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(54) **SUBMERSIBLE WELL PUMP WITH IMPROVED DIAPHRAGM**

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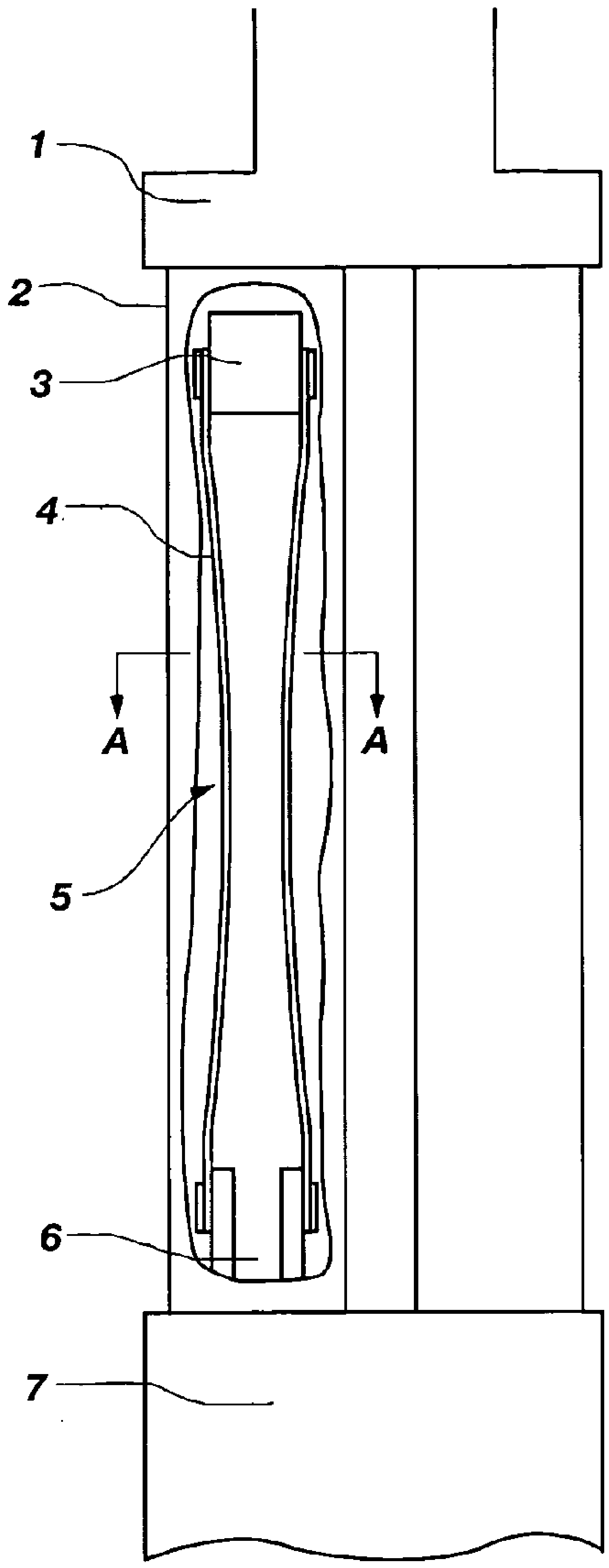
(57) **ABSTRACT**

A composite diaphragm for a hydraulically driven diaphragm pump that incorporates both non-rigid and semi-rigid materials to obtain the benefits of both, wherein the non-rigid materials provide desired resistance to flex fatigue, and wherein the semi-rigid materials provide desired shape characteristics to thereby increase pumping capacity of a hydraulically driven positive displacement diaphragm pump.



