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- **Headley, Thomas R.**
Bryan, Ohio 43506 (US)
- **Distel, Gerald M.**
Bryan, Ohio 43506 (US)

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(71) Applicant: **Ingersoll-Rand Company**
Woodcliff Lake, New Jersey 07677-7700 (US)

(74) Representative: **Feakins, Graham Allan et al**
RAWORTH, MOSS & COOK
RAWORTH HOUSE
36 Sydenham Road
Croydon, Surrey CRO 2EF (GB)

(72) Inventors:
• **Able, Stephen D.**
Bryan, Ohio 43506 (US)

(54) Partially preloaded pump diaphragms

(57) A partially preloaded diaphragm (10) having an outer attachment portion (12) defining a first plane (P) and disposed about an axis (21) substantially perpendicular to the first plane. An inner attachment portion (16) is disposed substantially perpendicular to the axis of the outer attachment portion and defines a second plane (C). The inner attachment portion is movable away from the outer attachment portion into a fully extended pumping position defining a third plane (F). The first plane and the second plane are spaced at a distance to define a preload distance (PC) when the diaphragm is at rest, and the first and third plane are spaced to define a pump stroke distance (PF) when the diaphragm is fully extended. The preload distance is from about 25 percent to about 85 percent of the pump stroke distance.

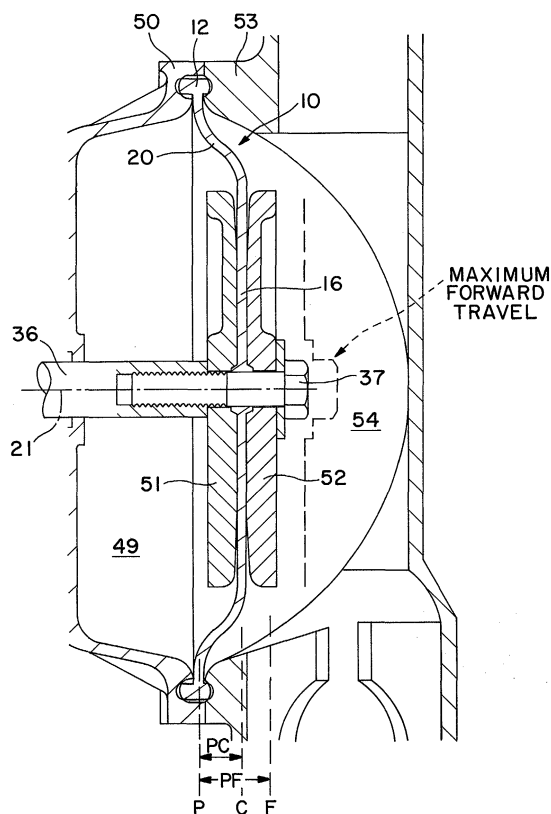


FIG. 6

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Description

[0001] This invention relates to diaphragms for such uses as air-operated or mechanically operated diaphragm pumps, brake actuators or other diaphragm-operated devices in which a central plate or plates is connected to or makes contact with the central portion of the diaphragm.

[0002] Diaphragm pumps are widely used in pumping a wide variety of materials including materials which are abrasive, have high viscosity, or consist of slurries that might damage other pump designs. Diaphragm pumps are often air driven which is advantageous in pumping flammable liquids or in environments where electrically driven equipment could otherwise be hazardous. Electrically or otherwise mechanically driven diaphragm pump designs, however, are also utilised.

[0003] The pump diaphragm is the critical driving member of the diaphragm pump and is a relatively flexible membrane that has an outer attachment portion that is clamped or otherwise held in a stationary position against the pump housing. Such diaphragms also include a centrally located portion and a working portion that joins the inner attachment and outer attachment portions. The inner attachment portion is clamped between a pair of clamping washers or the like during operation of the pump. The working and inner attachment portions of the diaphragm are displaced in a reciprocating manner along an axis to drive liquid out of the pump.

[0004] Pump diaphragms have traditionally been made of fabric reinforced rubber. Shown in Fig. 3 is an example of a conventional rubber diaphragm 9 shown having a dish shape with an inner attachment portion 6, an outer attachment portion 2 which may be dovetailed or beaded for retention in an associated pump housing, and an innerconnecting flexure sidewall working portion 4. Fabric reinforcement must be embedded in the body of these diaphragms to achieve adequate flex fatigue life, which drives up the cost. If the reinforcing fabric is not uniformly encased inside of the rubber, however, premature diaphragm failure may still occur. In certain applications the lack of chemical resistance presents problems as well.

[0005] Due to the wide nature of the different materials these pumps are used to move, a correspondingly wide variety of materials are used in their construction. To a limited extent, plastic materials with relatively stiff inner attachment portions and thinner, more flexible sidewall portions have been used in some diaphragm applications, for instance, as disclosed in US-A-3,011,758 thermoplastic polyurethane diaphragms have also been used as pump diaphragms. These polyurethane diaphragms have been constructed with a generally curvilinear flexure sidewall incorporating concentric ribs, terminating in an outer beaded flange and radially inward bead for mounting to a split piston plate.

