US 20120034109A1

(19) **United States**

(12) **Patent Application Publication**

Tout et al.

(10) **Pub. No.: US 2012/0034109 A1**

(43) **Pub. Date: Feb. 9, 2012**

(54) **SYSTEM AND METHOD FOR MEASURING PRESSURE APPLIED BY A PIEZO-ELECTRIC PUMP**

(76) Inventors: **Aidan Marcus Tout**, Alderbury (GB); **Christopher Brian Locke**, Bournemouth (GB)

(21) Appl. No.: **13/204,236**

(22) Filed: **Aug. 5, 2011**

Related U.S. Application Data

(60) Provisional application No. 61/371,954, filed on Aug. 9, 2010.

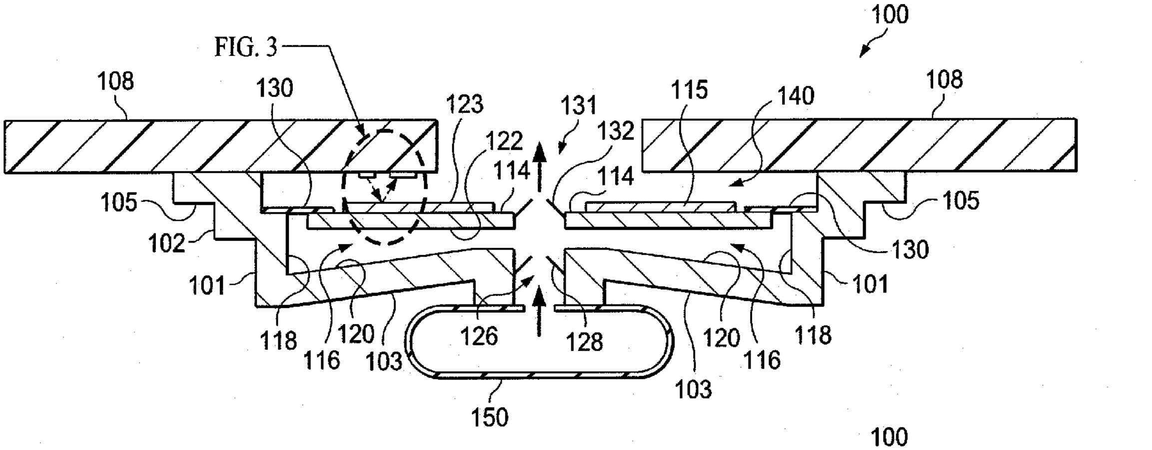
Publication Classification

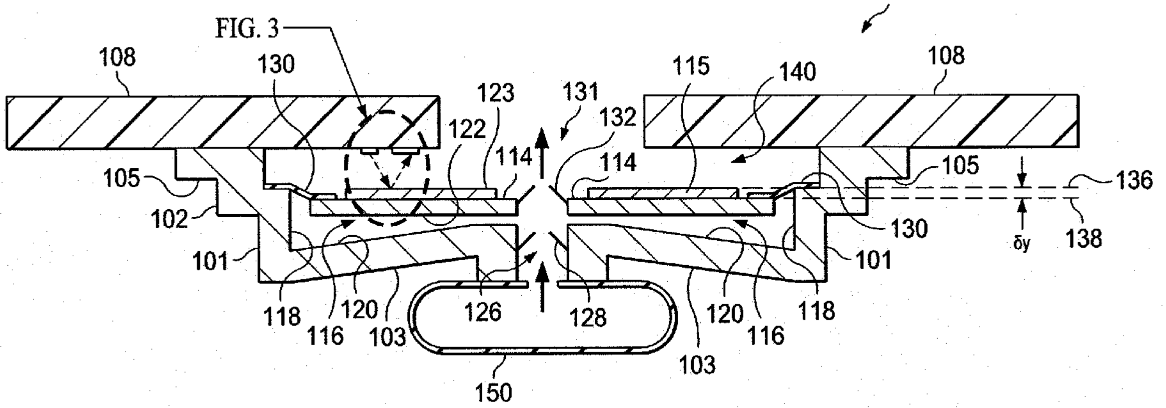
(51) **Int. Cl.**
F04B 53/00 (2006.01)

(52) **U.S. Cl.** **417/313**

(57) **ABSTRACT**

A system and method for measuring the pressure provided by a disc pump is disclosed. The disc pump comprises an actuator mounted within the disc pump on a flexible skirt that allows the actuator to oscillate for generating air flow through the cavity of the pump and allows the actuator to be displaced with increasing pressure to a load. The actuator moves from a rest position when air begins flowing through the cavity to a biased position when the load is fully pressurized or depressurized depending on the direction of fluid flow through the cavity. The pump further comprises a sensor which measures the displacement of the actuator at any position between the rest position and the biased position as fluid begins flowing through the cavity to pressurize or depressurize the load. The pressure being delivered by the disc pump is determined as a function of the displacement of the actuator.





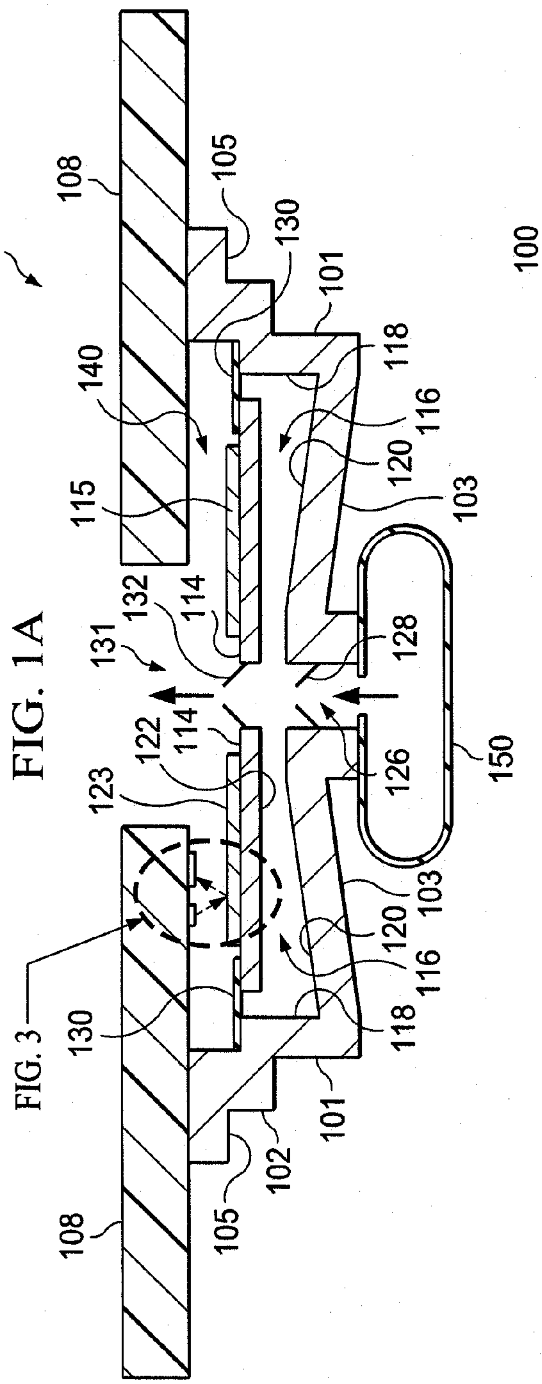

100
108
105
130
101
140
118
116
120
115
103
132
114
131
128
122
114
123
126
150
FIG. 3
130
120
103
116
118
101
102
105
108

FIG. 1A

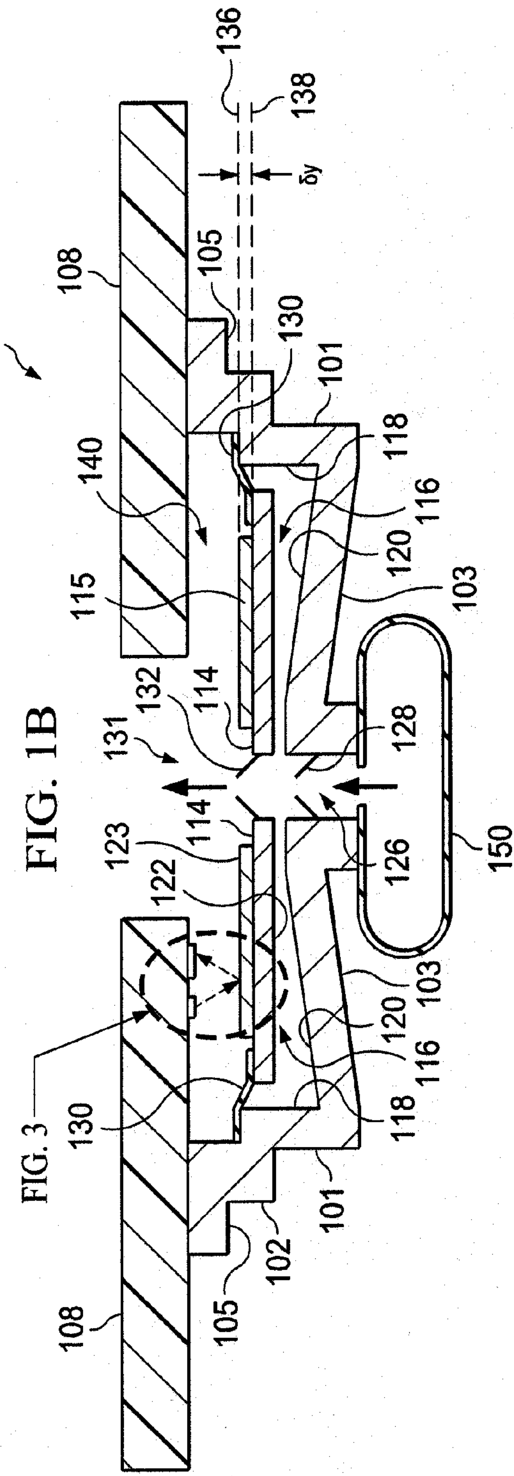

100
136
138
δy
108
105
130
101
140
118
116
120
115
103
132
114
131
128
123
114
122
126
150
FIG. 3
130
120
103
116
118
101
102
105
108