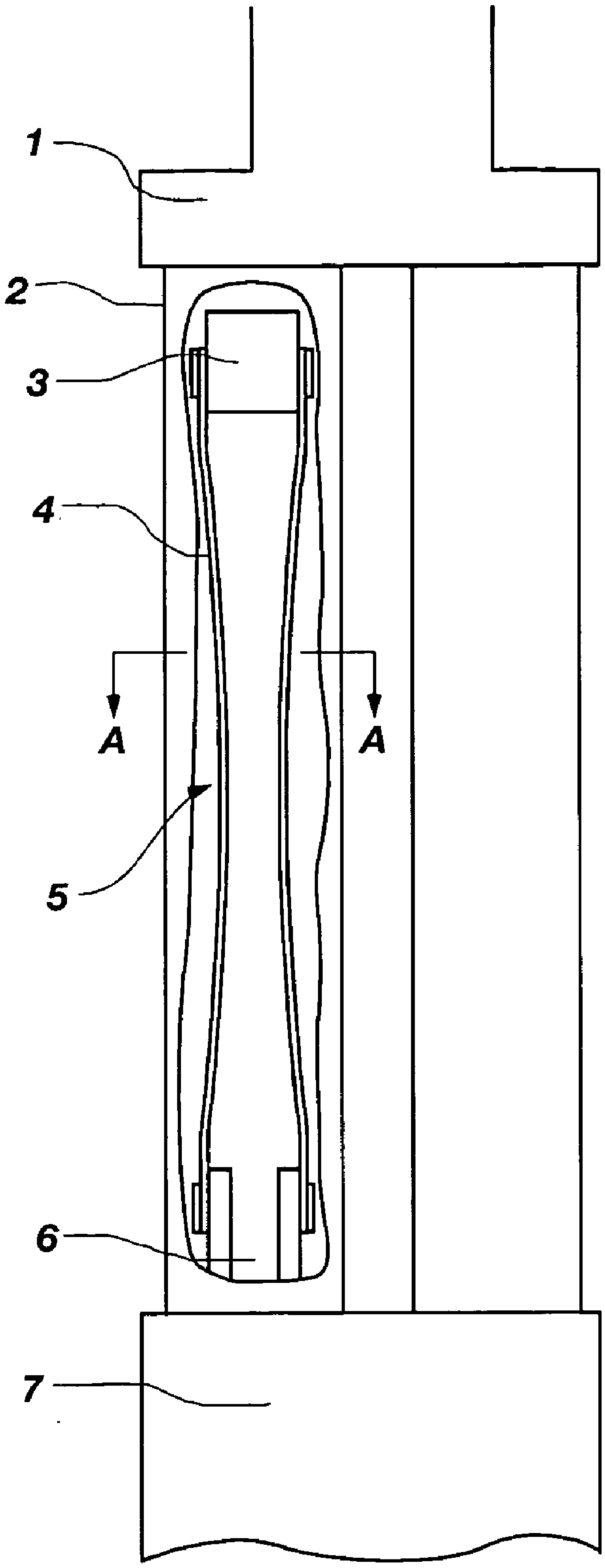


FIG. 1

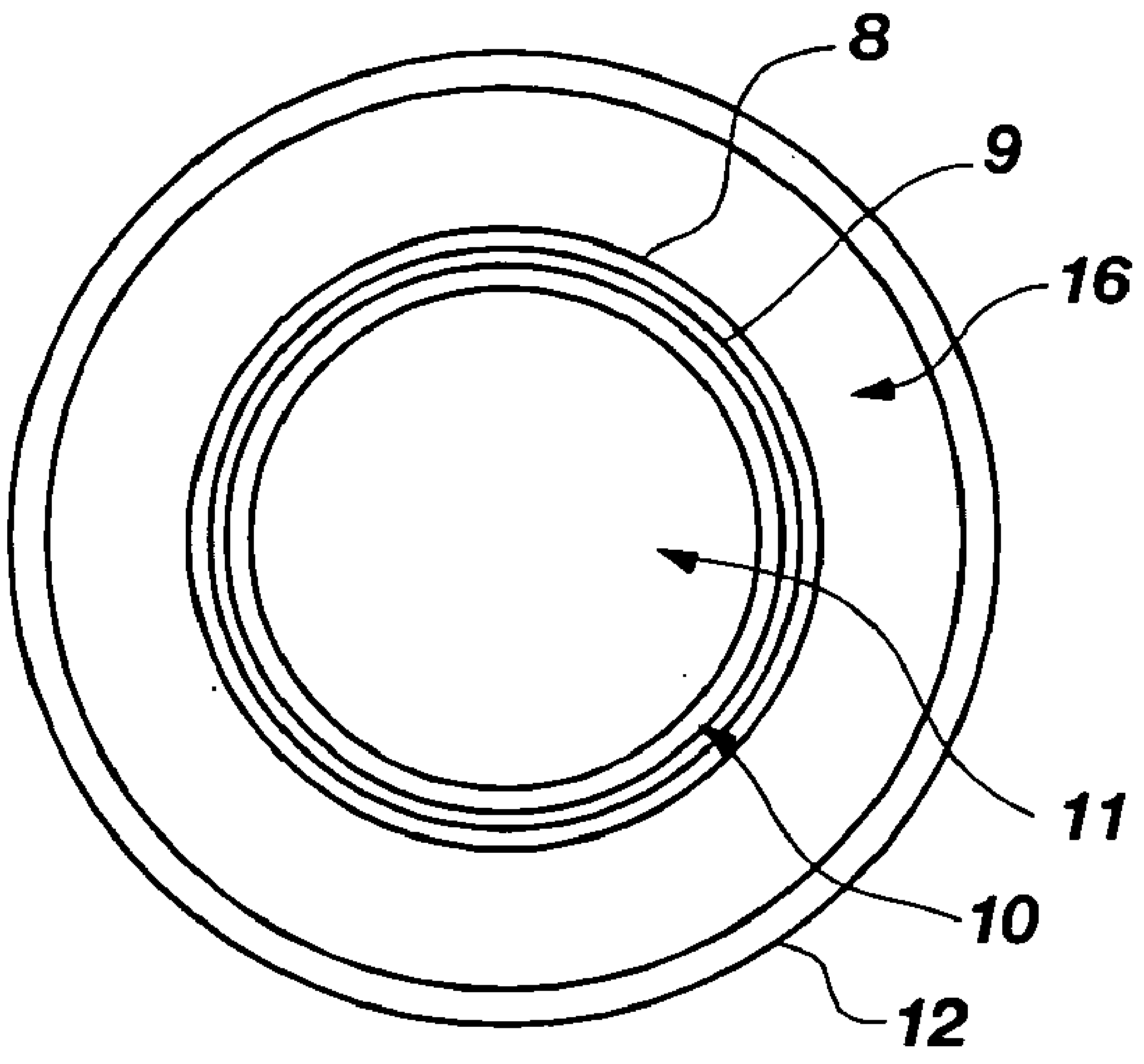


FIG. 2

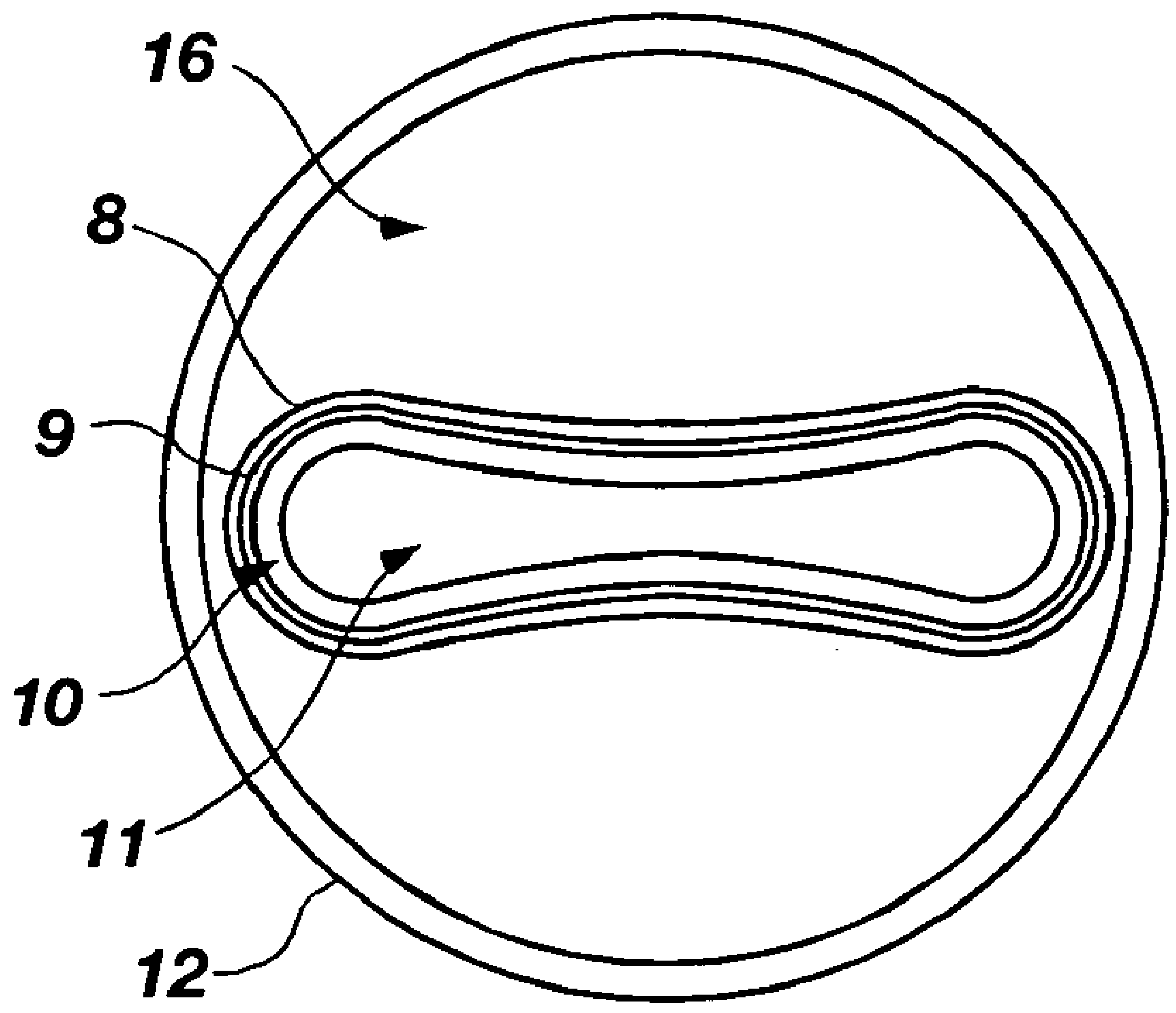


FIG. 3

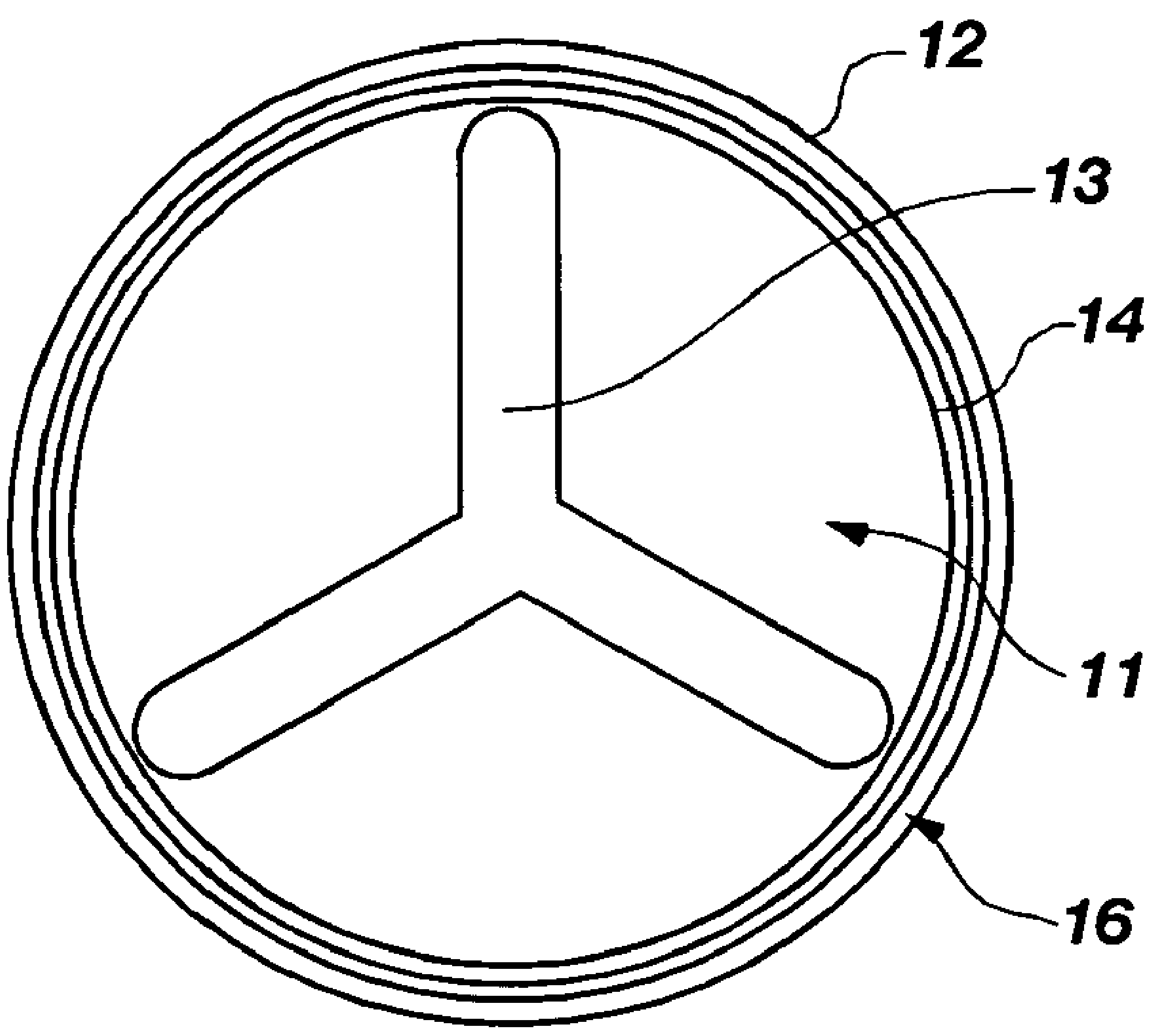


FIG. 4

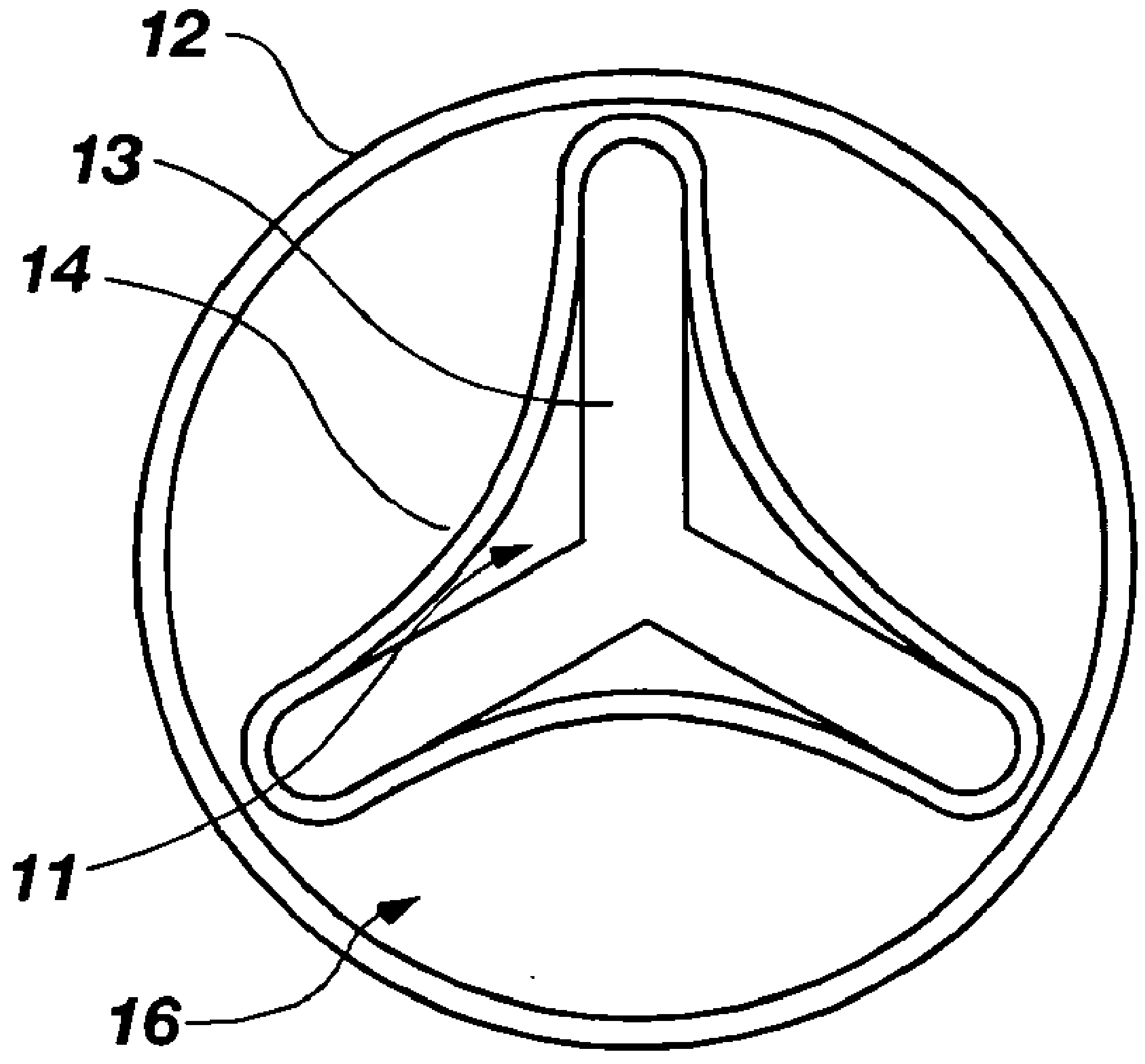


FIG. 5

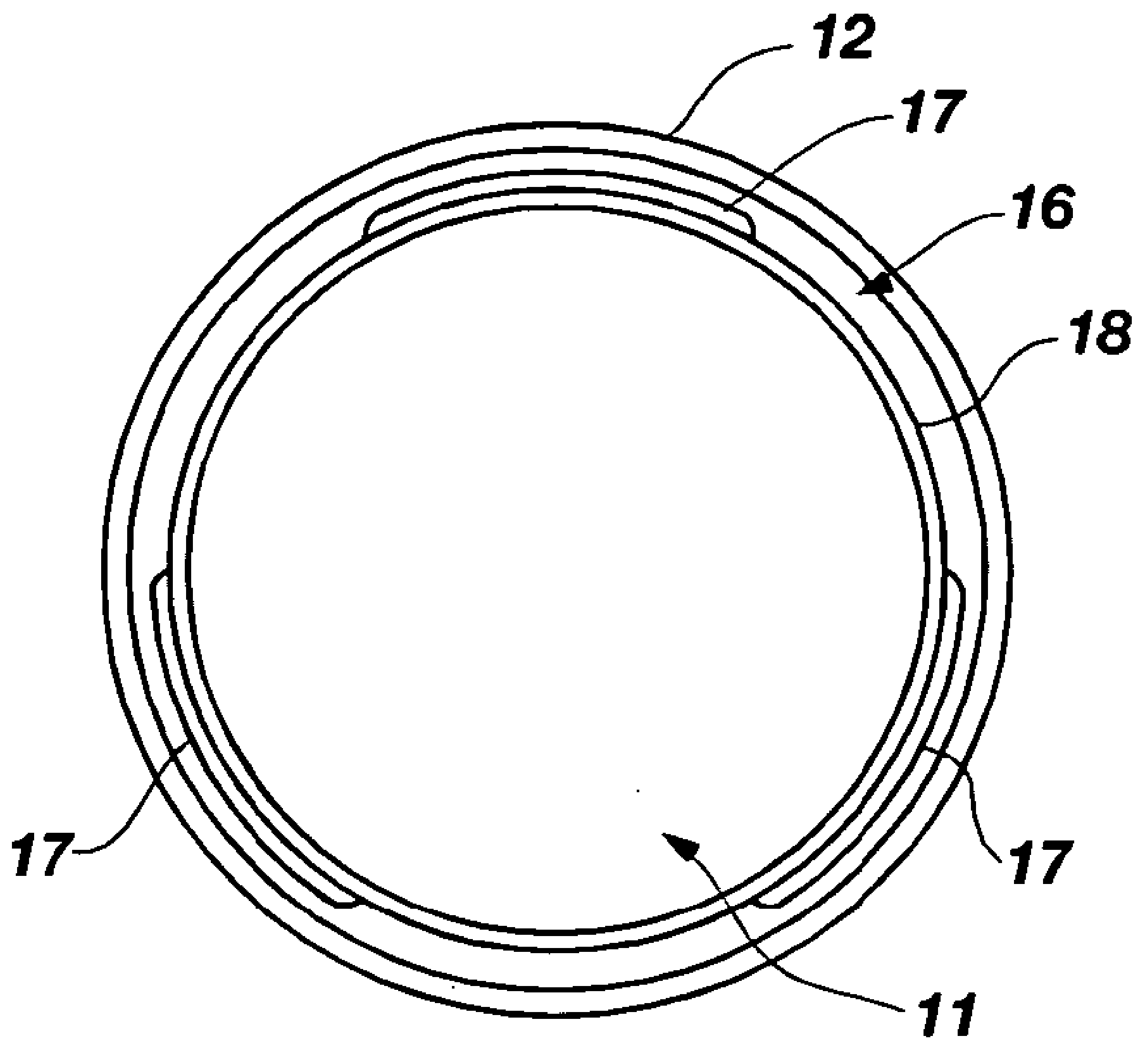


FIG. 6

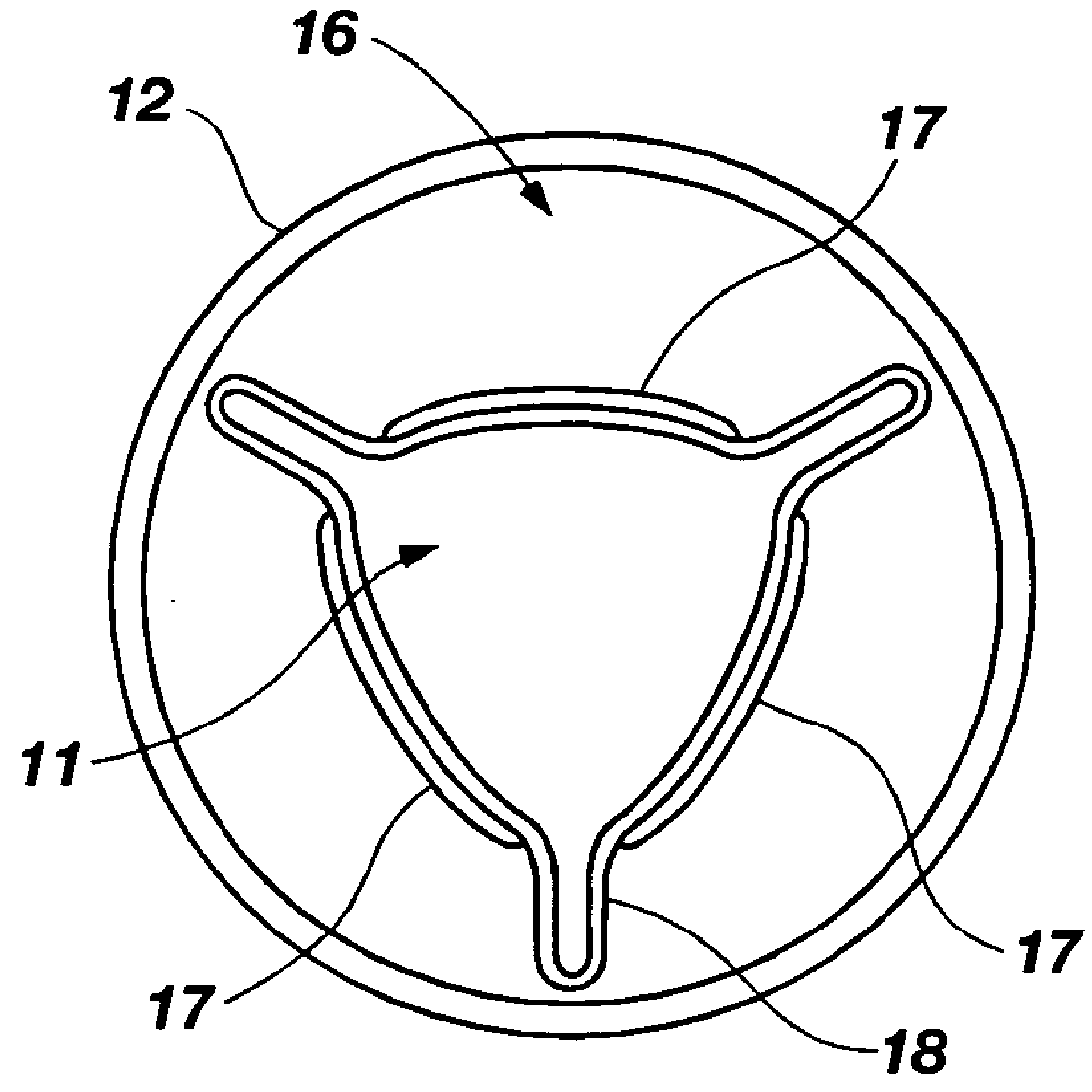


FIG. 7

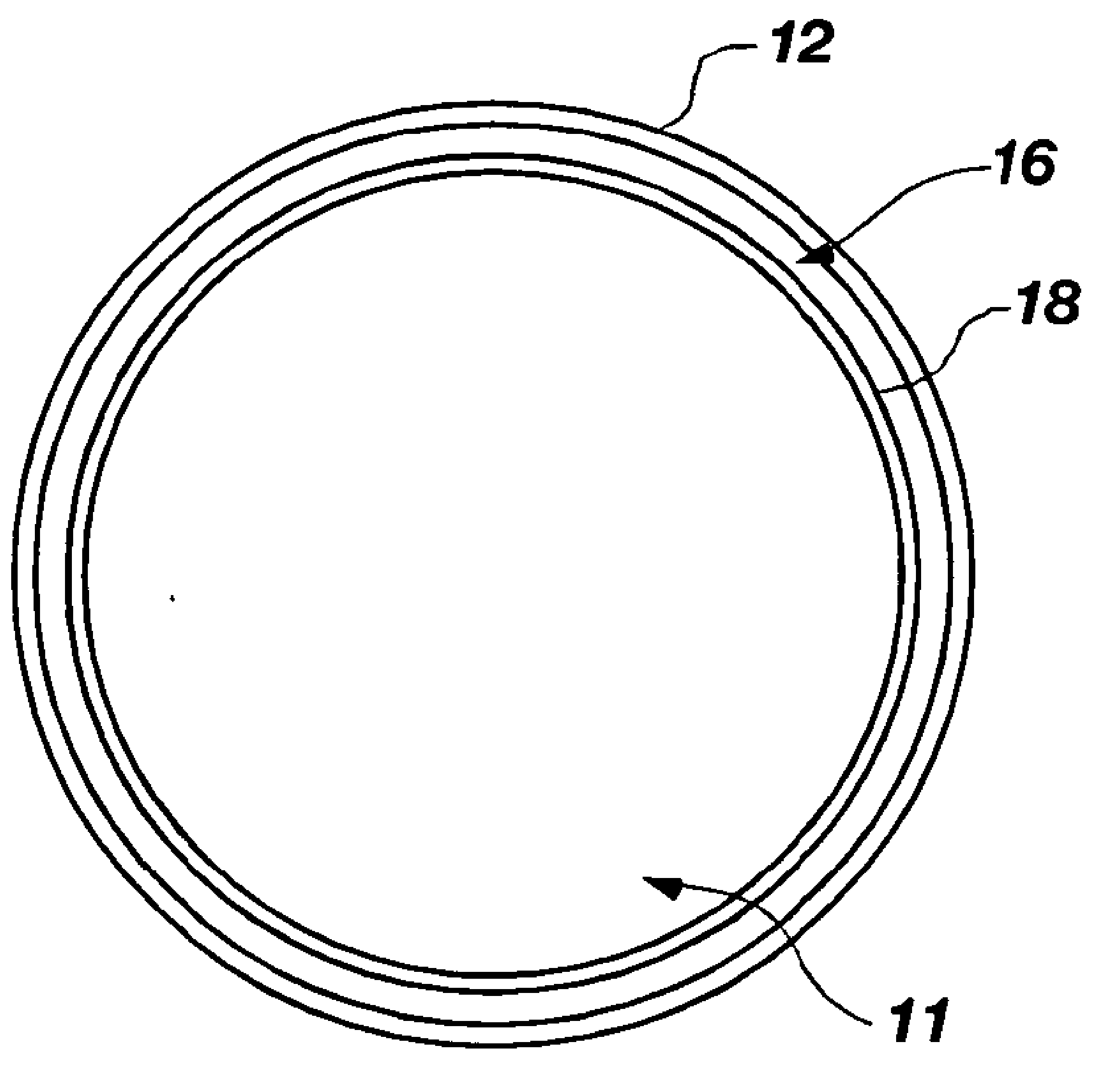


FIG. 8

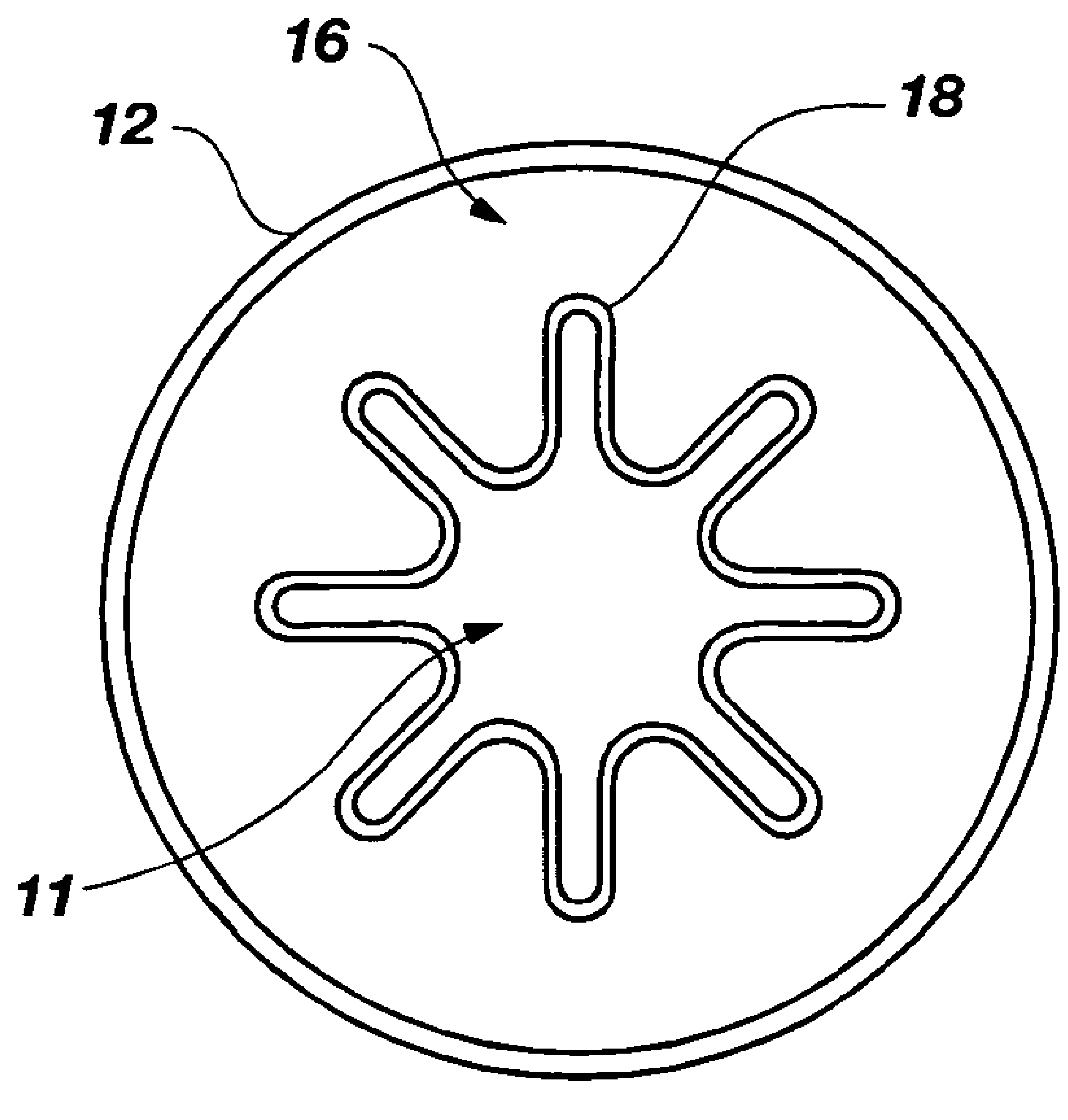


FIG. 9

SUBMERSIBLE WELL PUMP WITH IMPROVED DIAPHRAGM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This document incorporates by reference all of the subject matter filed in U.S. Provisional Patent Application Ser. No. 60/527,804, and filed on Dec. 8, 2003.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] This invention relates generally to submersible well pumps. More specifically, the present invention relates particularly to a multi-chamber, hydraulically driven positive displacement diaphragm pump, with an improved composite diaphragm that increases maximum flow rates and downhole lifetime.

[0004] 2. Description of Related Art

[0005] Hydraulically driven diaphragm pumps are positive displacement pumps that are nearly immune to the effects of sand in the pumped fluid because the pressure generating elements are isolated from the pumped fluid by a flexible diaphragm. In well pump applications, this type of pump is driven by a self contained, closed hydraulic system, activated by an electric or hydraulic motor where the pump, closed hydraulic system, and the motor are all enclosed in a common housing and submerged in a well, or by a hydraulic power source located at the surface and connected to the downhole diaphragm pump by one or more hydraulic lines. There are many examples of this type of well pump in the patent literature, but only one manufactured by Smith International, Inc. is in general use.