[0006] In all cases the repetitive flexing of the diaphragm eventually causes failure of the diaphragm. Failure

of the diaphragm may result in materials being pumped contaminating the pump equipment. A diaphragm failure may also cause the release of chemicals to an air stream that subsequently gets released into the environment where it may result in further damage or injury. Attempts have been made design the diaphragm to minimise these operating stresses to improve the life of diaphragms. Such attempts included varying the geometry of the diaphragms to minimise stress on the working portion during operation of the pump.

[0007] Other materials that are stiffer than rubber have also been incorporated into diaphragms for a number of reasons, among which are their low cost and ease of manufacturing by injection moulding. One such group of stiffer materials are thermoplastic elastomers (TPE's). SANTOPRENE TPE is an example of one type of TPE material typically used in pump diaphragms and comprises a polypropylene polymer and an ethylene propylene (EPDM) elastomer. Another group of stiffer materials are fluoropolymer materials. TEFLON polytetrafluoroethylene (PTFE) is an example of one type of fluoropolymer typically used in pump diaphragms.

[0008] In the case of pump diaphragms manufactured using these stiffer materials such as thermoplastic elastomer and fluoropolymer materials, however, relatively early fatigue failures are known to occur in the flexible working portions of these diaphragms. Attempts at varying geometry to increase flexure life in diaphragms of such thermoplastic and fluoropolymer diaphragms have been made. For example, shown in US-A-4,864,918 is a diaphragm for pumps or the like of a dish-shaped body of non-reinforced thermoplastic elastomer. The diaphragms have a curvilinear flexure sidewall portion of substantially less thickness than the inner attachment and outer attachment portions to which it connects. Shown in US-A-5,349,896. is a flexible pump diaphragm of PTFE having a number of ribs or troughs located radially across its flexure portion. In such stiffer diaphragms, however, the inner and outer attachment portions of the diaphragms are preloaded (i.e., not in the same plane) in the fully extended position thus subjecting the diaphragm to flexure problems as discussed further in detail below.

[0009] According to the present invention, there is provided a partially preloaded diaphragm, comprising an outer attachment portion defining a first plane and disposed about an axis substantially perpendicular to said first plane, and an inner attachment portion disposed substantially perpendicular to said axis of said outer attachment portion and defining a second plane, said inner attachment portion being movable away from said outer attachment portion into a fully extended pumping position defining a third plane, said first plane and said second plane being spaced at a distance to define a preload distance when said diaphragm is at rest, and said first and third plane being spaced to define a pump stroke distance when said diaphragm is fully extended, said preload distance being from about 25 per-

cent to about 85 percent of said pump stroke distance.

[0010] For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

Fig. 1 is a cross-sectional view of a conventional pump diaphragm having coplanar inner and outer attachment portions;

Fig. 2 is a cross-sectional view of a first embodiment of a preloaded pump diaphragm according to one embodiment of the present invention and taken along line 2--2 in Fig. 4;

Fig. 3 is a cross-sectional view of a conventional preloaded pump diaphragm;

Fig. 4 is a planar view of the preloaded pump diaphragm shown in Fig. 2;

Figs. 5-7 are cross-sectional, sequential views of the pump diaphragm of Fig. 2 and 4 shown with immediately adjacent parts of a driven diaphragm pump during operation of the pump through a pumping stroke; and

Fig. 8 is a graph illustrating the output fluid pressure curves obtained for a given motive (input) air pressure curve comparing a conventional coplanar diaphragm configuration shown in Fig. 1 with a partially preloaded configuration according to the present invention and shown in Fig. 2.

[0011] As used herein, the term "diaphragm" means a flexible barrier that divides two fluid containing chambers or compartments. Typically, such barriers are useful with diaphragm pumps, however, these diaphragms may also be employed as a barrier layer between two compartments in any application where a fluid exists in one compartment and would cause deleterious effects if present in the other compartment. The term "preloaded diaphragms" means a diaphragm that in a free state has inner and outer attachment portions that are not substantially coplanar.

[0012] To evaluate the effect of geometry on the failure mode of diaphragms made using materials stiffer than prior art rubber diaphragms, the present inventors tested competitor's benchmark diaphragms made of SANTOPRENE® TPE having conventional preloaded configurations like those shown in Fig. 3. The present inventors found that utilising these stiffer materials with preloaded configurations created problems, however, because thermoplastic elastomers (TPE's) are substantially stiffer than fabric reinforced rubber used in traditional diaphragms. One such problem encountered was during mechanical assembly of a pump using diaphragms made of stiffer materials. Unlike fabric-rein-

forced rubber diaphragms that can be easily inverted by hand, preloaded TPE diaphragms generally require the use of assembly fixtures such as a chain fall or press to overcome the preload in the diaphragm in order to clamp the outer attachment portion between housing portions. Another problem encountered when using stiff preloaded diaphragms was buckling of the diaphragm when inverted during installation. This buckling caused the formation of typically six or eight radial wrinkles in the working portion of the diaphragm. Because each fold or wrinkle in the working portion is known to be a natural place for the premature formation of a crack, the buckling that occurs is believed to have a detrimental effect on diaphragm life.