FIG. 1B

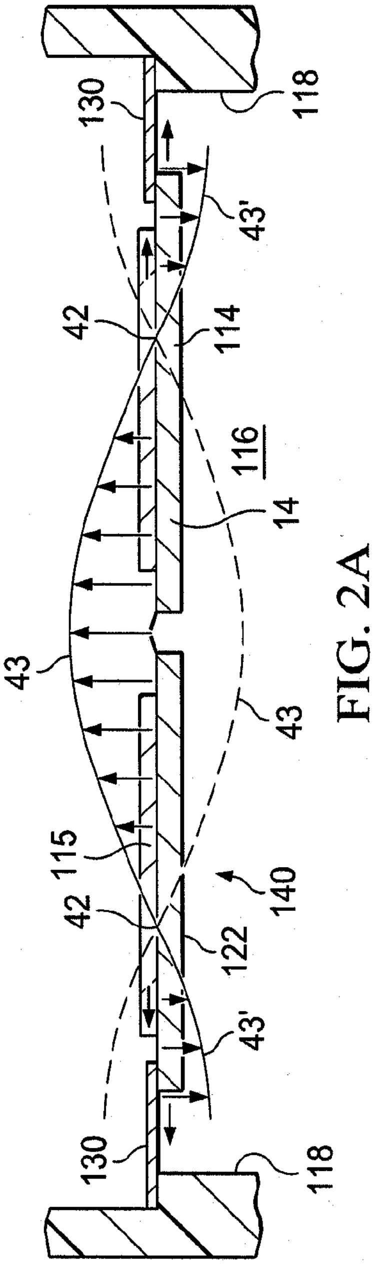

130
118
43'
42
114
116
14
43
43
115
42
122
140
43'
130
118

FIG. 2A

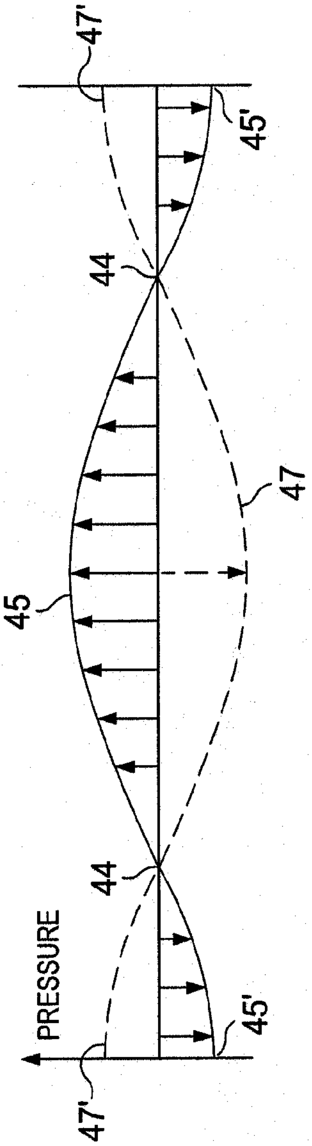

47'
45'
44
47
45
44
PRESSURE
45'
47'

FIG. 2B

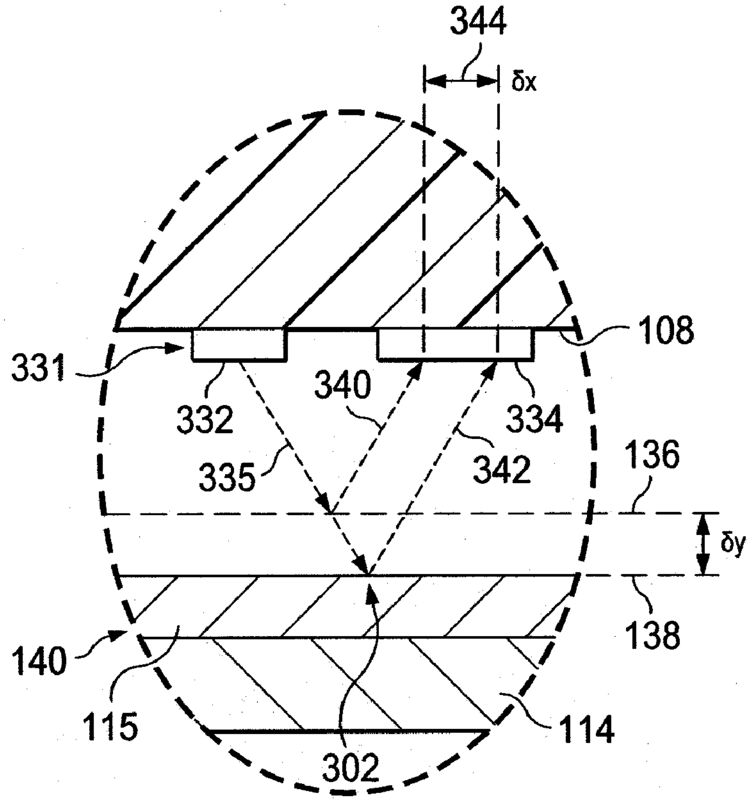

344
δx
331
108
332
340
334
335
342
136
δy
138
140
115
114
302

FIG. 3

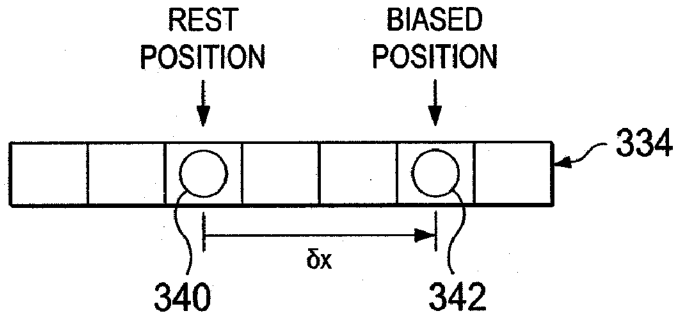

REST POSITION
BIASED POSITION
334
δx
340
342

FIG. 4

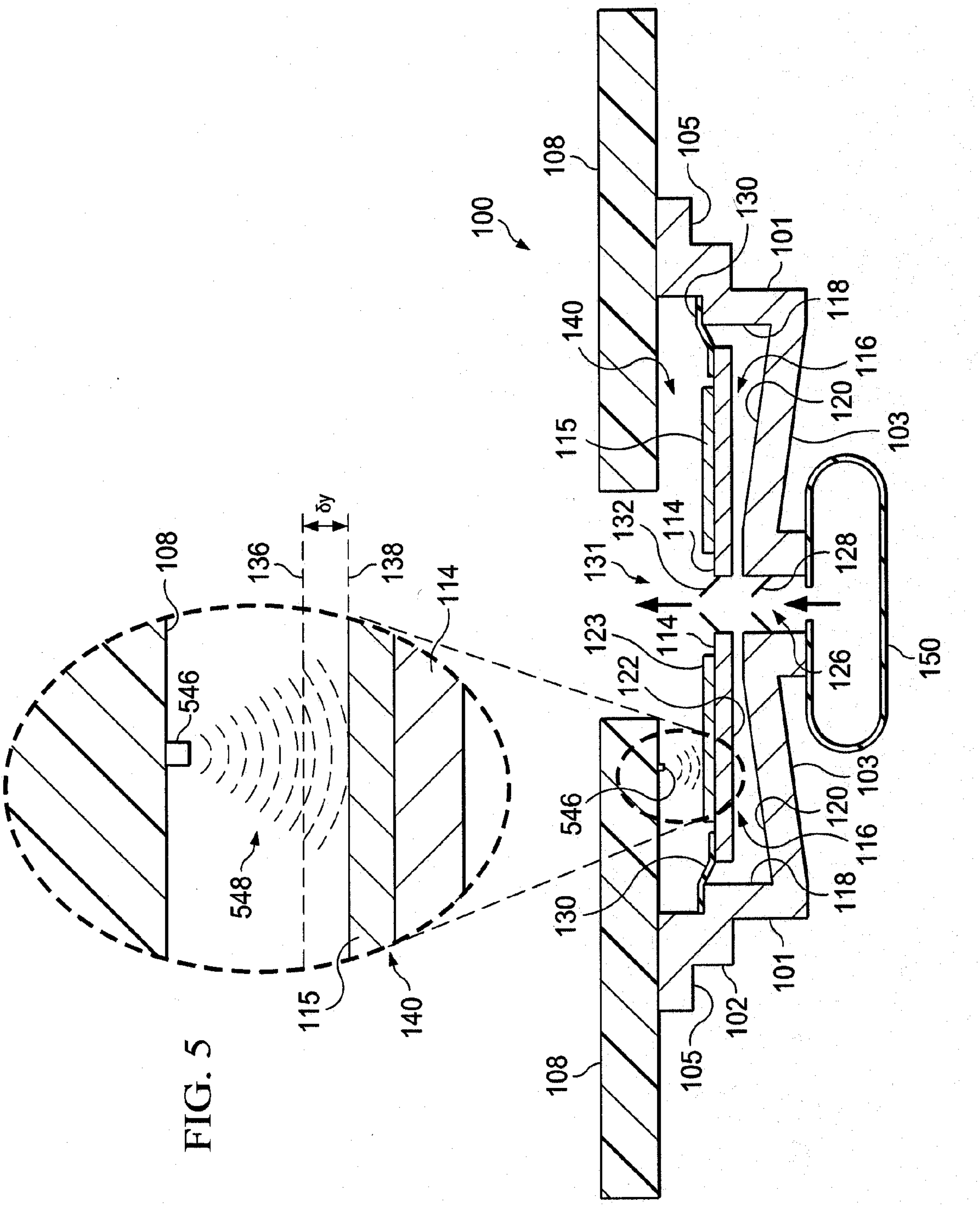

100
108
105
130
101
140
118
116
120
115
103
132
131
114
128
123
114
122
126
150
546
120
103
116
118
130
101
102
105
108
108
546
136
138
δy
114
548
115
140