[0006] Two important design parameters in well pump applications are downhole lifetime and maximum displacement. Both factors are almost exclusively a function of diaphragm characteristics. Pump failure is almost always caused when the working fluid inside the pump is compromised by: (1) leaks causing loss of working fluid from the working fluid volume, or (2) diffusion of gas or other species into the working fluid. Both problems will cause rapid failure and are occur when seals or diaphragms have excessive leak rates when installed, or which become leaky over time. Hydraulically driven diaphragm pumps have the unique advantage of not requiring dynamic seals. Accordingly, dynamic seals are eliminated as a source of possible leaks.

[0007] The remaining static seals are very resistant to leaks, leaving the flexible diaphragms as the sole source of possible leaks.

[0008] The most common failure of submersible pumping systems occurs when the materials used in the construction of the diaphragm suffer "flex fatigue". Flex fatigue causes a breech in the diaphragm, allowing the working fluid to leak.

[0009] Flex fatigue is a well known phenomenon that occurs when typically non-metals are repeatedly flexed, especially in an environment that degrades the mechanical properties of the base material. Flex fatigue is the primary failure mechanism of most diaphragm pumps. The second failure mechanism, which is not usually seen in other diaphragm applications, is the diffusion of gas or other materials through the diaphragm from the pumped fluid to the working fluid or into the volume of the diaphragm. Such diffusion can cause failure due to an increase in working fluid volume. Alternatively, diffusion can lead to the formation of gas bubbles when the pressure is reduced.

[0010] Gas saturation and diffusion are common problems in the oil and gas industry, and well characterized in many applications. In downhole (down inside a well) applications, the occurrence of gas diffusion driven failures is common, and has lead to the development and use of materials and techniques especially suited to resist gas diffusion related failures. Another factor that is considered when selecting a suitable material for the diaphragm is the downhole chemical environment that can also be very severe, restricting the choice of universally acceptable materials to a relatively small number that are known to be compatible with most downhole environments.

