fluid is directed into the pump. The pump **10** also includes an outlet **28**, associated with the volute housing **20**, through which fluid is discharged from the pump.

[0022] Referring to **FIGS. 2, 3A**, and 3B, the rotor **12** includes an impeller structure **30** that includes a generally disk shaped motor side end wall **32** and a generally disk shaped ICB side end wall **34**. The end walls **32** and **34** are spaced from each other, parallel to each other, and centered on the axis **16**. The impeller structure **30** also includes a plurality of impeller vanes **36** that extend between the end walls **32** and **34** and help define a plurality of impeller passages **38**. A central axially extending inlet passage **40** extends through the rotor **12** is in fluid communication with the impeller passages **38**.

[0023] Referring to **FIGS. 2 and 3**A, the motor side end wall **32** supports a motor permanent magnet (PM) ring **50** and a motor side PM radial bearing ring **60** of the rotor **12**. The motor side PM radial bearing ring **60** is positioned radially inward of the motor PM ring **50**. An annular insulating portion **52** may help isolate the motor PM ring **50** and the motor side PM radial bearing ring **60**. The motor PM ring **50** and motor side PM radial bearing ring **60** are fixed to or embedded in the motor side end wall **32** of the rotor **12**. The motor PM ring **50** includes a plurality of PM motor magnets **54** arranged in an annular fashion about the motor side end wall **32**. In the embodiment illustrated in **FIG. 2**, the motor PM ring **50** includes eight (8) motor magnets **54** equal in size and arranged spaced evenly in an annular fashion about the motor PM ring **50**. The motor PM ring **50** could, however, have an alternative configuration, such as including a different number of PM motor magnets **54**.

[0024] The motor side PM radial bearing ring **60** may be made of a permanent magnet material with high coercivity such as neodymium boron iron. The motor side PM radial bearing ring **60** has an annular single magnet construction. The motor side PM radial bearing ring **60** could, however, have an alternative construction. For example, the motor side PM radial bearing ring **60** may include multiple magnet segments and may include flux carrying material, such as iron, to aid in creating a desired magnetic flux path.

[0025] Referring to **FIGS. 2 and 3**B, the bearing side end wall **34** supports a ring-shaped axial bearing target **70** and a bearing side PM radial bearing ring **80** of the rotor **12**. The bearing side PM radial bearing ring **80** is positioned radially inward of the axial bearing target **70**. An annular insulating portion **72** of the bearing side end wall **34** may help isolate the axial bearing target **70** and the bearing side PM radial bearing ring **80**. The axial bearing target **70** and bearing side PM radial bearing ring **80** are fixed to or embedded in the bearing side end wall **34** of the rotor **12**. The axial bearing target **70** has an annular configuration and is constructed of ferrite, powder iron, or laminated silicon steel. For example, the axial bearing target **70** could be formed from a thin flat strip or strips of material that are wound to form the axial bearing target. The axial bearing target **70** could, however, have an alternative configuration, an alternative material construction, or both.

[0026] The bearing side PM radial bearing ring **80** may be made of a permanent magnet material with high coercivity such as neodymium boron iron. The bearing side PM radial bearing ring **80** has an annular single magnet construction. The bearing side PM radial bearing ring **80** could, however, have an alternative construction. For example, the bearing side PM radial bearing ring **80** may include multiple magnet segments and may include flux carrying material, such as iron, to aid in creating a desired magnetic flux path.

[0027] The volute housing part **20 (FIG. 2)** has a generally cylindrical main portion **100** that helps define a volute pump chamber **102**. The main portion **100** has a first end forming a motor side **106** of the volute housing **20** and an opposite second end forming a stator side **108** of the volute housing. The pump chamber **102** is sized to receive the rotor **12** and form a predetermined clearance with the rotor. An annular pumping channel **104** is formed in the main portion **100** an is in fluid communication with the pump chamber **102** and the impeller passages **38** when the pump **10** is assembled. The outlet **28** extends generally tangentially from the main portion **100** of the volute housing part **20** and is in fluid communication with the pumping channel **104**.

[0028] The motor stator housing **22** is adapted to support a motor stator assembly **120** of the pump **10**. In the illustrated embodiment, the motor stator assembly **120** includes