FIG. 5

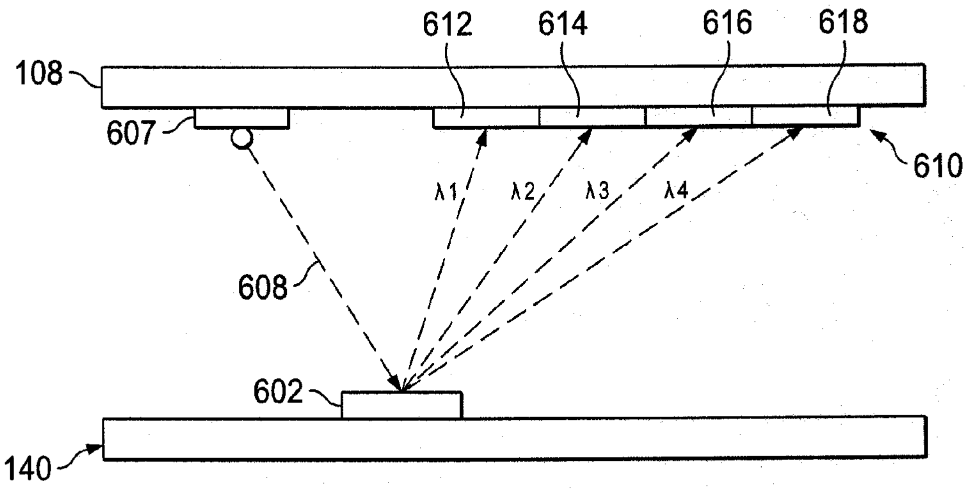

612
614
616
618
108
607
610
λ1
λ2
λ3
λ4
608
602
140

FIG. 6

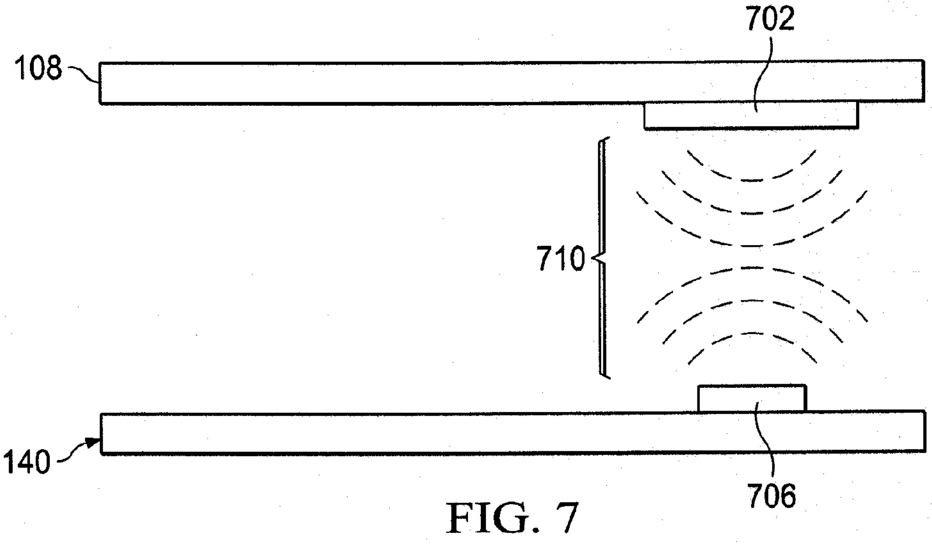

702
108
710
140
706

FIG. 7

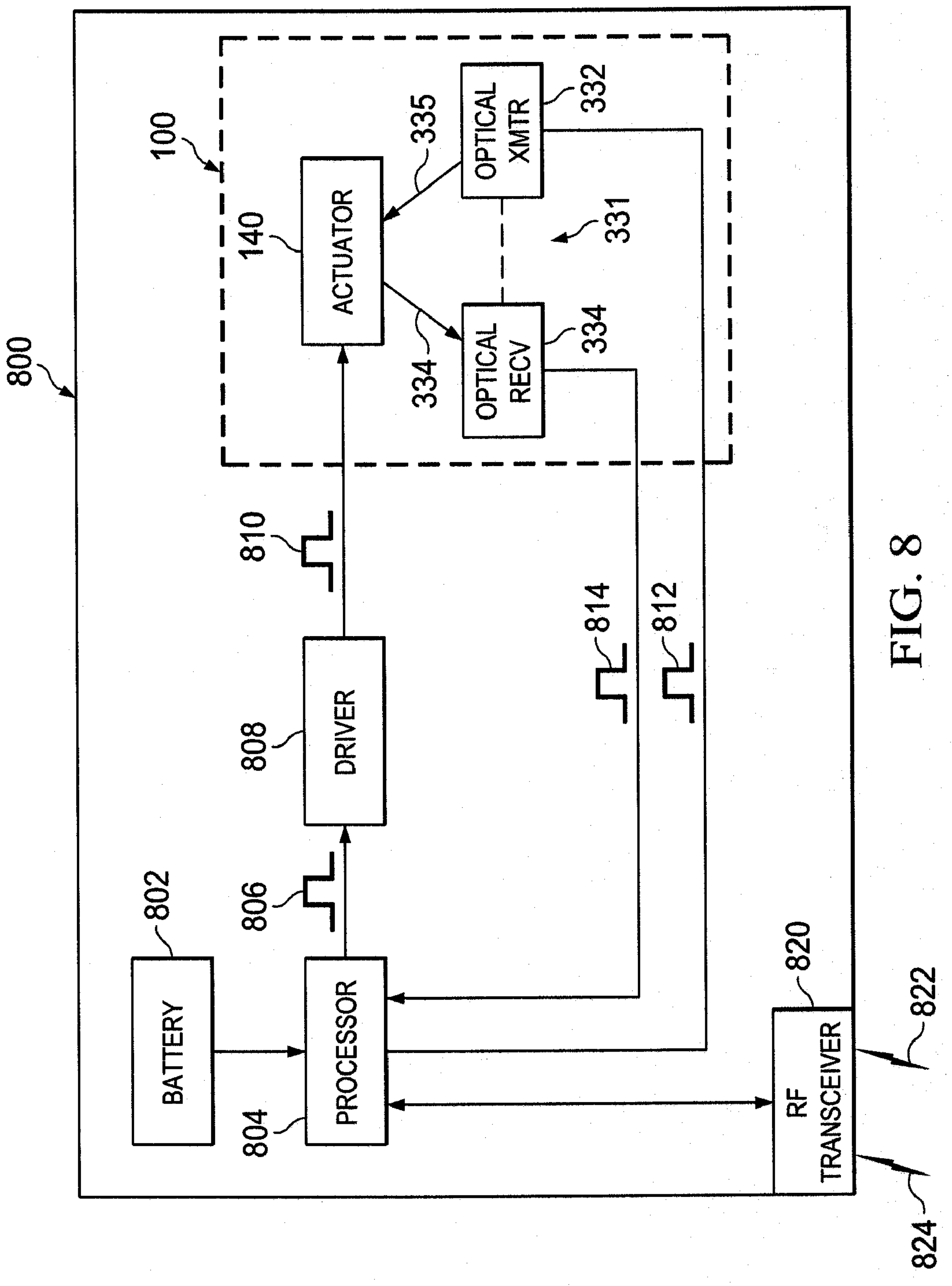

800
100
BATTERY
802
PROCESSOR
804
806
DRIVER
808
810
ACTUATOR
140
335
OPTICAL XMTR
332
331
OPTICAL RECV
334
334
814
812
RF TRANSCEIVER
820
822
824

FIG. 8

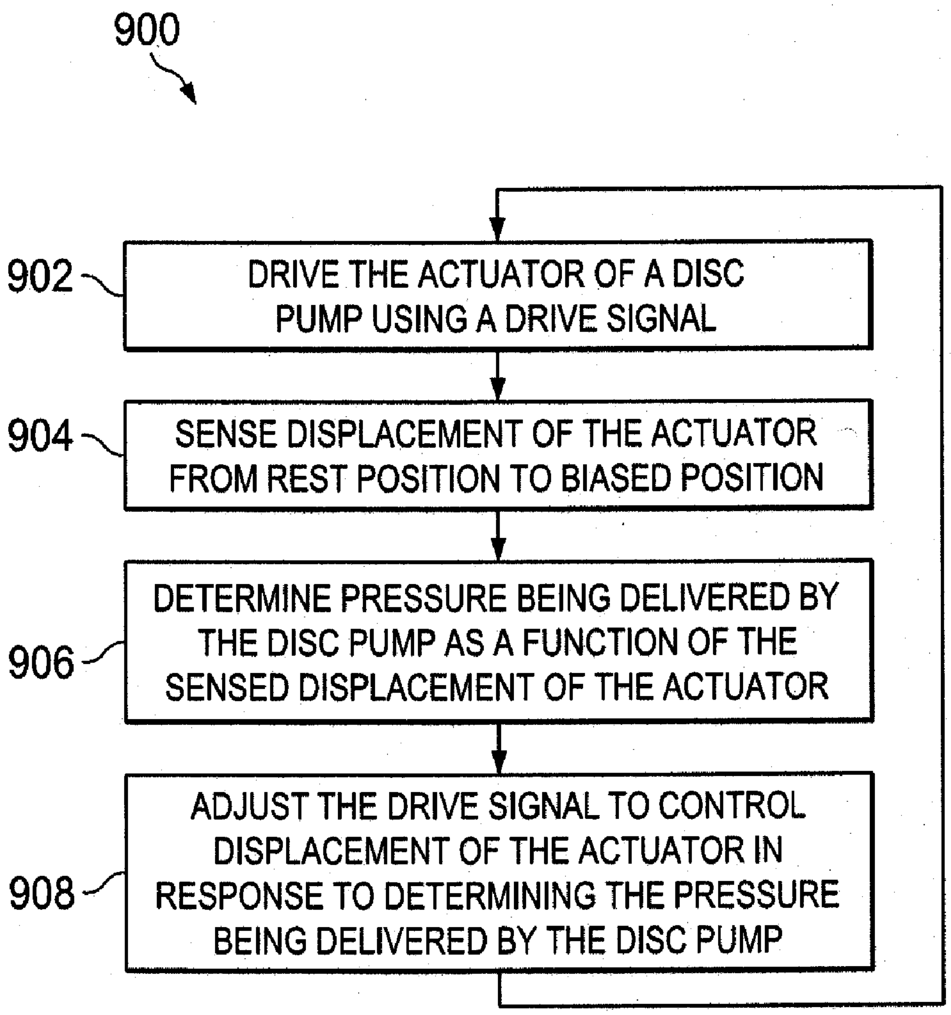

900
902
DRIVE THE ACTUATOR OF A DISC PUMP USING A DRIVE SIGNAL
904
SENSE DISPLACEMENT OF THE ACTUATOR FROM REST POSITION TO BIASED POSITION
906
DETERMINE PRESSURE BEING DELIVERED BY THE DISC PUMP AS A FUNCTION OF THE SENSED DISPLACEMENT OF THE ACTUATOR
908
ADJUST THE DRIVE SIGNAL TO CONTROL DISPLACEMENT OF THE ACTUATOR IN RESPONSE TO DETERMINING THE PRESSURE BEING DELIVERED BY THE DISC PUMP

FIG. 9

SYSTEM AND METHOD FOR MEASURING PRESSURE APPLIED BY A PIEZO-ELECTRIC PUMP

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/371,954, filed Aug. 9, 2010, and is hereby incorporated by reference.