[0013] In early investigations by ARO Fluid Products, a subsidiary of Ingersoll-Rand Company, it was learned that upon cycling preloaded diaphragms (i.e., diaphragms having inner and outer attachment portions in different planes) made of stiff materials such as PTFE, failures appearing as radial or "wagon-wheel" cracks occurred in the working portion of diaphragms. With these radial cracks, it was observed that the working portion of the diaphragm was formed into a convoluted shape. To alleviate this radial cracking problem, a diaphragm 7 shown in Fig. 1 was provided having no preload with substantially coplanar inner and outer attachment portions (6,2) and a convoluted working portion 3 provided to join the attachment portions. This diaphragm having an improved flex life is available today from ARO Fluid Products as the Model PD20 series diaphragm.

[0014] In an attempt to prevent the buckling that occurred with a preloaded TPE diaphragm, the present inventors similarly considered moulding a diaphragm with the inner and outer attachment portions in a coplanar configuration, i.e., without a preload, like that shown in Fig. 1. With the use of stiffer materials such as TPE, however, the extra force required to deform such a diaphragm as it approaches the fully extended position becomes significant and can result in a pressure loss from the air to the liquid side of the pump. Parenthetically, the diaphragm performs work on the fluid being pumped by force transfer. The force transferred to the liquid side of the diaphragm is the air pressure times the area of the diaphragm minus frictional losses, minus the force to extend each diaphragm. Thus, as the stiffness of the diaphragms increases, the pressure loss of the air causes a decreasing output fluid pressure as the diaphragm moves into its forward pumping position.

[0015] As described in greater detail below, to alleviate the problems associated described above, the present inventors have developed a partially preloaded diaphragm having outer and inner attachment portions spaced at a distance to define a preload distance when the diaphragm is at rest, of from about 25 percent to about 85 percent of the pump stroke distance. Shown in Fig. 8 is a graph illustrating the output fluid pressure curves obtained for a given motive (input) air pressure curve for a forward pumping stroke using two SANTO-

PRENE® TPE diaphragms, one having a conventional configuration with coplanar inner and outer attachment portions shown in Fig. 1, and the other having a partially preloaded configuration shown in Fig. 2 according to the present invention. As can be seen from the graph, the output fluid pressure obtained using the partially preloaded configuration results in an output fluid pressure that substantially corresponds to the motive air (input) pressure while the prior art coplanar configuration has a decreasing output fluid pressure as the diaphragm moves to the forward position in its stroke. This pressure loss is due to the air pressure needed to extend the inner attachment portion from its coplanar position with the outer attachment portion.

[0016] Shown in Figs. 2, 4, and 5-7 is a pump diaphragm 10 that is partially preloaded according to the present invention. Diaphragm 10 includes an outer attachment portion 12 that is clamped or otherwise attached and held stationary between pump housing sections 50 and 53 during operation of the pump as shown sequentially in Figs. 5-7. Preferably, outer attachment portion 12 is adapted for attachment to a pump. For instance, outer attachment portion 12 can be formed with an enlarged bead, or a dovetailed portion as shown or may alternately be provided with a plurality of holes for receiving fastening members to retain the diaphragm in the pump housing.

[0017] Diaphragm 10 also includes an inner attachment portion 16 having an opening 18 located at approximately the centre of the diaphragm. Preferably, an annular working portion 20 connects the outer and inner attachment portions.

[0018] As shown in Figs. 5-7, inner attachment portion 16 is attached to a pump to define a motive fluid chamber 49 and a pumping fluid chamber 54 by clamping between a pair of clamping washers 51, 52 each having a centrally positioned opening to be aligned with diaphragm opening 18. The openings in clamping washers 51, 52 and inner attachment portion 16 are adapted to attach to an end of a diaphragm rod 36 or other member for moving the annular working portion 20 and the inner attachment portion 16 in a reciprocating manner, relative to the fixed outer attachment portion 12, along axis 21. Preferably, one end of diaphragm rod 36 is connected to clamping washers 51, 52 at diaphragm inner attachment portion 16 by a threaded bolt 37 passing there-through as shown. Diaphragm rod 36 may also be either operatively connected to a mechanical driving means or may be connected to a second diaphragm.

[0019] As best seen in Fig. 6, in which the diaphragm is shown moving through the at rest position shown in Fig. 2, outer attachment portion 12 defines a first plane (P) and is disposed about an axis 21 that is substantially perpendicular to the first plane. Inner attachment portion 16 is disposed substantially perpendicular to axis 21 of the outer attachment portion 12 and defines a second plane (C). Inner attachment portion 16 is movable away from the outer attachment portion 12 into a fully extended

ed pumping position defining a third plane (F). The first plane (P) and the second plane (C) are spaced at a distance to define a preload distance (PC) when the diaphragm is at rest. The first plane (P) and third plane (F) are spaced to define a pump stroke distance (PF) when the diaphragm is fully extended with the preload distance (PC) being from about 25 percent to about 85 percent of the pump stroke distance. Preferably the preload distance is from about 50 percent to about 75 percent of the pump stroke distance with most preferred loading being at 67 percent.