[0011] Controlling downhole gas diffusion and related failures is especially difficult given limited material choices due to chemical compatibility, high ambient gas pressures (hundreds of bar in some cases), and the number and type of gassed encountered (carbon dioxide, hydrogen sulfide, methane, nitrogen, and others) that can saturate and diffuse through susceptible materials. Gas saturation failure in elastomers is caused when a susceptible material is present in a high pressure environment for a long time, and then the pressure is suddenly reduced, such as when the material is removed from the well, or the well is pumped down. In that kind of failure event, the gas comes out of solution, and forms gas bubbles, especially in elastomers, thereby forming voids in the material. Gas bubbling of rubber insulated electrical cable, and downhole packers, is a common failure occurrence in the oil and gas industry.

[0012] Gas diffusion through barriers is another common problem, and has the same root cause as gas saturation failures: namely the tendency of gas with time to move through and saturate susceptible materials. In the context of diaphragm pumps, the diffusion of gas through the diaphragm must be considered an important design parameter. Accordingly, poor material selection and design can lead to subsequent failure in many downhole environments.

[0013] Key to diaphragm selection is the selection of a material that: (1) can withstand the given chemical environment; (2) will not saturate with gas, or suffer gas bubbling; (3) will be a sufficient barrier to gas diffusion; and (4) will operate free from flex fatigue for the longest possible time.