BACKGROUND

[0002] 1. Field of the Invention

[0003] The illustrative embodiments of the invention relate generally to a pump for fluid and, more specifically, to a pump in which the pumping cavity is substantially elliptical in shape having end walls and a side wall with an actuator disposed between the end walls. The illustrative embodiments of the invention relate more specifically to a disc pump having a valve mounted in the actuator and/or one additional valve mounted in one of the end walls.

[0004] 2. Description of Related Art

[0005] The generation of high amplitude pressure oscillations in closed cavities has received significant attention in the fields of thermo-acoustics and pump type compressors. Recent developments in non-linear acoustics have allowed the generation of pressure waves with higher amplitudes than previously thought possible.

[0006] It is known to use acoustic resonance to achieve fluid pumping from defined inlets and outlets. This can be achieved using a elliptical cavity with an acoustic driver at one end, which drives an acoustic standing wave. In such a elliptical cavity, the acoustic pressure wave has limited amplitude. Varying cross-section cavities, such as cone, horn-cone, bulb have been used to achieve high amplitude pressure oscillations thereby significantly increasing the pumping effect. In such high amplitude waves the non-linear mechanisms with energy dissipation have been suppressed. However, high amplitude acoustic resonance has not been employed within disc-shaped cavities in which radial pressure oscillations are excited until recently. International Patent Application No. PCT/GB2006/001487, published as WO 2006/111775, discloses a pump having a substantially disc-shaped cavity with a high aspect ratio, i.e., the ratio of the radius of the cavity to the height of the cavity.

[0007] Such a pump has a substantially elliptical cavity comprising a side wall closed at each end by end walls. The pump also comprises an actuator that drives either one of the end walls to oscillate in a direction substantially perpendicular to the surface of the driven end wall. The spatial profile of the motion of the driven end wall is described as being matched to the spatial profile of the fluid pressure oscillations within the cavity, a state described herein as mode-matching. When the pump is mode-matched, work done by the actuator on the fluid in the cavity adds constructively across the driven end wall surface, thereby enhancing the amplitude of the pressure oscillation in the cavity and delivering high pump efficiency. The efficiency of a mode-matched pump is dependent upon the interface between the driven end wall and the side wall. It is desirable to maintain the efficiency of such pump by structuring the interface so that it does not decrease or dampen the motion of the driven end wall thereby mitigating any reduction in the amplitude of the fluid pressure oscillations within the cavity.

[0008] The actuator of the pump described above causes an oscillatory motion of the driven end wall ("displacement oscillations") in a direction substantially perpendicular to the end wall or substantially parallel to the longitudinal axis of the elliptical cavity, referred to hereinafter as "axial oscillations" of the driven end wall within the cavity. The axial oscillations of the driven end wall generate substantially proportional "pressure oscillations" of fluid within the cavity creating a radial pressure distribution approximating that of a Bessel function of the first kind as described in International Patent Application No. PCT/GB2006/001487 which is incorporated by reference herein, such oscillations referred to hereinafter as "radial oscillations" of the fluid pressure within the cavity. A portion of the driven end wall between the actuator and the side wall provides an interface with the side wall of the pump that decreases dampening of the displacement oscillations to mitigate any reduction of the pressure oscillations within the cavity, that portion being referred to hereinafter as an "skirt" or a "skirt" as described more specifically in U.S. patent application Ser. No. 12/477,594 which is incorporated by reference herein. The illustrative embodiments of the skirt are operatively associated with the peripheral portion of the driven end wall to reduce dampening of the displacement oscillations.

[0009] Such pumps also require one or more valves for controlling the flow of fluid through the pump and, more specifically, valves being capable of operating at high frequencies. Conventional valves typically operate at lower frequencies below 500 Hz for a variety of applications. For example, many conventional compressors typically operate at 50 or 60 Hz. Linear resonance compressors known in the art operate between 150 and 350 Hz. However, many portable electronic devices including medical devices require pumps for delivering a positive or negative pressure that are relatively small in size and quiet during operation so as to provide discrete therapy. To achieve these objectives, such pumps must operate at very high frequencies requiring valves capable of operating at about 20 kHz and higher. To operate at these high frequencies, the valve must be responsive to a high frequency oscillating pressure that can be rectified to create a net flow of fluid through the pump.

[0010] Such a valve is described more specifically in International Patent Application No. PCT/GB2009/050614 which is incorporated by reference herein. Valves may be disposed in either the first or second aperture, or both apertures, for controlling the flow of fluid through the pump. Each valve comprises a first plate having apertures extending generally perpendicular therethrough and a second plate also having apertures extending generally perpendicular therethrough, wherein the apertures of the second plate are substantially offset from the apertures of the first plate. The valve further comprises a sidewall disposed between the first and second plate, wherein the sidewall is closed around the perimeter of the first and second plates to form a cavity between the first and second plates in fluid communication with the apertures of the first and second plates. The valve further comprises a flap disposed and moveable between the first and second plates, wherein the flap has apertures substantially offset from the apertures of the first plate and substantially aligned with the apertures of the second plate. The flap is motivated between the first and second plates in response to a change in direction of the differential pressure of the fluid across the valve.

BRIEF SUMMARY OF THE INVENTION

[0011] In addressing measurement and control issues of tissue treatment systems, which may include a disc pump or micro-pump, the principles of the present invention may be utilized to measure the pressure being generated by the disc pump to more effectively and economically control the operation of the disc pump. The disc pump includes an actuator that vibrates within a cavity to generate a radial pressure wave to provide a reduced pressure for application to a load or tissue site as described above. Displacement of the actuator may be measured using one or more sensors. Pressure being generated by the disc pump for the tissue site may be determined in response to the measured displacement of the actuator. A drive signal for the actuator may be adjusted to control operation and, consequently, displacement of the actuator to reach a desired pressure at the tissue site.

[0012] One embodiment of a disc pump includes a disc pump housing, skirt, actuator, sensor, and electronic circuit. The skirt is fixed to the disc pump housing to support the actuator, and may be any material that is sufficiently flexible to allow the actuator to vibrate. The actuator and the skirt face an opposing base plate to form a cavity within the disc pump wherein radial pressure waves are generated. The actuator may have a first surface and a second surface and be directly or indirectly coupled to the skirt. The sensor may be positioned outside the cavity to sense a position of the actuator with respect to the disc pump housing that corresponds to the pressure being provided. An electronic circuit may be in communication with the sensor and be configured to calculate pressure provided by the disc pump as a function of the position of the actuator with respect to the disc pump housing while the actuator is activated.

[0013] In another embodiment, a pump body comprises a substantially elliptical shaped side wall closed at one end by a base wall and the other end by a pair of interior plates to form a cavity within said pump body for containing a fluid wherein a first one of the interior plates adjacent the cavity includes a center portion and a peripheral portion. The pump further comprises an actuator formed by the end plates wherein the second one of the interior plates is operatively associated with the central portion of the first interior plate to cause an oscillatory displacement motion thereby generating radial pressure oscillations of the fluid within the cavity in response to a drive signal being applied to said actuator when in use The pump also comprises a skirt flexibly connected between the side wall and the peripheral portion of the first interior plate to facilitate the oscillatory displacement motion. The pump also comprises a first aperture extending through said actuator to enable fluid to flow through the cavity and a second aperture extending through the base wall to enable fluid to flow through the cavity. A valve is disposed in at least one of said first aperture and second apertures and is adapted to permit the fluid to flow through the cavity in substantially one direction to pressurize or depressurize a load as fluid begins flowing through the cavity, thereby causing said actuator to move toward the base wall from a rest position to a biased position with increasing pressure and flexing of the skirt. The pump further comprises a sensor mounted outside the cavity in a fixed position with respect to said pump body for measuring the displacement of said actuator at any position between the rest position and the biased position as fluid begins flowing through the cavity to pressurize or depressurize the load.

[0014] One method for controlling a disc pump includes driving an actuator within a housing of a disc pump using a drive signal. The actuator is mounted within the disc pump by the skirt which is flexible. As the actuator vibrates in response to the drive signal, the pressure created in a load increases while airflow decreases from a free-flow state to a stall state. The pressure being built up in the load by the disc pump may be measured by a sensor as a function of the displacement of the actuator from a rest position in the free-flow state to a biased position in the stall state when the pressure forces the actuator away from the rest position as the skirt flexes with the actuator from its fixed position toward the biased position. Because the actuator generates radial pressure waves within the cavity of the disc pump, such a sensor is preferably positioned outside the cavity of the disc pump so that it does not interfere with the operation of the disc pump itself.