[0020] Preferably, annular working portion 20 is provided in a convoluted form shown in Figs. 2 and 6 comprising empirically derived radii such that when inner attachment portion 16 is moved to the fully extended position (shown in Fig. 7), the annular working portion 20 is stretched to form a linear wall. Most preferably, the radii of annular working portion 20 are provided such that, when inner attachment portion 16 is in the fully extended position, a peripheral portion 17 forms annularly between the inner attachment portion 16 and the annular working portion 20. Additionally, the convoluted portion of annular working portion 20 is preferably spaced from outer attachment portion 12 as shown to reduce wear caused by pump housing sections 50 and 53 during operation of the pump. In this manner, excess material at the juncture between the inner attachment portion 16 and the annular working portion 20 is eliminated and wear of the juncture between the annular working portion 20 and the outer attachment portion 12 is reduced, thereby prolonging the flex life of diaphragm 10.

[0021] Although not intending to be bound by or otherwise limited to any theory, it is believed that the useful life of the partially preloaded diaphragm may be further enhanced by reducing the amount of excess material to reduce the tendency of the diaphragm to buckle during mid-stroke. The chord length of annular working portion 20 is, preferably, the minimum that is needed to prevent overstressing at the end of the stroke. Thus, diaphragms having an annular working portion 20 that stretches to form peripheral portion 17, described above and shown in Figure 7, is most preferred because it achieves this reduction in diaphragm material.

[0022] Suitable thermoplastic elastomers which may be employed include SANTOPRENE® blend of EPDM rubber and polypropylene (available from Advanced Elastomer Systems, Akron, OH), HYLENE® diisocyanate and HYTREL® polyester elastomers (available from DuPont Company, Wilmington, DE), GEOLAST® polypropylene and nitrile rubber blend (available from Advanced Elastomer Systems, Akron, OH), SARLINK® elastomer (available from DSM Elastomers, The Netherlands), and various thermoplastic urethanes including polyether and polyester based polyurethanes, such as ESTANE® thermoplastic polyurethane (available from B F Goodrich, Cleveland, OH). A suitable listing of usable thermoplastic elastomers is given in "Elastomerics," Oct. 1986, v. 118, no. 10. pp. 13-19. Although the poly-

urethanes yield superior abrasion resistance and have excellent flexing properties, SANTOPRENE® thermoplastic elastomer is preferred for many applications because of lower cost, and long flex life when employing the preferred wall design. The thermoplastic elastomers provide advantages of both thermoplastics and elastomers separately. Additionally, fluoropolymers such as TEFLON® polytetrafluoro-ethylene (available from DuPont Company, Wilmington, DE) may also be employed in the diaphragms.

[0023] Although described above with respect to thermoplastic elastomers, it is envisaged that diaphragms of other materials with similar or greater stiffnesses may be utilised to improve their useful flexure lives.

Claims

1. A partially preloaded diaphragm (10), comprising:
 - an outer attachment portion (12) defining a first plane (P) and disposed about an axis (21) substantially perpendicular to said first plane, and an inner attachment portion (16) disposed substantially perpendicular to said axis of said outer attachment portion and defining a second plane (C), said inner attachment portion being movable away from said outer attachment portion into a fully extended pumping position defining a third plane (F), said first plane and said second plane being spaced at a distance to define a preload distance (PC) when said diaphragm is at rest, and said first and third plane being spaced to define a pump stroke distance (PF) when said diaphragm is fully extended, said preload distance being from about 25 percent to about 85 percent of said pump stroke distance.
2. A diaphragm according to claim 1, wherein said preload distance is from about 50 percent to about 75 percent of said pump stroke distance.
3. A diaphragm according to claim 2, wherein said preload distance is about 50 percent of said pump stroke distance.
4. A diaphragm according to claim 2, wherein said preload distance is about 67 percent of said pump stroke distance.
5. A diaphragm according to any one of the preceding claims, wherein said outer and inner attachment portions (12, 16) are adapted for attachment to a pump and further comprise an annular working portion (20) connecting said outer and inner attachment portions.
6. A diaphragm according to claim 5, further comprising a peripheral portion (17) formed annularly between said inner attachment portion (16) and said annular working portion (20) when said inner attachment portion is moved into a fully extended pumping position.
7. A diaphragm according to any one of the preceding claims, wherein said diaphragm comprises a thermoplastic elastomer.
8. A diaphragm according to any one of claims 1 to 6, wherein said diaphragm comprises a thermoplastic elastomer selected from the group consisting of an EPDM rubber and polypropylene blend and a thermoplastic urethane.
9. A diaphragm according to any one of claims 1 to 6, wherein said diaphragm comprises a thermoplastic elastomer selected from the group consisting of SANTOPRENE, ESTANE, HYLENE, HYTREL, GEOLAST, SARLINK elastomers, and combinations thereof.
10. A diaphragm according to any one of claims 1 to 6, wherein said diaphragm comprises a fluoropolymer.
11. A diaphragm according to claim 10, wherein said fluoropolymer is polytetrafluoroethylene.
12. A diaphragm according to any one of the preceding claims, wherein said outer attachment portion (12) comprises a bead or a dovetailed portion.
13. A diaphragm according to any one of the preceding claims, wherein said outer attachment portion (12) comprises a plurality of holes for receiving fastening members.