[0014] In addition to these critical materials issues, the geometry and mechanical characteristics of the diaphragm are important. Downhole diaphragm pumps have a high length to width ratio due to the limitations on the diameter of the wellbore. Standard oil well casing sizes limit the maximum diameter of the pump to either 3¾" or 4½" OD. Also, most diaphragm pump designs are double acting; that is two identical chambers are used. These chambers are typically cylindrical in shape, either of a coaxial or side-by-side design. When a non-rigid material is used for the diaphragm, material characteristics limit the geometry of the diaphragm to a long, slender shape that alternates between a round cylindrical configuration when full and a flat oval shape when empty. This default configuration for a non-rigid material limits the maximum diameter of the full diaphragm relative to the inside diameter of the pumping chamber, because when the diaphragm is emptied, the corners of the flat oval shape interfere with the inside diameter of the pumping chamber. The use of non-rigid materials also limits the maximum flow rate due to the tendency of the diaphragms to obstruct the flow path into the diaphragms by non-uniform collapse, resulting in excessive cavitation in the main hydraulic pump.

[0015] All prior art for the use of downhole hydraulically driven diaphragm pumps either use a non-rigid rubber diaphragm or do not specify any specific diaphragm configurations. U.S. Pat. No. 2,435,179, U.S. Pat. No. 2,961, 966, and U.S. Pat. No. 6,017,198 disclose a hydraulically driven diaphragm pump which uses either a non-rigid rubber, or unspecified construction diaphragm.

[0016] Unlike mechanically driven diaphragm pumps, hydraulically driven diaphragm pumps do not require semi-rigid diaphragm materials to support mechanical loads related to operating the air valve. This construction provides an advantage over air operated diaphragm pumps that do require semi-rigid diaphragms, because non-rigid diaphragms do not suffer from frequent flex fatigue failures. For example, semi-rigid TPFE diaphragms are used extensively in air operated, dish type diaphragm pumps. These semi-rigid materials provide the characteristics needed for proper operation of this type of pump, such as load carrying capabilities and chemical resistance, but often fail due to flex fatigue.