[0015] Other objects, features, and advantages of the illustrative embodiments are disclosed herein and will become apparent with reference to the drawings and detailed description that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Illustrative embodiments of the present invention are described in detail below with reference to the attached drawing figures, which are incorporated by reference herein and wherein:

[0017] FIG. **1**A is a schematic, cross-sectional view of a first disc pump having an actuator shown in a rest position according to a first illustrative embodiment;

[0018] FIG. **1**B is a schematic, cross-sectional view of the first disc pump showing the actuator in a biased position according to a first illustrative embodiment;

[0019] FIG. **2**A is a graph of the axial displacement oscillations for a fundamental bending mode of the actuator of the first disc pump;

[0020] FIG. **2**B is a graph of the pressure oscillations of fluid within the cavity of the first disc pump in response to the bending mode shown in FIG. **2**A;

[0021] FIG. **3** is a zoomed-in view of a first sensor for measuring the displacement of the actuator of the first disc pump according to a first illustrative embodiment;

[0022] FIG. **4** is a schematic view of an illustrative receiver of the first sensor indicating the position of the actuator when in the rest position and the biased position;

[0023] FIG. **5** is a schematic, cross-sectional view of the disc pump with the actuator shown in the biased position including a zoomed-in view of a second sensor for measuring the displacement of the actuator according to a second illustrative embodiment;

[0024] FIG. **6** is a third illustrative sensor including a diffraction grating for measuring displacement of an actuator in a disc pump;

[0025] FIG. **7** is a fourth illustrative sensor including a magnetic element for measuring displacement of an actuator in a disc pump;

[0026] FIG. **8** is a block diagram of an illustrative circuit of a disc pump for measuring and controlling a reduced pressure generated by the disc pump; and

[0027] FIG. **9** is a flow chart of an illustrative process for controlling pressure generated by a disc pump.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0028] FIGS. **1**A and **1**B are illustrations of a cross-section view of an illustrative disc pump **100** in accordance with illustrative embodiments. As shown, the disc pump **100** may include a pump housing **102** having a substantially elliptical shape including a elliptical wall **101** closed at one end by a base wall **103** and mounted at the other end by legs **105** attached to a circuit board **108** or other substrate to support the pump housing **102**. The elliptical wall **101**, the legs **105**, and base wall **103** together form the pump housing **102**. The pump **100** further comprises a pair of disc-shaped interior plates **114**, **115** supported within the pump **100** by a ring-shaped skirt **130** affixed to the elliptical wall **101** of the pump body. The internal surfaces of the elliptical wall **101**, the base wall **103**, the interior plate **114**, and the ring-shaped skirt **130** form a cavity **116** within the pump **100**. The internal surfaces of the cavity **116** comprise a side wall **118** which is a first portion of the inside surface of the elliptical wall **101** that is closed at one end by end wall **120** wherein the end wall **120** is the internal surface of the end plate **103** and the end wall **122** comprises the internal surface of the interior plate **114** and a first side of the skirt **130**. The end wall **122** thus comprises a central portion corresponding to the inside surface of the interior plate **114** and a peripheral portion corresponding to the inside surface of the ring-shaped skirt **130**.

[0029] Although the pump **100** and its components are substantially elliptical in shape, the specific embodiment disclosed herein is a circular, elliptical shape. In the embodiments shown in FIGS. **1**A and **1**B, the end wall **120** is shown as being a frusto-conical surface, but may also be generally planar and parallel with the end wall **122**. The base wall **103** and elliptical wall **101** of the pump body may be formed from any suitable rigid material including, without limitation, metal, ceramic, glass, or plastic including, without limitation, injection-molded plastic.

[0030] The interior plates **114**, **115** of the pump **100** together form an actuator **140** that is operatively associated with the central portion of the end wall **122** which is one of the internal surfaces of the cavity **116**. One of the interior plates **114**, **115** must be formed of a piezoelectric material which may include any electrically active material that exhibits strain in response to an applied electrical signal, such as, for example, an electro-strictive or magneto-strictive material. In one preferred embodiment, for example, the interior plate **115** is formed of piezoelectric material that that exhibits strain in response to an applied electrical signal, i.e., the active interior plate. The other one of the interior plates **114**, **115** preferably possess a bending stiffness similar to the active interior plate and may be formed of a piezoelectric material or an electrically inactive material, such as a metal or ceramic. In this preferred embodiment, the interior plate **114** possess a bending stiffness similar to the active interior plate **115** and is formed of an electrically inactive material, such as a metal or ceramic, i.e., the inert interior plate. When the active interior plate **115** is excited by an electrical current, the active interior plate **115** expands and contracts in a radial direction relative to the longitudinal axis of the cavity **116** causing the interior plates **114**, **115** to bend, thereby inducing an axial deflection of their respective end wall **122** in a direction substantially perpendicular to the end wall **122** (See FIG. **2**A).

[0031] In other embodiments not shown, the skirt **130** may support either one of the interior plates **114**, **115**, whether the active or inert internal plate, from the top or the bottom surfaces depending on the specific design and orientation of the pump **100**. In another embodiment, the actuator **140** may be replaced by a device in a force-transmitting relation with only one of the interior plates **114**, **115** such as, for example, a mechanical, magnetic or electrostatic device, wherein the interior plate may be formed as an electrically inactive or passive layer of material driven into oscillation by such device (not shown) in the same manner as described above.

[0032] The pump **100** further comprises at least two apertures extending from the cavity **116** to the outside of the pump **100**, wherein at least one of the apertures contains a valve to control the flow of fluid through the aperture. Although the apertures may be located at any position in the cavity **116** where the actuator **140** generates a pressure differential as described below in more detail, one preferred embodiment of the pump **100** comprises aperture **126** located at approximately the centre of and extending through the base wall **103**. The aperture **126** contains at least one end valve. In one preferred embodiment, the aperture **126** contains a valve **128** which regulates the flow of fluid in one direction as indicated by the arrow. Thus, for this embodiment, the valve **128** functions as an inlet valve for the pump.

[0033] The pump **100** further comprises at least one aperture from the cavity **116** through the actuator **140**, wherein at least one of the apertures contains a valve to control the flow of fluid through the aperture. Although these apertures may be located at any position on the actuator **140** from the cavity **116** where the actuator **140** generates a pressure differential as described below in more detail, one embodiment of the pump **100** comprises a single aperture **131** located at approximately the centre of and extending through the interior plates **114**, **115**. The aperture **131** contains an actuator valve **132** which regulates the flow of fluid in one direction from the cavity **116** as indicated by the arrow so that the actuator valve **132** functions as an outlet valve from the cavity **116**. The actuator valve **132** enhances the output of the pump **100** by supplementing the operation of the inlet valve **128** as described in more detail below.

[0034] The dimensions of the cavity **116** described herein should preferably satisfy certain inequalities with respect to the relationship between the height (h) and radius (r) of the cavity **116** which is the distance from the longitudinal axis of the cavity **116** to the side wall **118**. These equations are as follows:

$r/h>1.2$; and

$h^2/r>4\times10^{-10}$ meters.

[0035] In one embodiment of the invention, the ratio of the cavity radius to the cavity height (r/h) is between about 10 and about 50 when the fluid within the cavity **116** is a gas. In this example, the volume of the cavity **116** may be less than about 10 ml. Additionally, the ratio of h^2/r is preferably within a range between about 10^{-6} and about 10^{-7} meters where the working fluid is a gas as opposed to a liquid.

[0036] Additionally, the cavity **116** disclosed herein should preferably satisfy the following inequality relating the cavity radius (r) and operating frequency (f) which is the frequency at which the actuator **140** vibrates to generate the axial displacement of the end wall **122**. The inequality equation is as follows:

$$\frac{k_0(c_s)}{2\pi f} \le r \le \frac{k_0(c_f)}{2\pi f} \qquad \text{[Equation 1]}$$

wherein the speed of sound in the working fluid within the cavity **116** (c) may range between a slow speed (c_s) of about 115 m/s and a fast speed (c_f) equal to about 1,970 m/s as expressed in the equation above, and k_0 is a constant (k_0=3.

83). The frequency of the oscillatory motion of the actuator **140** is preferably about equal to the lowest resonant frequency of radial pressure oscillations in the cavity **116**, but may be within 20% that value. The lowest resonant frequency of radial pressure oscillations in the cavity **116** is preferably greater than about 500 Hz.

[0037] Although it is preferable that the cavity **116** disclosed herein should satisfy individually the inequalities identified above, the relative dimensions of the cavity **116** should not be limited to cavities having the same height and radius. For example, the cavity **116** may have a slightly different shape requiring different radii or heights creating different frequency responses so that the cavity **116** resonates in a desired fashion to generate the optimal output from the pump **100**.

[0038] In operation, the pump **100** may function as a source of positive pressure adjacent the outlet valve **132** to pressurize a load (not shown) or as a source of negative or reduced pressure adjacent the inlet valve **128** to depressurize a load **150** as illustrated by the arrows. The inlet of the pump **100** as shown is in fluid communication with the load **150** such that the pump **100** functions as a source of negative or reduced pressure adjacent the inlet valve **128**. The load **150** may be a tissue treatment system that utilizes negative pressure for treatment. The term "reduced pressure" as used herein generally refers to a pressure less than the ambient pressure where the pump **100** is located. Although the term "vacuum" and "negative pressure" may be used to describe the reduced pressure, the actual pressure reduction may be significantly less than the pressure reduction normally associated with a complete vacuum. The pressure is "negative" in the sense that it is a gauge pressure, i.e., the pressure is reduced below ambient atmospheric pressure. Unless otherwise indicated, values of pressure stated herein are gauge pressures. References to increases in reduced pressure typically refer to a decrease in absolute pressure, while decreases in reduced pressure typically refer to an increase in absolute pressure.