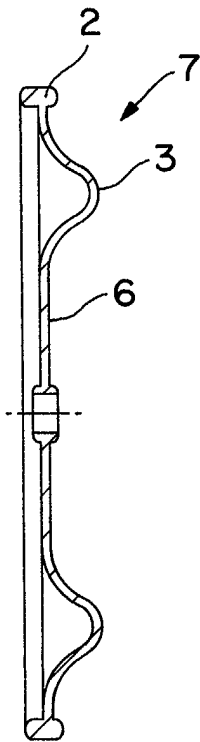


FIG. 1
(PRIOR ART)

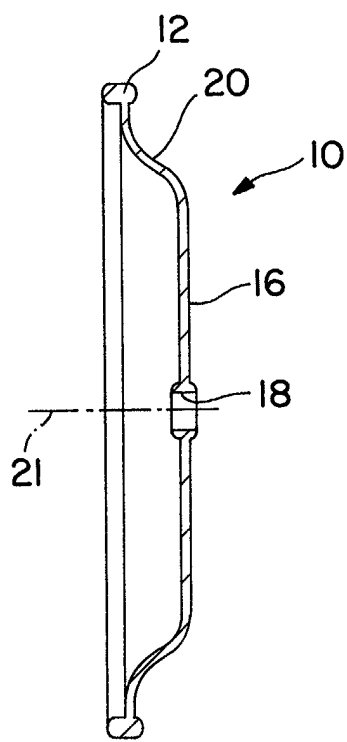


FIG. 2

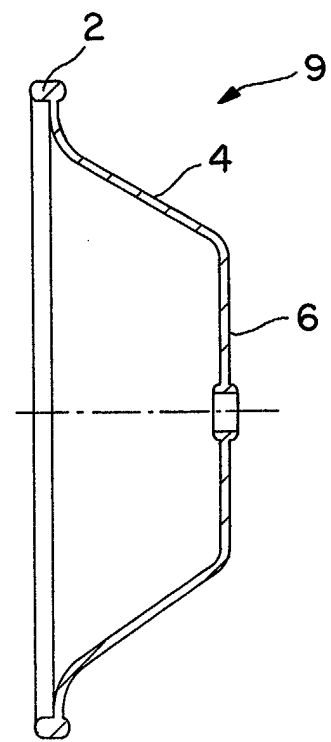


FIG. 3
(PRIOR ART)