[0017] Typical hydraulically actuated diaphragm pumps for downhole use have a non-rigid diaphragm construction, and do not suffer from flex fatigue, but do suffer from other problems such as limited capacity and diffusion of gasses across the diaphragm. A common solution for air operated diaphragm pumps (as opposed to hydraulically operated) is to use two diaphragms, one semi-rigid, the other non-rigid, one on top of the other, such that the loads are carried by the semi-rigid diaphragm, and the seal is provided by the non-rigid diaphragm. A significant improvement to the air operated diaphragm pump was the introduction by Gore Industries of a composite construction One-Up® diaphragms. These diaphragms were introduced to solve the reverse problem from hydraulically actuated diaphragm pumps, namely to increase flex fatigue life which can be greatly improved by switching to a non-rigid material, but in this particular application, the load carrying capabilities of the flex fatigue prone semi-rigid diaphragm are required. The Gore Industries diaphragm uses a bonded composite of reinforced rubber with TPFE. According to test results reported by Gore Industries from product literature, this type of construction can increase flex life by a factor of three or more over conventional semi-rigid diaphragm construction.

[0018] It is important to recognize that the Gore Industries diaphragm was created to solve a completely different problem. The success of that construction, however, can be applied to other types of diaphragm pumps. Those pumps include hydraulically actuated diaphragm pumps where large performance and life improvements are obtained if the diaphragm has the shape holding and diffusion resistance properties of the semi-rigid material and the flex fatigue resistance on the non-rigid material.

BRIEF SUMMARY OF THE INVENTION

[0019] It is an object of the present invention to provide a diaphragm for a hydraulically driven diaphragm pump that incorporates non-rigid and semi-rigid materials in the diaphragm.

[0020] It is another object to provide a diaphragm for a hydraulically driven diaphragm pump that has improved flex fatigue characteristics.

[0021] It is another object to provide a diaphragm for a hydraulically driven diaphragm pump that has an optimum shape for maximum pump capacity.

[0022] It is another object to provide a diaphragm for a hydraulically driven diaphragm pump that has a geometry that can be predictably controlled to thereby increase the compression ratio.

[0023] It is another object to provide a single diaphragm for a hydraulically driven diaphragm pump that can have hinge areas of increased flexibility as well as areas that do not require as much flexibility.

[0024] The present invention is a composite diaphragm for a hydraulically driven diaphragm pump that incorporates both non-rigid and semi-rigid materials to obtain the benefits of both, wherein the non-rigid materials provide desired resistance to flex fatigue, and wherein the semi-rigid materials provide desired shape characteristics to thereby increase pumping capacity of a hydraulically driven positive displacement diaphragm pump.

[0025] In a first aspect of the invention, the semi-rigid material forms the outer layer of the composite diaphragm, and the non-rigid material forms the inner layer of the composite diaphragm.

[0026] In a second aspect of the invention, a rigid or semi-rigid form is disposed at a center position, and a non-rigid diaphragm is disposed around the form.

[0027] In a third aspect of the invention, a non-rigid composite diaphragm has disposed thereon discontinuous but evenly spaced sections of a semi-rigid material on an outer surface.

[0028] In a fourth aspect of the invention, discontinuous but evenly spaced sections of the non-rigid material are made thicker than the remaining areas to thereby form alternating sections of non-rigid and semi-rigid areas, even though the diaphragm is comprised of a single type of material.

[0029] In a fifth aspect of the invention, a non-rigid diaphragm is pre-formed in a desired shape, such that the diaphragm collapses into the pre-formed shape.

[0030] These and other objects, features, advantages and alternative aspects of the present invention will become apparent to those skilled in the art from a consideration of the following detailed description taken in combination with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0031] **FIG. 1** is a typical hydraulically driven diaphragm pump for downhole use. The pump has two chambers, one of which is cut away to reveal the pumping diaphragm of this invention.

[**0032**] **FIG. 2** is a cross section at A—A of **FIG. 1** showing a composite diaphragm of this invention in the fully expanded state, where the semi-rigid and non-rigid materials are attached, with the outer layer comprised of a semi rigid material, and the inner layer comprised of a non-rigid material.

[**0033**] **FIG. 3** is a cross section at A-A of **FIG. 1** showing the diaphragm of **FIG. 2** in the fully collapsed state.

[**0034**] **FIG. 4** is a cross section at A—A of **FIG. 1** showing a semi-rigid diaphragm of this invention in the fully expanded state, wherein the semi-rigid and non-rigid materials are not attached to each other, with the outer layer comprised of a non-rigid material, and the inner layer comprised of a semi-rigid material.

[**0035**] **FIG. 5** is a cross section at A—A of **FIG. 1** showing the diaphragm of **FIG. 4** in the fully collapsed state.

[**0036**] **FIG. 6** is a cross section at A—A of **FIG. 1** showing a non rigid diaphragm of this invention in the fully expanded state, wherein the semi-rigid and non-rigid materials are used in specific areas, creating a single composite structure composed of non-rigid and semi-rigid regions.

[**0037**] **FIG. 7** is a cross section at A—A of **FIG. 1** showing the diaphragm of **FIG. 6** in the fully collapsed state.

[**0038**] **FIG. 8** is a cross section at A—A of **FIG. 1** showing a pre-formed diaphragm of this invention in the fully expanded state, where the non-rigid diaphragm is pre-molded to create pre-formed non-rigid areas that result in a predictable collapse.

[**0039**] **FIG. 9** is a cross section at A—A of **FIG. 1** showing the diaphragm of **FIG. 8** in the fully collapsed state.

DETAILED DESCRIPTION OF THE INVENTION

[**0040**] Reference will now be made to the drawings in which the various elements of the present invention will be given numerical designations and in which the invention will be discussed so as to enable one skilled in the art to make and use the invention. It is to be understood that the following description is only exemplary of the principles of the present invention, and should not be viewed as narrowing the claims which follow.

[**0041**] The present invention results in a marked improvement in the longevity and maximum flow rates of downhole, hydraulically operated diaphragm pumps. That improvement is achieved using non-rigid and semi-rigid materials in combination for diaphragm construction. These materials can be combined as layers one on top of the other, or used only in specific regions of the diaphragm. That combination of materials results in a non-homogenous diaphragm with engineered stiffness. In turn, those properties allow a diaphragm to obtain an optimum shape and flex behavior to achieve maximum flex life and pump capacity.

[**0042**] Hydraulically operated diaphragm pumps for downhole use are unique because they require the use of diaphragms with large length to width ratios because of limited wellbore diameter. Because of this geometry constraint, long, cylindrical diaphragms are typical for this type of pump. Semi-rigid materials are not used in diaphragm construction for hydraulically operated diaphragm pumps because they are not needed to carry loads, and due to the tendency of these materials to flex fatigue.

[**0043**] However in the case of a hydraulically operated diaphragm pump for downhole use, where long, tubular diaphragms are used, the use of semi-rigid materials in the construction of such diaphragms, as opposed to the normal non-rigid materials, presents two distinct advantages. The first advantage is that semi-rigid materials do not restrict the flow of working fluid flowing into and out of the diaphragm as non-rigid materials can, especially on the down stroke (fluid flowing away from the diaphragm). Such restrictions cause cavitation in the main hydraulic pump under many conditions of operation, which reduces output, and can cause pump damage. This problem becomes worse at high flow rates where higher flow velocities collapse the area of the diaphragm nearest the main hydraulic pump due to the “Venturi” effect when the working fluid flows through the diaphragm at high velocity.

[**0044**] The Venturi effect occurs when fluid at high velocity flows through the diaphragm creating a lower pressure area to either side of the jet of fluid, causing the jet to draw the diaphragm inward. The same area tends to also become pinched when the difference of density between the working fluid and the pumped fluid create an inverted teardrop diaphragm shape, much like a hot air balloon is bigger at the top than at the bottom. Semi-rigid materials will maintain a pre-determined, controlled opening, allowing the flow of working fluid without restriction.

[**0045**] The second advantage of semi-rigid materials over non-rigid materials is that semi-rigid materials allow the diaphragm geometry to be predictably controlled. That predictability allows geometries that increase the ratio of the minimum volume of pumped fluid remaining in the pumping chambers at the top of the stroke divided by the total pumped fluid volume delivered by each Stroke. That ratio is sometimes referred to as the compression ratio.