[0039] FIG. **2**A shows one possible displacement profile illustrating the axial oscillation of the driven end wall **122** of the cavity **116**. The solid curved line and arrows represent the displacement of the driven end wall **122** at one point in time, and the dashed curved line represents the displacement of the driven end wall **122** one half-cycle later. The displacement as shown in this figure and the other figures is exaggerated. Because the actuator **140** is not rigidly mounted at its perimeter, but rather suspended by the ring-shaped skirt **130**, the actuator **140** is free to oscillate about its centre of mass in its fundamental mode. In this fundamental mode, the amplitude of the displacement oscillations of the actuator **140** is substantially zero at an annular displacement node **42** located between the centre of the driven end wall **122** and the side wall **118**. The amplitudes of the displacement oscillations at other points on the end wall **122** are greater than zero as represented by the vertical arrows. A central displacement anti-node **43** exists near the centre of the actuator **140** and a peripheral displacement anti-node **43'** exists near the perimeter of the actuator **140**. The central displacement anti-node **43** is represented by the dashed curve after one half-cycle.

[0040] FIG. **2**B shows one possible pressure oscillation profile illustrating the pressure oscillation within the cavity **116** resulting from the axial displacement oscillations shown in FIG. **2**A. The solid curved line and arrows represent the pressure at one point in time In this mode and higher-order modes, the amplitude of the pressure oscillations has a positive central pressure anti-node **45** near the centre of the cavity **116** and a peripheral pressure anti-node **45'** near the side wall **118** of the cavity **116**. The amplitude of the pressure oscillations is substantially zero at the annular pressure node **44** between the central pressure anti-node **45** and the peripheral pressure anti-node **45'**. At the same time, the amplitude of the pressure oscillations as represented by the dashed line has a negative central pressure anti-node **47** near the centre of the cavity **116** with a peripheral pressure anti-node **47'** and the same annular pressure node **44**. For a elliptical cavity, the radial dependence of the amplitude of the pressure oscillations in the cavity **116** may be approximated by a Bessel function of the first kind. The pressure oscillations described above result from the radial movement of the fluid in the cavity **116** and so will be referred to as the "radial pressure oscillations" of the fluid within the cavity **116** as distinguished from the axial displacement oscillations of the actuator **140**.

[0041] With further reference to FIGS. **2**A and **2**B, it can be seen that the radial dependence of the amplitude of the axial displacement oscillations of the actuator **140** (the "mode-shape" of the actuator **140**) approximates a Bessel function of the first kind so as to match more closely the radial dependence of the amplitude of the desired pressure oscillations in the cavity **116** (the "mode-shape" of the pressure oscillation). Other symmetric and asymmetric functions may also be used to generate pressure oscillations within the cavity **116**. In any event, by not rigidly mounting the actuator **140** at its perimeter and allowing it to vibrate more freely about its centre of mass, the mode-shape of the displacement oscillations substantially matches the mode-shape of the pressure oscillations in the cavity **116** thus achieving mode-shape matching or, more simply, mode-matching. Although the mode-matching may not always be perfect in this respect, the axial displacement oscillations of the actuator **140** and the corresponding pressure oscillations in the cavity **116** have substantially the same relative phase across the full surface of the actuator **140** wherein the radial position of the annular pressure node **44** of the pressure oscillations in the cavity **116** and the radial position of the annular displacement node **42** of the axial displacement oscillations of actuator **140** are substantially coincident.

[0042] As the actuator **140** vibrates about its centre of mass, the radial position of the annular displacement node **42** will necessarily lie inside the radius of the actuator **140** when the actuator **140** vibrates in its fundamental bending mode as illustrated in FIG. **2**A. Thus, to ensure that the annular displacement node **42** is coincident with the annular pressure node **44**, the radius of the actuator (r_{act}) should preferably be greater than the radius of the annular pressure node **44** to optimize mode-matching. Assuming again that the pressure oscillation in the cavity **116** approximates a Bessel function of the first kind, the radius of the annular pressure node **44** would be approximately 0.63 of the radius from the centre of the end wall **122** to the side wall **118**, i.e., the radius of the cavity **116** ("r"). Therefore, the radius of the actuator **140** (r_{act}) should preferably satisfy the following inequality: $r_{act} \geqq 0.63r$.

[0043] The ring-shaped skirt **130** may be a flexible membrane which enables the edge of the actuator **140** to move more freely as described above by bending and stretching in response to the vibration of the actuator **140** as shown by the displacement at the peripheral displacement anti-node **43'**. The flexible membrane overcomes the potential dampening effects of the side wall **118** on the actuator **140** by providing a low mechanical impedance support between the actuator **140** and the elliptical wall **101** of the pump **100** thereby reducing the dampening of the axial oscillations at the peripheral displacement anti-node **43'** of the actuator **140**. Essentially, the flexible membrane minimizes the energy being transferred from the actuator **140** to the side wall **118** with the outer peripheral edge of the flexible membrane remaining substantially stationary. Consequently, the annular displacement node **42** will remain substantially aligned with the annular pressure node **44** so as to maintain the mode-matching condition of the pump **100**. Thus, the axial displacement oscillations of the driven end wall **122** continue to efficiently generate oscillations of the pressure within the cavity **116** from the central pressure anti-nodes **45**, **47** to the peripheral pressure anti-nodes **45'**, **47'** at the side wall **118** as shown in FIG. **2**B.

[0044] As the actuator **140** vibrates in response to the drive signal, the pressure created in the load **150** increases while airflow decreases from a free-flow state to a stall state. The pressure being built up in the load **150** by the disc pump **100** may be measured by a sensor as a function of the displacement (δy) of the actuator **140** from a rest position **136** in the free-flow state as shown in FIG. **1**A to a biased position **138** in the stall state as shown in FIG. **1**B when the pressure forces the actuator **140** away from the rest position as the skirt **130** flexes with the actuator **140** from its fixed position at the side wall **101** toward the biased position **138**. Because the actuator **140** generates radial pressure waves within the cavity **116** of the disc pump **100**, such a sensor is preferably positioned outside the cavity **116** of the disc pump **100** so that it does not interfere with the operation of the disc pump **100**.

[0045] FIG. **3** is a zoomed-in view of a sensor **331** mounted on the circuit board **108** to face the actuator **140** and measure the displacement of the actuator **140** of the disc pump **100**. The sensor **331** includes an optical transmitter **332** and optical receiver **334** for use in measuring displacement **130** of the actuator **140**. The optical transmitter **332** communicates an optical signal **335** that may be a light wave in a visible or non-visible spectrum. The optical signal **335** is reflected off the surface of the interior plate **115** of the actuator **140** so that the reflected signal is received by the optical receiver **334** regardless of the displacement (δy) of the actuator **140** as shown in FIG. **4**. When the actuator **140** is in the rest position **136**, a first reflected signal **340** impinges on the optical receiver **334** at the position shown in both FIGS. **3** and **4**. As the actuator **140** is displaced from the rest position **136** to the biased position **138**, the first reflected signal **340** is correspondingly displaced by a corresponding reflected displacement (δx) as a second reflected signal **342** depending on the displacement (δy) of the actuator **140**. Essentially, the image of the reflected signals that impinge on the optical receiver **334** follow a path from the rest position **136** to the fully biased position **138** as shown in FIG. **4**. The reflected displacement (δx) is proportional to the displacement (δy) of the actuator **140** which is a function of the pressure provided by the disc pump **100** as described above.

[0046] In one embodiment, the optical transmitter **332** may be a laser, a light emitting diode (LED), a vertical cavity surface emitting laser (VCSEL), or light emitting element. The optical transmitter **332** may be positioned on the circuit board **108** and oriented to reflect the optical signal **335** off any point of the interior plate **115** of the actuator **140** as long as that the first reflected signal **340** and the second reflected signal **342** are still received and measured by the optical sensor **334**. However, as the actuator **140** oscillates in a fundamental mode to generate airflow as described and shown in FIG. **2**A, the amplitude of the displacement oscillations of the actuator **140** may be substantially zero at any annular displacement nodes **42** that are generated. Correspondingly, the amplitudes of the displacement oscillations at other points along the actuator **140** are greater than zero as also described. Therefore, the optical transmitter **332** should be positioned and oriented so that the optical signal **335** is reflected from a position close to the annular displacement nodes **42** to minimize the effect of the high frequency oscillations of the actuator **140** and more accurately measure the displacement (δy) of the actuator **140** as it moves more slowly from the rest position **136** to the biased position **138**.

[0047] In one embodiment, the optical sensor **334** may include multiple pixels forming a sensor array. The optical sensor **334** may be configured to sense the position of one or more reflected beams at one or more wavelengths. As a result, the optical receiver **334** may be configured to sense the reflected displacement (δx) **144** between the first reflected signal **340** and the second reflected signal **342**. The optical receiver **334** may be configured to convert the reflected signals **340** and **342** sensed by the optical receiver **334** into electrical signals by the respective pixels of the optical receiver **334**. The reflected displacement (δx) may be measured or calculated in real-time or utilizing a specified sampling, frequency to determine the position of the actuator **140** relative to the pump housing **102**. In one embodiment, the position of the actuator **140** is computed as an average or mean position over a given time period. Pixels of the optical receiver **334** may be sized to provide additional sensitivity to detect relatively small displacements (δy) of the actuator **140** to better monitor the pressure being provided by the disc pump **100** so that it can be controlled in real-time.

[0048] Alternative methods of computing the displacement of the actuator **140** may be utilized in accordance with the principles of the present invention. It should be understood that determining the displacement of the actuator **140** may be accomplished relative to any other fixed-position element in the pump housing **102**. Although generally substantially proportional, the reflected displacement (δx) may equal the displacement (δy) of the actuator **140** multiplied by a scale factor where the scale factor may be predetermined value based in the configuration of the pump housing **102** of the disc pump **100** or other alignment factors. As a result, the reduced pressure within the cavity **116** of the disc pump **100** may be determined by sensing the displacement (δy) of the actuator **140** without the need for pressure sensors that directly measure the pressure provided to a load, but are too bulky and expensive for measuring the pressure provided by the disc pump **100** in a reduced pressure system for example. The illustrative embodiments optimize the utilization of space within the pump housing **102** without interfering with the pressure oscillations being created within the cavity **116** of the disc pump **100**.