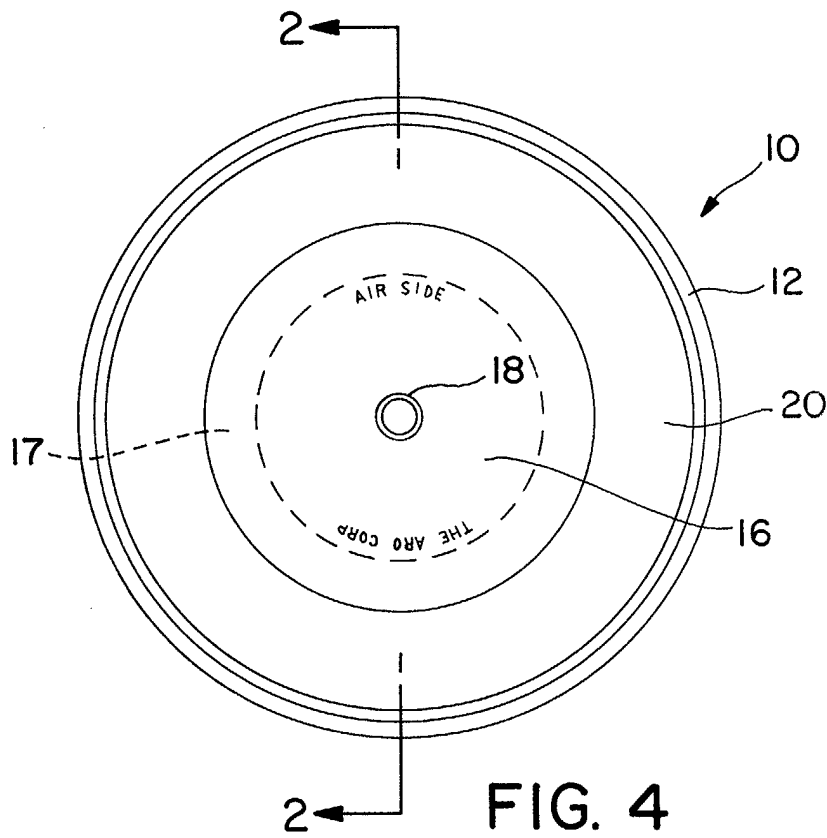


FIG. 4

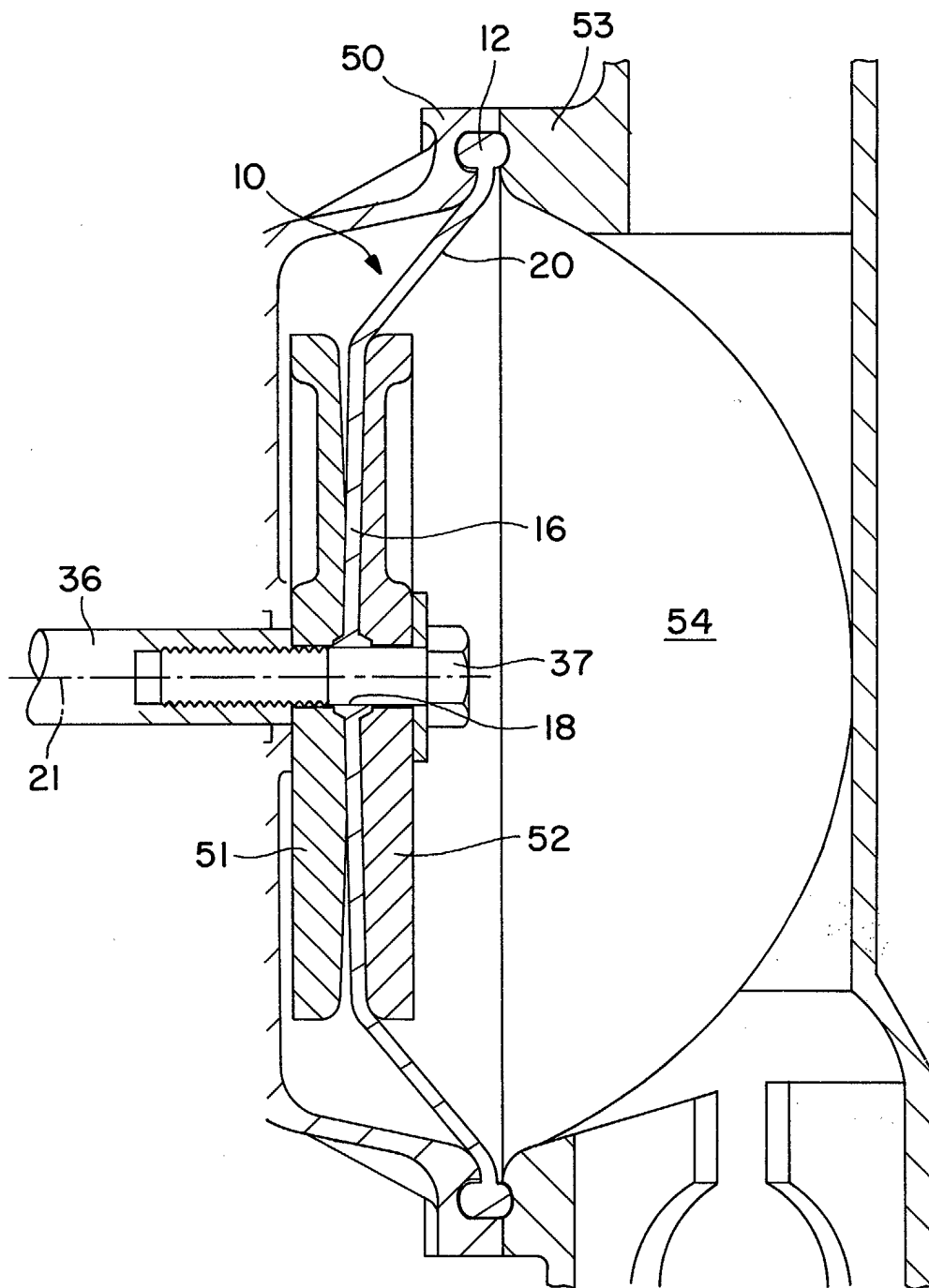