[**0046**] The higher the compression ratio, the better the pump in terms of volumetric efficiency, maximum flow rate, and most importantly, resistance to gas lock. The ability to predetermine the shape of the diaphragm allows the most efficient filling of the cylindrical (or any other shape) pumping chamber by the cylindrical (or any other shape) diaphragm, thus generating the highest compression ratio. A non-rigid material alternates between a “lay flat” and round configuration, which limits the maximum diameter of the diaphragm due to the interference of the diaphragm with the pumping chamber wall in the lay flat state. In fact, this “natural” shape is the least efficient in terms of generating a favorable compression ratio.

[**0047**] Examples of semi-rigid materials are thermoplastics such as polyolefins such as polyethylene and polypropylene, Fluoropolymers such as TPFE, Polyvinylidene Fluoride (PVDF) and associated copolymers such as Kynar Flex®. Other materials outside the thermoplastic family can be used, assuming they have sufficient rigidity to be formed into predetermined shapes, and have adequate chemical resistance and mechanical properties. Polyurethane and highly cross-linked Nitrile are examples of thermoset materials that have suitable properties and can be formed into semi-rigid diaphragms.

[**0048**] Other techniques have been successfully used to change non-rigid materials into semi-rigid materials in localized areas. Simply the addition of non-uniform thickness can make selected areas more rigid regardless of the materials of construction. The most common method of adding strength and rigidity to diaphragm materials is to use a fabric or metal reinforcement to the entire cross section or the entire structure, or to selected areas. Materials such as chopped polyamide fiber can significantly increase rigidity and strength of rubber materials, when mixed in with the base rubber. Also, woven reinforcement layers are commonly used to provide greatly increased strength and stiffness in one plane.

[0049] Non-rigid diaphragms are typically made of elastomeric materials such as rubber, in most cases with a reinforcement layer. The non-rigid materials of this invention are generally the same types of materials. Typical rubber materials are thermoset rubbers such as nitrile, highly saturated nitrile, EPDM, Polyurathane, natural rubber, SBR, Flororubber compounds such as Viton®, thermoplastic rubbers such as Sanoprene®, Hytrel®, and other types of thermoplastic rubber are examples of non-rigid materials. Non-rigid materials of this invention are typically reinforced with a layer of continuous fabric embedded in the non-rigid material for added strength and to limit elongation when the diaphragm is flexed.

[0050] Two methods have been developed to increase the flex fatigue life of diaphragms that use semi-rigid materials. The goal is to enjoy the benefits of semi-rigid materials without the decrease in life due to flex fatigue. First, semi-rigid materials can be used in layers with non-rigid materials to obtain the best properties of each. For example, a composite tubular diaphragm can be constructed by using a non-rigid rubber tube on the inside layer attached to a semi-rigid material such as Teflon® on the outside layer. That arrangement results in the non-rigid material increasing flex life, while the semi-rigid material provides shape, control and diffusion resistance. Although not a compatible geometry, the dish shaped Gore Industries One-Up® Diaphragm for air operated diaphragm pumps presents an example of such a construction for a different application. The advantage of this combination is realized in hydraulically operated diaphragm pumps for well applications, where the length to diameter ratio is very high. The shape holding advantages of the semi-rigid material allow the resulting diaphragm, which is a slender closed tube, to be realized by using a rubber liner on the inside and a semi-rigid thermoplastic material on the outside.

[0051] Another method to obtain a similar result is to put a smaller sized, semi-rigid form inside a non-rigid tubular diaphragm such that the non-rigid tubular diaphragm conforms to the shape of the semi-rigid material in the empty state. The form is designed to be porous, with the inside area open to allow the flow of working fluid along the length of the form, and numerous passages from the inside area to the outside of the form to allow working fluid to act on the non-rigid diaphragm, which is located on the outside of the form.

[0052] A "star" shaped form, where the legs of the star are relatively thin compared to the diameter of the form would work as well. The need for passages from the inside to the outside is eliminated, as the diaphragm would not fully collapse into the central portion of the form, leaving a natural passage toward the center of the star. The non-rigid diaphragm, that encloses the form, is much like conventional non-rigid diaphragms for hydraulically operated diaphragm pumps. This arrangement gives the shape controlling advantages of the combination of semi-rigid form on the inside, with a non-rigid diaphragm on the outside, that is a very simple, efficient construction. A simple example, for illustrative purposes, would be a non-rigid reinforced rubber diaphragm on the outside with a semi-rigid plastic tube inside that maintains an opening from the top to the bottom of the diaphragm when the diaphragm is in the empty state. The plastic tube would have numerous holes to allow the flow of working fluid from the inside of the tube to the outside, to move the non-rigid diaphragm. This simple example would have considerably lower back pressure, and would allow a larger diameter non-rigid diaphragm due to improved geometry at the empty state.

[0053] Second, semi-rigid materials can be used in specific areas with non-rigid materials in a single structure to obtain the best properties of each in a composite diaphragm construction. In this method, non-rigid material in the "hinge" areas, or areas pre-engineered as flex zones, and semi-rigid material, is used in other areas that do not flex significantly. By using such construction, the resulting diaphragm will be non-rigid in some areas, and semi-rigid in others, controlling the geometry of the diaphragm, and maximizing the advantages of this invention. In most cases, this technique is used in diaphragms that require improved diffusion resistance, and less cost sensitive applications. In the areas that are designed to flex, other materials such as fabrics can provide mechanical strength, while additional thickness of flexible material or coatings can at least reduce diffusion rates if needed. This composite design retains the shape advantages of the semi-rigid material, and provides a diaphragm life greater than either material alone, facilitates higher flow rates, and provides improved chemical and diffusion resistance.

[0054] Another application of this same principle is to use a "shaped" diaphragm where a non-rigid diaphragm is molded to a particular shape such that, the collapse is predictable. Although no changes in the material characteristics of the non-rigid diaphragm are needed to define the shape, the molding process itself imparts non-rigidity by pre-forming areas that will either flex or not flex depending on the geometry. The molding process creates "memory" in the material by leaving built-in stress in the diaphragm material. These areas of built-in stress create semi-rigid regions that cause the diaphragm to predictably collapse to the shape the diaphragm was originally molded.

[0055] By using a semi-rigid material with a non-rigid material, the advantages of this invention can be obtained, along with other desirable properties attributable to the composite design, including increased life, greater displacement per stroke, improved diffusion resistance and higher flow rates.

[0056] Referring to **FIG. 1**, a typical two chamber hydraulically driven diaphragm pump, with a long, slender diaphragm **1** contained inside a pumping chamber. The diaphragm is plugged with endplug **3**. Working fluid is fed into and out of the diaphragm **1** through port **6**. The flow of working fluid into and out of the diaphragm **1** is regulated and generated by the diaphragm pump power and control system **7**. The flow of pumped fluid **5** which is forced into and out of pumping chamber **2** is regulated by a pair of checkvalves connected to the inlet and outlet of the pump in the valveblock **1**.

[**0057**] Referring to **FIGS. 2 and 3**, a composite diaphragm, consisting of semi-rigid layer **8**, adhesive layer **9**, and non-rigid layer **10** is shown inside pumping chamber **12** with working fluid, **11** inside, and pumped fluid **16**, outside. The semi-rigid layer **8** is bonded to the non-rigid layer **10** with an adhesive layer **9**; the preferred adhesive is locktite **454**. The preferred semi-rigid layer **8** is made of Kynar flex®, which is a product of ATO Fina Chemicals, is a proprietary co-polymer that combines the high strength and chemical resistance of Polyvinylidene Fluoride (PVDF) with increased flexibility, making it an ideal material for diaphragm pump application. Several different grades of this material are available, each with different mechanical properties and melting points; for this preferred embodiment, Kynar flex® 2800 is used. The preferred non-rigid layer **10** is reinforced nitrile rubber, where nitrile tube is reinforced with polyester cord with a nitrile cover.

[**0058**] Referring to **FIGS. 4 and 5**, non-rigid diaphragm **14** is shown inside pumping chamber **12** with working fluid **11** inside, and pumped fluid **16** outside the diaphragm. The preferred non-rigid diaphragm **14** is made of reinforced nitrile rubber, where nitrile tube is reinforced with polyester cord with a nitrile cover. Located inside the diaphragm is form **13** made of a semi-rigid material. The preferred semi-rigid material in this embodiment is high molecular weight polypropylene plastic. The working fluid **11** maintains a passageway up the length of the diaphragm, even at the minimum condition shown in **FIG. 5**. Also, in this embodiment, the volume of pumped fluid **16** contained inside the pumping chamber **12** is a minimum, providing maximum compression ratio.