[0049] FIG. **5** is another schematic, cross-sectional view of the disc pump **100** showing the actuator **140** in the biased position **138** including a assumed-in view of another sensor for measuring the displacement of the actuator **140** according to another illustrative embodiment. The sensor is an ultrasonic transceiver **546** that transmits ultrasonic waves **548** to determine the position of the actuator **140** based on the ultrasonic waves **548** reflected by the actuator **140** and received by the ultrasonic transceiver **546**. For purposes of simplicity, the ultrasonic waves that echo back to the ultrasonic transceiver **546** are not shown. The ultrasonic transceiver **546** may send raw measurements or processed data regarding the displacement (δy) of the actuator **140** to one or more electronic devices including, for example, a processor to determine the reduced pressure generated by the this pump **100** and other operational characteristics.

[0050] With regard to FIG. **6**, a diffraction grating **602** for measuring displacement (δy) of the actuator **140** in the disc pump **100** is shown. The diffraction grating **602** may be attached to or integrated with the actuator **140**. For example, the diffraction grating **602** may be a reflective optical element attached to or the actuator **140** with adhesives or other fastening means during manufacturing of the disc pump. As shown, a transmitter **607** transmits a multi-spectral optical signal **608** onto the diffraction grating **602**. The diffraction grating **602** diffracts the multi-spectral optical signal **608** into several beams with different wavelengths **λ1**, **λ2**, **λ3**, and **λ4**. The wavelengths of beams **λ1**, **λ2**, **λ3**, and **λ4** are detected by a sensor array **610**. In one embodiment, the sensor array **610** may include multiple pixels **612**, **614**, **616**, and **618**. The pixels **612**, **614**, **616**, and **618** of the sensor array **610** may also be referred to as a pixel array. Alternatively, the sensor array **610** may be a single sensor or pixel element, such as the pixel **614**. The transmitter **607** and the sensor array **610** may be connected to circuit board **108** or any other fixed-position element of the pump housing **102** to ensure stability during operation.

[0051] In operation, the transmitter **607** may be a light generation circuit or element that transmits the multi-spectral optical signal **608** in the form of multi-spectrum optical signal onto the diffraction grating. The diffraction grating **602** may be an optical component with a regular pattern, which diffracts light of the multi-spectral optical signal **608** into several beams **λ1**, **λ2**, **λ3**, and **λ4** and reflects the beams in different directions, as shown in FIG. **6**. As is known in the art, the diffraction grating **602** may include grooves or rulings within the grating of the diffraction grating configured to diffuse the **λ1**, **λ2**, **λ3**, and **λ4** over the sensor, array **610** during normal operation and displacement of the actuator **140**.

[0052] The sensor array **610** determines the displacement of the actuator **140** based on the one or more wavelengths received by one or more of the pixels **612**, **614**, **616**, and **618**. For example, as shown in FIG. **6** the dispersion of wavelengths **λ1**, **λ2**, **λ3**, and **λ4** on the pixels **612**, **614**, **616**, and **618** may correspond to a maximum displacement between the actuator **140** and the circuit board **108**. As the actuator **140** moves toward the housing body (i.e., into the cavity), the pixels **612-618** may detect one or more of the wavelengths **λ1**, **λ2**, **λ3**, and **λ4**. In one embodiment, the measurements from the sensor array **610** may indicate the displacement of the actuator **140**. For example, if both **λ3** and **λ4** are detected by pixel **618**, the displacement may be 2 mm indicating optimal displacement for producing a desired pressure in the cavity of the reduced pressure delivery system. The wavelengths **λ1**, **λ2**, **λ3**, and **λ4** detected by each of the pixels **612**, **614**, **616**, and **618** may indicate the exact displacement or may provide data utilized to calculate the displacement. In an alternative embodiment, a sensor may be a single pixel configured to sense optical wavelengths in the multi-spectral optical signal **608** so that as the actuator **140** moves, the wavelength sensed by the sensor is indicative of the position of the actuator relative to the housing. In yet another embodiment, an optical sensor with a single cell having known dimensions may be positioned at an optimal location of a certain light spectrum (or any light at all) be sensed by the optical sensor, and, if sensed, a determination may be made that the pump is generating a pressure in a certain tolerance range may be made.

[0053] With regard to FIG. **7**, a magnetic sensor **702** for measuring displacement (δy) of the actuator **140** in the disc pump **100** is shown. The magnetic sensor **702**, which may be a Hall Effect or analogous sensor, is mounted to the circuit board **108** or the pump housing **102**. A conductor **706** may be mounted to an actuator **140**. The conductor **706** may be metallic, magnetic, or otherwise that is capable of providing for magnetic sensing by the magnetic sensor **702**. The magnetic sensor **702** measures a magnetic field **710** between the magnetic sensor **702** and the conductor **706**. The magnetic sensor **702** may be calibrated or configured to measure the changing electric field resulting in the magnetic field **710** to determine the displacement between the magnetic sensor **702** and the conductor **706**.

[0054] Referring to FIG. **8**, a block diagram of an illustrative disc pump system **800** that includes a disc pump such as the disc pump **100** described above and a sensor for measuring and, controlling a pressure generated by the disc pump **100** such as the optical sensor **331** including the optical transmitter **332** and the optical receiver **334** is shown. It should be understood that other sensors as described above may also be utilized as part of the disc pump system **800**. The disc pump system **800** also comprises a battery **802** utilized to power the disc pump system **800**. The elements of the disc pump system **800** are interconnected and communicate through wires, paths, traces, leads, and other conductive elements. The disc pump system **800** may also include a processor **804** and a driver **808** where the processor **804** is adapted to communicate with the driver **808** including communicating a control signal **806** to the driver **808**. The driver **808** generates a drive signal **810** that energizes an actuator in the disc pump **100** such as the actuator **140** as described above. The actuator **140** may include a piezoelectric component that generates the radial pressure oscillations of the fluid within the cavity of the disc pump **100** when energized causing fluid flow through the cavity to pressurize or depressurize the load as described above. The processor **804** may be configured to provide in illumination signal **812** to the optical transmitter **332** for illuminating the actuator **140** with an optical beam such as optical beam **335** which is reflected by the actuator **140** to the optical receiver **334** as illustrated by the reflected signals **340**, **342** which are also described above. When the reflected signals **340**, **342** to impinge on the optical receiver **334**, the optical receiver **334** provides a displacement signal **814** to the processor **804** corresponding to the displacement (δy) of the actuator **140**. The processor **804** is configured to calculate the pressure generated by the pump **100** at the load as a function of the displacement (δy) of the actuator **140** as represented by the displacement signal **814**. In one embodiment, the processor **804** may be configured to average a plurality of reflected signals **340**, **342** to determine an average displacement of the actuator **130** over time. In yet another embodiment, the processor **804** may utilize the displacement signal **814** as feedback to adjust the control signal **806** and corresponding drive signal **810** for regulating the pressure at the load.

[0055] The processor **804**, driver **808**, and other control circuitry of the disc pump system **800** may be referred to as an electronic circuit. The processor **804** may be circuitry or logic enabled to control functionality of the disc pump **100**. The processor **804** may function as or comprise microprocessors, digital signal processors, application-specific integrated circuits (ASIC), central processing units, digital logic or other devices suitable for controlling an electronic device including one or more hardware and software elements, executing software, instructions, programs, and applications, converting and processing signals and information, and performing other related tasks. The processor **804** may be a single chip or integrated with other computing or communications elements. In one embodiment, the processor **804** may include or communication with a memory. The memory may be a hardware element, device, or recording media configured to store data for subsequent retrieval or access at a later time. The memory may be static or dynamic memory in the form of random access memory, cache, or other miniaturized storage medium suitable for storage of data, instructions, and information. In an alternative embodiment, the electronic circuit may be analog circuitry that is configured to perform the same or analogous functionality for measuring the pressure and controlling the displacement of the actuator **140** in the cavity of the disc pump **100** as described above.

[0056] The disc pump system **800** may also include an RF transceiver **820** for communicating information and data relating to the performance of the disc pump system **800** including, for example, the current pressure measurements, the actual displacement (δy) of the actuator **140**, and the current life of the battery **802** via a wireless signals **822** and **824** transmitted from and received by the RF transceiver **820**. The RF transceiver **820** may be a communications interface that utilizes radio, infrared, or other wired or wireless signals to communicate with one or more external devices. The RF transceiver **820** may utilize Bluetooth, WiFi, WiMAX, or other communications standards or proprietary communications systems. Regarding the more specific uses, the RF transceiver **820** may send the signals **822** to a computing device that stores a database of pressure readings for reference by a medical professional. The computing device may be a computer, mobile device, or medical equipment device that may perform processing locally or further communicate the information to a central or remote computer for processing of the information and data. Similarly, the RF transceiver **820** may receive the signals **824** for externally regulating the pressure generated by the disc pump **100** at the load based on the motion of the actuator **140**.

[0057] The driver **808** is an electrical circuit that energizes and controls the actuator **140**. For example, the driver **808** may be a high-power transistor, amplifier, bridge, and/or filters for generating a specific waveform as part of the drive signal **810**. Such a waveform may be configured by the processor **804** and the driver **806** to provide a drive signal **810** that causes the actuator **140** to vibrate in an oscillatory motion at the frequency (f) as described in more detail above. The oscillatory displacement motion of the actuator **140** generates the radial pressure oscillations of the fluid within the cavity of the pump **100** in response to the drive signal **810** to generate pressure at the load.

[0058] In another embodiment, the disc pump system **800** may include a user interface for displaying information to a user. The user interface may include a display, audio interface, or tactile interface for providing information, data, or signals to a user. For example, a miniature LED screen may display the pressure being applied by the disc pump **100**. The user interface may also include buttons, dials, knobs, or other electrical or mechanical interfaces for adjusting the performance of the disc pump, and particularly, the reduced pressure generated. For example, the pressure may be increased or decreased by adjusting a knob or other control element that is part of the user interface.

[0059] A method for measuring pressure generated by a pump to a load is also disclosed. The pump includes an actuator mounted within the pump on a flexible skirt that that forms a cavity within the pump. The flexible skirt allows the actuator to oscillate in order to generate air flow through the cavity of the pump and allows the actuator to be displaced with increasing pressure to the load. The method comprising electrically driving the actuator to cause an oscillatory displacement motion of the actuator within the pump to generate radial pressure oscillations of fluid within the cavity. The method further comprises measuring the displacement of the actuator as fluid begins flowing through the cavity causing the actuator to move from a rest position to a biased position with increasing pressure at the load as accommodated by the flexibility of the skirt. The method also comprises calculating the pressure at the load based on the displacement of the actuator.