FIG. 5

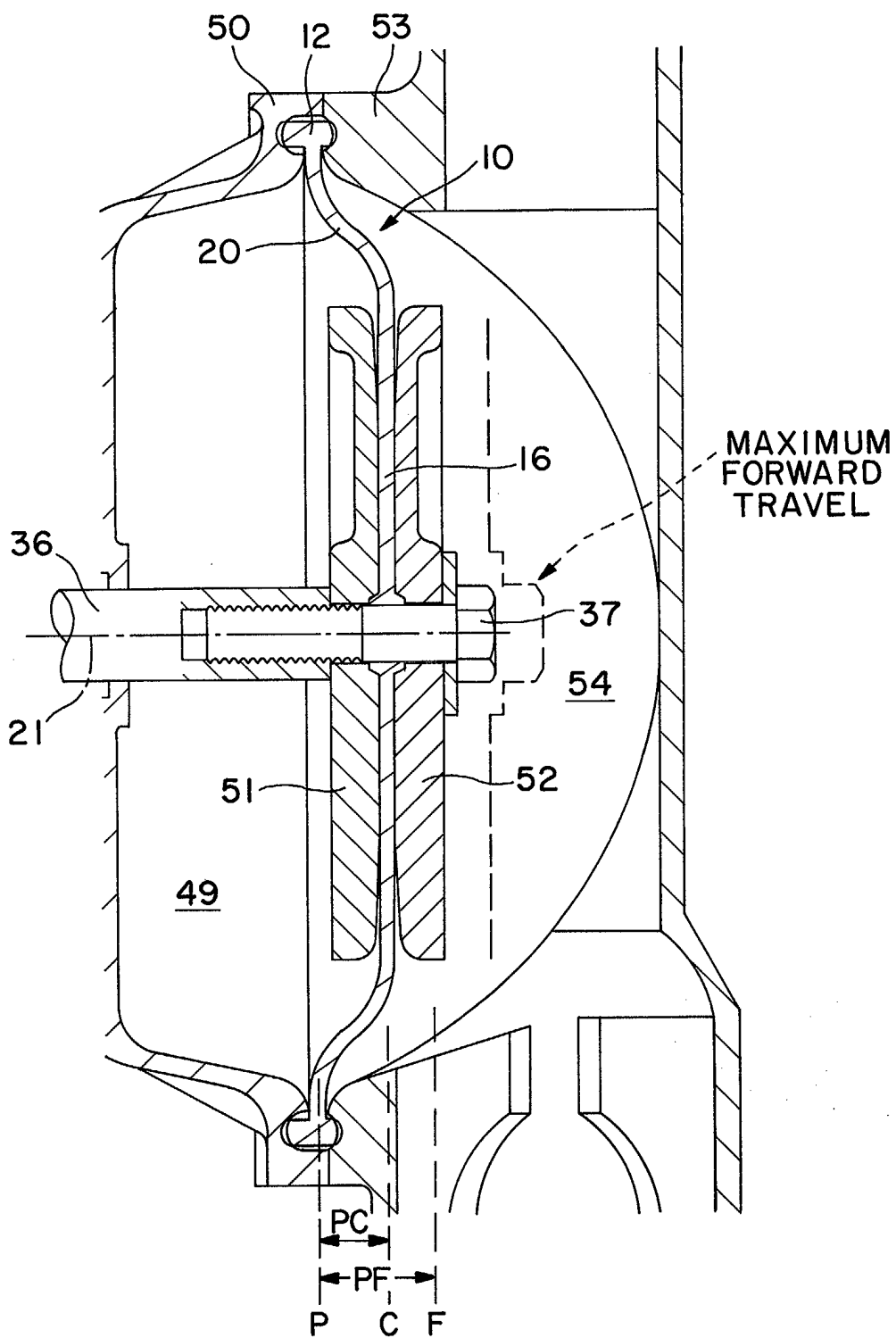


FIG. 6