[**0059**] Referring to **FIGS. 6 and 7**, a non-rigid diaphragm **18** is shown inside pumping chamber **12** with working fluid **11** inside, and pumped fluid **16** outside the diaphragm. The preferred non-rigid diaphragm **18** is made of reinforced nitrile rubber, where nitrile tube is reinforced with polyester cord with a nitrile cover. Bonded to the non-rigid diaphragm are semi-rigid sections **17**. The preferred semi-rigid material is Kynar Flex® 2800. The preferred attachment of the non-rigid material to the semi-rigid material would be by adhesive locktite **454**. A number of methods can be used to bond or create the semi-rigid sections **17** to the non-rigid diaphragm **18**, including molding the semi-rigid material directly into the not-rigid material, adhesives, and treating non-rigid materials to make them rigid. In an alternate embodiment of this same concept, semi-rigid sections **17** would simply be thickened areas of the non-rigid diaphragm **18** to where the additional thickness creates a semi-rigid region wherever the non-rigid areas are thickened.

[**0060**] Referring to **FIGS. 9 and 10**, in this embodiment, the pre-formed diaphragm **18** is molded in the shape of the collapsed configuration shown in **FIG. 10**. The pre-formed diaphragm **18** is shown inside pumping chamber **12** with working fluid **11** inside, and pumped fluid **16** outside the diaphragm. The preferred pre-formed diaphragm **18** is made of reinforced nitrile rubber, where a nitrile tube is reinforced with polyester cord with a nitrile cover.

[**0061**] The preferred process for creating the preformed shape is extrusion, where the extrusion die has the preformed shape, and a slight vacuum is maintained inside the shape during the curing process to set the shape into the diaphragm. Other processes can be used such as transfer molding.

[**0062**] The descriptions and examples contained herein are examples of the many combinations of rigid and non-rigid materials that would result in an improved diaphragm for downhole hydraulic diaphragm pumps, all such possible combinations are claimed as part of this application.

[**0063**] It is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention. The appended claims are intended to cover such modifications and arrangements.

What is claimed is:

1. A diaphragm for use in a hydraulically driven diaphragm pump, said diaphragm comprising:

at least one non-rigid and at least one semi-rigid material used to construct the diaphragm; and

a port for transferring a working fluid into and out of the diaphragm.

2. The diaphragm as defined in claim 1 wherein the at least one semi-rigid material is further comprised of a semi-rigid diaphragm forming an outer layer of the diaphragm.

3. The diaphragm as defined in claim 2 wherein the at least one non-rigid material is further comprised of a non-rigid diaphragm forming an inner layer of the diaphragm.

4. The diaphragm as defined in claim 3 wherein the diaphragm is further comprised of an adhesive disposed between the non-rigid diaphragm and the semi-rigid diaphragm.

5. The diaphragm as defined in claim 1 wherein the diaphragm is further comprised of:

the at least one non-rigid material forming an inner layer of the diaphragm;

the at least one semi-rigid material forming a discontinuous outer layer of the diaphragm; and

an adhesive disposed between the at least one non-rigid inner layer and the at least one semi-rigid material discontinuous outer layer.

6. The diaphragm as defined in claim 5 wherein the at least one discontinuous semi-rigid layer is disposed symmetrically about the non-rigid inner layer of the diaphragm.

7. The diaphragm as defined in claim 1 wherein the at least one semi-rigid material is further comprised of a thicker or multiple layers of the at least one non-rigid material to thereby add stiffness.

8. The diaphragm as defined in claim 7 wherein the thicker or multiple layers of the at least one non-rigid material is disposed discontinuously about the diaphragm.

9. The diaphragm as defined in claim 1 wherein the at least one semi-rigid material is further comprised of a pre-formed layer of the least one non-rigid material to thereby add stiffness.

10. The diaphragm as defined in claim 1 wherein the diaphragm is further comprised of:

the at least one semi-rigid material disposed in a center of the pumping chamber, the semi-rigid material forming a column of at least three spokes; and

the at least one non-rigid material disposed as an outer layer around the semi-rigid material, wherein the at least one non-rigid material forms at least three channel between the at least one non-rigid material and the semi-rigid material when the at least one non-rigid material is collapsed.

11. A hydraulically driven diaphragm pump comprising:

a) at least one pumping chamber;

b) a diaphragm comprised of non-rigid and semi-rigid materials, wherein the diaphragm is disposed within the at least one pumping chamber;

c) a port for transferring a working fluid into and out of the diaphragm;

d) a diaphragm pump power and control system for controlling movement of the working fluid; and

e) a valve block including at least two check valves for controlling movement of a pumped fluid outside the diaphragm.

12. The hydraulically driven diaphragm pump as defined in claim 11 wherein the semi-rigid material is further comprised of a semi-rigid diaphragm forming an outer layer of the diaphragm.

13. The hydraulically driven diaphragm pump as defined in claim 12 wherein the non-rigid material is further comprised of a non-rigid diaphragm forming an inner layer of the diaphragm.

14. The hydraulically driven diaphragm pump as defined in claim 13 wherein the diaphragm is further comprised of an adhesive disposed between the non-rigid diaphragm and the semi-rigid diaphragm.

15. The diaphragm as defined in claim 11 wherein the diaphragm is further comprised of:

the at least one non-rigid material forming an inner layer of the diaphragm;

the at least one semi-rigid material forming a discontinuous outer layer of the diaphragm; and

an adhesive disposed between the at least one non-rigid inner layer and the at least one semi-rigid material discontinuous outer layer.

16. The diaphragm as defined in claim 15 wherein the at least one discontinuous semi-rigid layer is disposed symmetrically about the non-rigid inner layer of the diaphragm.

17. The diaphragm as defined in claim 11 wherein the at least one semi-rigid material is further comprised of a thick layer of the at least one non-rigid material to thereby add stiffness.

18. The diaphragm as defined in claim 17 wherein the thick layer of the at least one non-rigid material is disposed discontinuously about the diaphragm.

19. The diaphragm as defined in claim 11 wherein the at least one semi-rigid material is further comprised of a pre-formed layer of the least one non-rigid material to thereby add stiffness.

20. The diaphragm as defined in claim 11 wherein the at least one semi-rigid material is selected from the group of semi-rigid materials comprised of Polyvinylidene Fluoride (PVDF), TPFE, thermoplastics, highly cross-linked nitrile, polyolefins, polyethylene, polypropylene, and Fluoropolymers.

21. The diaphragm as defined in claim 11 wherein the at least one non-rigid material is selected from the group of non-rigid materials comprised of elastomeric materials including rubber, thermoset rubber, nitrile, highly saturated nitrile, EPDM, Polyurathane, natural rubber, SBR, and Flororubber.

22. A method for providing a diaphragm for use in a hydraulically driven diaphragm pump that has improved downhole life and greater pump capacity, said method comprising the steps of:

a) providing at least one non-rigid and at least one semi-rigid material;

b) forming a wall of the diaphragm using the at least one non-rigid material and the at least one semi-rigid material, wherein the at least one non-rigid material increases flex fatigue life, and wherein the at least one semi-rigid material provides improved shape control and diffusion resistance; and

c) providing a port in one end of the diaphragm for transferring a working fluid into and out of the diaphragm.

23. The method as defined in claim 22 wherein the method further comprises the step of using the at least one semi-rigid material to form an outer layer of the diaphragm to thereby control an overall shape of the diaphragm.

24. The method as defined in claim 23 wherein the method further comprises the step of using the at least one non-rigid material to form an inner layer of the diaphragm to thereby provide increased flex fatigue resistance.

25. The method as defined in claim 24 wherein the method further comprises the step of disposing an adhesive between the non-rigid diaphragm and the semi-rigid diaphragm.

26. The method as defined in claim 22 wherein the method is further comprised of the steps of:

a) forming an inner layer of the diaphragm using the at least one non-rigid material;

b) forming a discontinuous outer layer of the diaphragm using the at least one semi-rigid material; and

c) disposing an adhesive between the at least one non-rigid inner layer and the at least one semi-rigid material discontinuous outer layer, wherein the discontinuous outer layer defines a collapsed shape of the diaphragm.

27. The method as defined in claim 26 wherein the method is further comprised of the step of symmetrically disposing the at least one discontinuous semi-rigid layer around the non-rigid inner layer of the diaphragm, to thereby form a symmetrical shape when the diaphragm is collapsed.

28. The method as defined in claim 22 wherein the method is further comprised of the step of providing a thicker layer of the at least one non-rigid material to function as a semi-rigid material, to thereby add stiffness to the diaphragm without adding a different semi-rigid material.

29. The method as defined in claim 28 wherein the method is further comprised of the step of discontinuously disposing the at least one non-rigid material about the diaphragm in order to obtain a non-symmetrical cross-section for the collapsed diaphragm.

30. The method as defined in claim 22 wherein the method is further comprised of the steps of:

a) disposing the at least one semi-rigid material in a center of the pumping chamber, wherein the semi-rigid material forms a column of three spokes; and

b) disposing the at least one non-rigid material as an outer layer around the semi-rigid material, wherein the at least one non-rigid material forms at least three channels between the at least one non-rigid material and the semi-rigid material when the at least one non-rigid material is collapsed.

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