[0060] Referring more specifically to FIG. **9**, a flow chart of an illustrative process **900** for measuring and controlling pressure generated by a disc pump is shown. The process **900** starts at step **902**, where an actuator within a housing of a disc pump may be driven by a drive signal. The actuator may be driven by a piezo-electric actuator or device. The actuator may be driven to generate a reduced pressure for application at a tissue site For example, the disc pump may directly or indirectly communicate with a tissue site covered by a drape, as is understood in the art. At step **904**, displacement of the actuator may be sensed as the actuator moves from a rest position to a biased position as a result of the pressure increasing within the load. In one embodiment, the rest position occurs when the disc pump when is deactivated or unpowered, and the biased position is reached when pressure within the load is at a maximum value. The displacement of the actuator and the corresponding pressure the load varies between these two positions. The drive signal may be configured, shaped, or otherwise generated by a processor, driver, or control logic of the disc pump for controlling the operation of the actuator and the corresponding pressure being applied to the load.

[0061] At step **906**, the pressure being generated by the disc pump may be determined as a function of the sensed displacement of the actuator. In one embodiment, the displacement may be determined by reflection or refraction of an optical signal between a housing of the disc pump and the actuator. Similarly, ultrasonic, radio frequency, magnetic, or other optical sensors or transmitter and receiver combinations may be utilized to determine displacement of the actuator. The displacement of the actuator may indicate the pressure being generated by the disc pump for the load. Digital and/or analog electronics may be utilized to determine the pressure applied at the tissue site based on the known differential, factors, losses, and other characteristics of the load such as a tissue treatment system that includes the disc pump as a component. The electronics may utilize any number of static or dynamic algorithms, functions, or sensory measurements to determine the pressure. At step **908**, the drive signal is adjusted to control displacement of the actuator in response to determining the pressure being delivered by the disc pump. The drive signal may be generated in response to measurements of feedback signals received from the one or more sensors measuring the displacement of the actuator. In one embodiment, the amplitude of the drive signal may be increased to increase the reduced pressure generated by the disc pump and correspondingly communicated to the tissue site Similarly, the amplitude or the shape of the drive signal may be modified to drive the actuator of the disc pump for decreasing or maintaining pressure at the load.

[0062] The illustrative embodiments provide a low cost system for indirectly monitoring the pressure generated by a disc pump by interpreting data provided by a sensor in the disc pump that measures the displacement of an actuator relative to fixed-position components within the disc pump when the actuator moves from a rest position to a biased position. It should be understood that the sensor or any component thereof such as the optical transmitter of an optical sensor may be connected directly to the actuator for measuring the displacement by reflecting the optical signal off of the pump housing or any other fixed position on the disc pump. The illustrative embodiments reduce the equipment, space, and cost to monitor pressure being generated by the disc pump beyond that available utilizing traditional pressure sensors and monitors that directly sense the pressure generated by a pump at the load.

[0063] The previous detailed description is one of a small number of embodiments for implementing the invention and is not intended to be limiting in scope. One of skill in this art will immediately envisage the methods and variations used to implement this invention in other areas than those described in detail. The following claims set for a number of the embodiments of the invention disclosed with greater particularity.

1. A pump comprising:

a pump body having a substantially elliptical shaped side wall closed at one end by a base wall and the other end by a pair of interior plates to form a cavity within said pump body for containing a fluid, wherein a first one of the interior plates adjacent the cavity includes a center portion and a peripheral portion;

an actuator formed by the end plates wherein the second one of the interior plates is operatively associated with the central portion of the first interior plate to cause an oscillatory displacement motion thereby generating radial pressure oscillations of the fluid within the cavity in response to a drive signal being applied to said actuator when in use;

a skirt flexibly connected between the side wall and the peripheral portion of the first interior plate to facilitate the oscillatory displacement motion;

a first aperture extending through said actuator to enable fluid to flow through the cavity;

a second aperture extending through the base wall to enable fluid to flow through the cavity;

a valve disposed in at least one of said first aperture and second apertures and is adapted to permit the fluid to flow through the cavity in substantially one direction to pressurize or depressurize a load as fluid begins flowing through the cavity, thereby causing said actuator to move toward the base wall from a rest position to a biased position with increasing pressure and flexing of the skirt; and,

a sensor mounted outside the cavity in a fixed position with respect to said pump body for measuring the displacement of said actuator at any position between the rest position and the biased position as fluid begins flowing through the cavity to pressurize or depressurize the load.

2. The pump of claim **1** wherein the ratio of the radius of the cavity (r) extending from the longitudinal axis of the cavity to the side wall to the height of the side wall of the cavity (h) is greater than or equal to 1.2.

3.-**9**. (canceled)

10. The pump of claim **1** wherein said skirt is a flexible membrane.

11. The pump of claim **10** wherein the flexible membrane is formed from plastic.

12. The pump of claim **11** wherein the annular width of flexible membrane is between about 0.5 and 1.0 mm and the thickness of the flexible membrane is less than about 200 microns.

13. The pump of claim **10** wherein the flexible membrane is formed from metal.

14. The pump of claim **13** wherein the annular width of flexible membrane is between about 0.5 and 1.0 mm and the thickness of the flexible membrane is less than about 20 microns.

15.-**20**. (canceled)

21. The pump of claim **1** further comprising an electronic circuit in communication with said sensor and configured to calculate the pressure at the load as a function of the displacement of said actuator.

22. The pump of claim **21** wherein the electronic circuit is further, configured to calculate the rate of change of the pressure at the load.

23. The pump of claim **1** wherein said sensor is an optical sensor configured to illuminate and measure the displacement of said actuator.

24. The pump of claim **23** wherein the optical sensor illuminates an annular displacement node of the oscillatory displacement motion of said actuator.

25. The pump of claim **23** wherein said optical sensor comprises an optical transmitter and an optical receiver.

26. The pump of claim **25** wherein the optical transmitter includes a light emitting diode that illuminates said actuator with an optical beam, and wherein the optical receiver includes a light sensor array of pixel elements that sense reflections of the optical beam as of the reflections move along the array of pixel elements corresponding to the displacement of said actuator as said actuator moves from the rest position to the biased position.

27. The pump of claim **25** further comprising an electronic circuit in communication with the optical receiver and configured to calculate the pressure at the load as a function of the displacement of said actuator.

28. The pump of claim **23** wherein the optical sensor comprises an illumination source for providing an optical beam having a multi-frequency spectrum, a diffraction grating disposed on said actuator for reflecting the optical beam as a plurality of reflected beams at different wavelengths within the multi-frequency spectrum, and an optical receiver for receiving the reflected beams, each of which corresponds to a different displacement of said actuator as said actuator moves from the rest position to the biased position.

29. The pump of claim **1** wherein said sensor is a magnetic sensor.

30. The pump of claim **1** wherein said sensor is and RF sensor.

31. A method for measuring pressure generated for a load by a pump having an actuator mounted within the pump on a flexible skirt that allows the actuator to oscillate for generating air flow through a cavity of the pump and allows the actuator to be displaced with increasing pressure to the load, said method comprising:

driving the actuator to cause an oscillatory displacement motion of the actuator to generate radial pressure oscillations of fluid within the cavity;

measuring the displacement of the actuator as fluid begins flowing through the cavity causing the actuator to move from a rest position to a biased position with increasing pressure at the load and flexing of the skirt; and

calculating the pressure at the load based on the displacement of the actuator.

32.-**43**. (canceled)

44. A disc pump comprising:

a pump body having an end wall closing one end of the pump body, the end wall having an aperture for airflow through the aperture;

an actuator having a peripheral portion and a flexible skirt portion extending from the peripheral portion to the pump body wherein the actuator closes the other end of the pump body to form a cavity therein, the actuator including an aperture for airflow through the aperture, and configured to vibrate in an oscillatory motion to generate airflow from one aperture to the other aperture for building pressure at a load;

a valve disposed in one of the apertures and adapted to permit airflow through the cavity in substantially in one direction to pressurize or depressurize the load thereby causing the actuator to move from a rest position to a biased position with increasing pressure at the load; and

a sensor configured to measure the displacement of the actuator as the pressure builds within the load and to calculate the pressure as a function of the displacement.

45. A disc pump according to claim **44**, wherein the sensor is mounted outside the cavity in a fixed position with respect to said pump body.

46. The pump of claim **44** wherein said sensor is an optical sensor configured to illuminate and measure the displacement of the actuator.

47. The pump of claim **46** wherein the optical sensor illuminates an annular displacement node of the oscillatory motion of the actuator.

48. The pump of claim **47** wherein said optical sensor comprises an optical transmitter and an optical receiver.

49. The pump of claim **48** wherein the optical transmitter includes a light emitting diode that illuminates the actuator with an optical beam, and wherein the optical receiver includes a light sensor array of pixel elements that sense reflections of the optical beam as of the reflections move along the array of pixel elements corresponding to the displacement of the actuator as the actuator moves from the rest position to the biased position.

50. The pump of claim **48** further comprising an electronic circuit in communication with the optical receiver and configured to calculate the pressure at the load as a function of the position of said actuator.

51. The pump of claim **46** wherein the optical sensor comprises an illumination source for providing an optical beam having a multi-frequency spectrum, a diffraction grating disposed on said actuator for reflecting the optical beam as a plurality of reflected beams at different wavelengths within the multi-frequency spectrum, and an optical receiver for receiving the reflected beams, each of which corresponds to a different position of said actuator.

52. The pump of claim **44** wherein said sensor is a magnetic sensor.

53. The pump of claim **44** wherein said sensor is an RF sensor.

54. The pump of claim **44** wherein said sensor is an ultrasonic sensor.

55. The pump of claim **44** wherein the load is calculated as a function of the average position of a sensed part of the actuator.

* * * * *