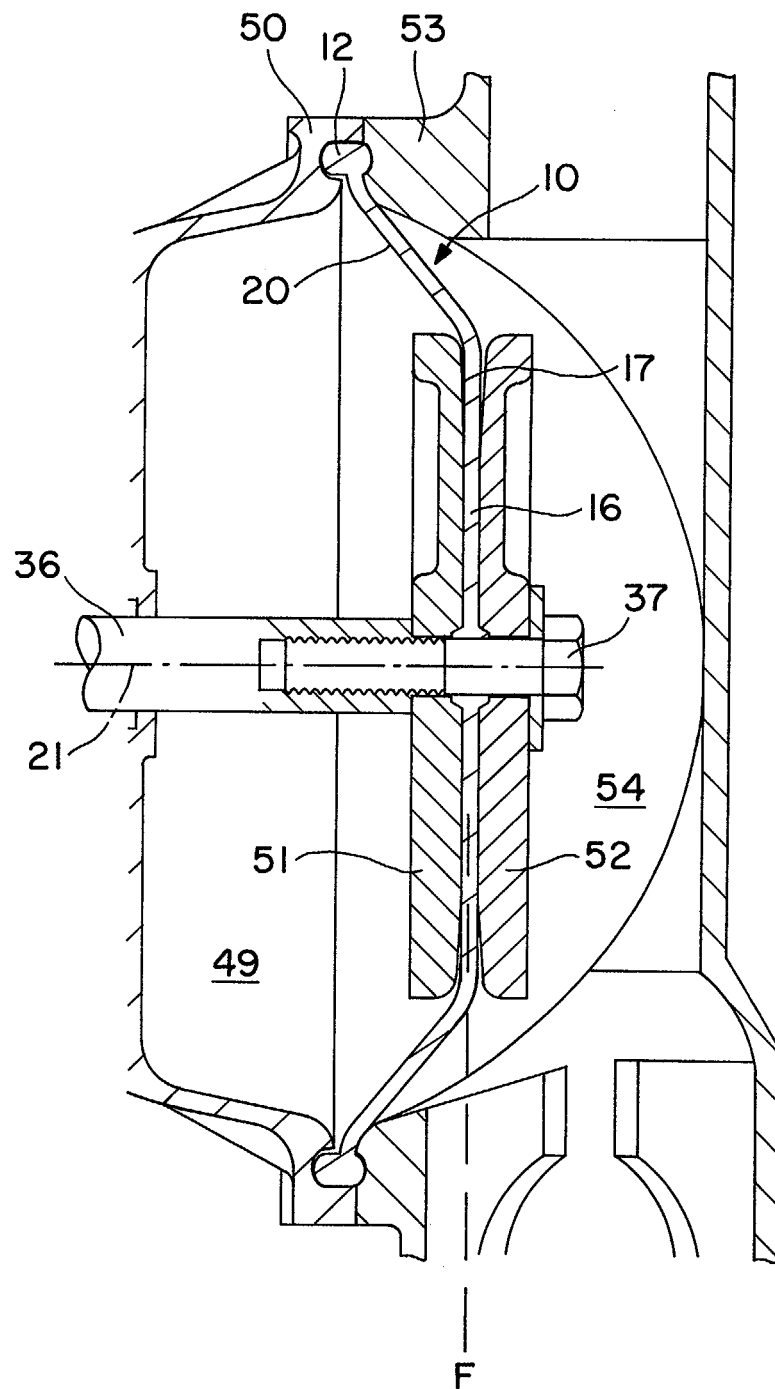


FIG. 7

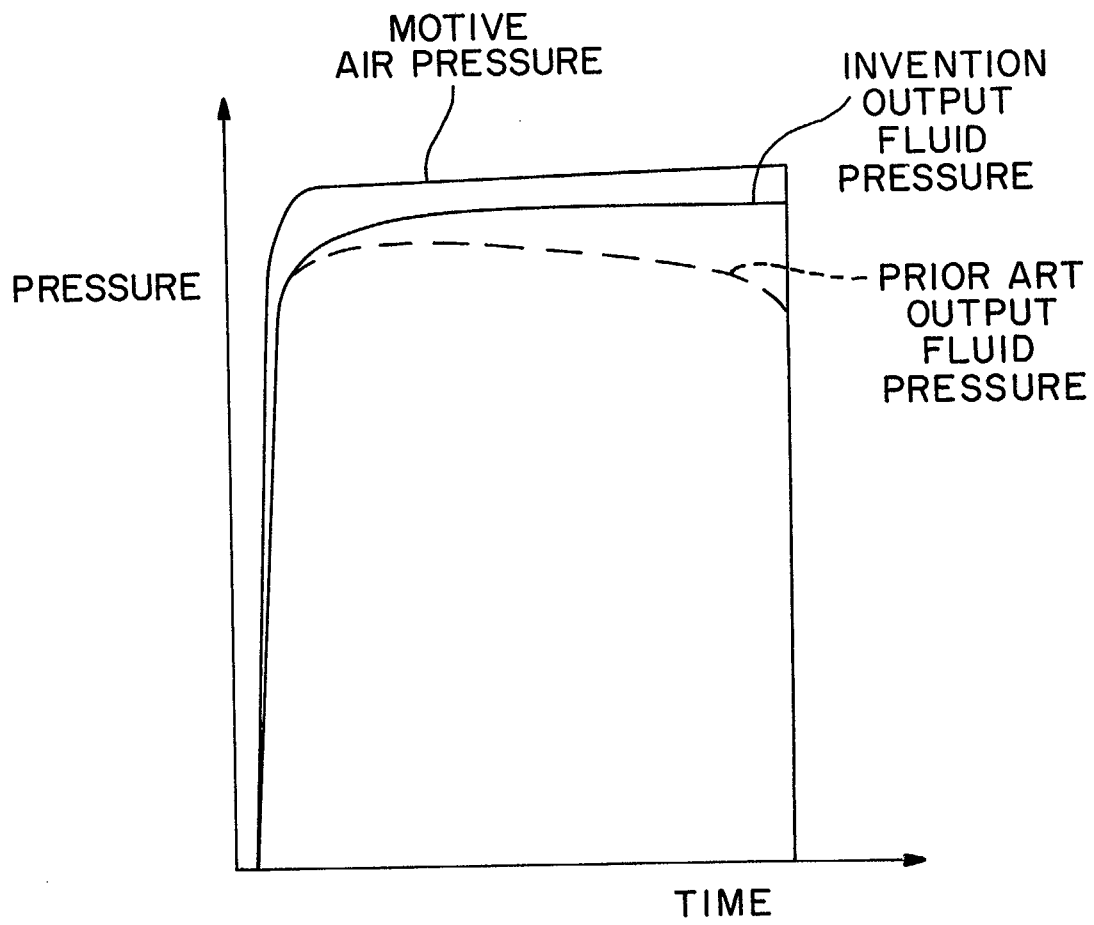


FIG. 8