Aug. 26, 1958 J. F. TAPLIN 2,849,026

FLEXIBLE FLUID SEALING DIAPHRAGM

Filed Dec. 12, 1955 3 Sheets-Sheet 1

Fig. 1.

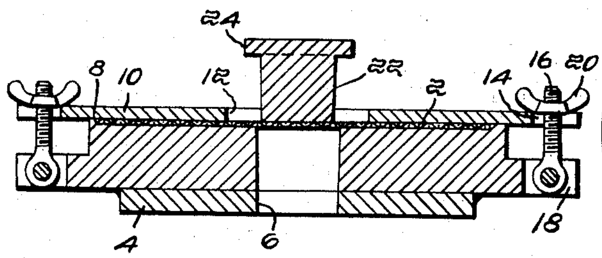

Fig. 2.

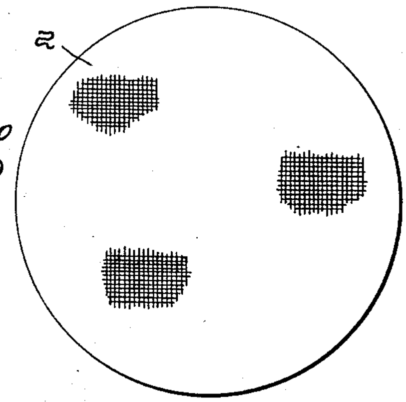

Fig. 3.

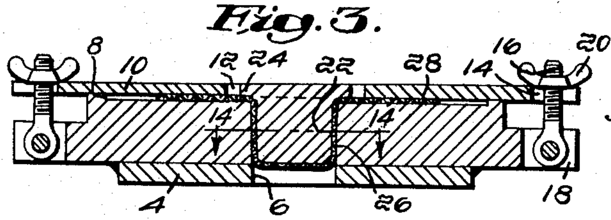

Fig. 4.

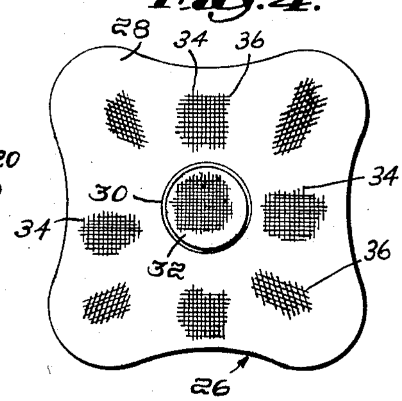

Fig. 7.

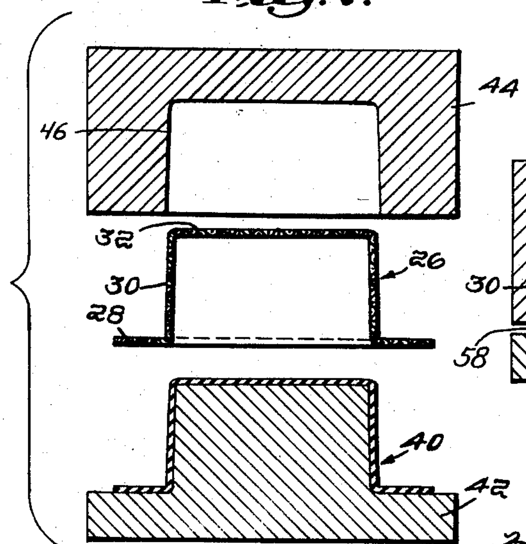

Fig. 8.

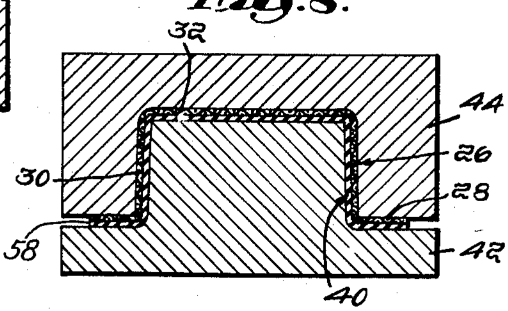

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Fig. 5.

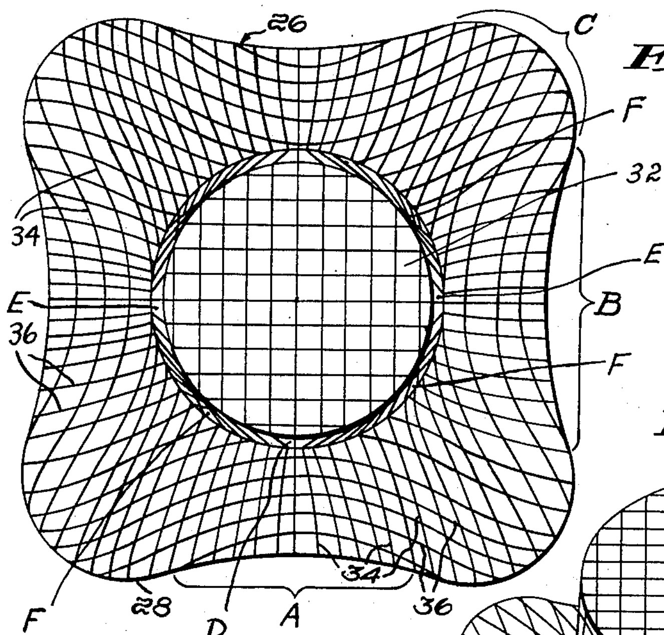

Fig. 6.

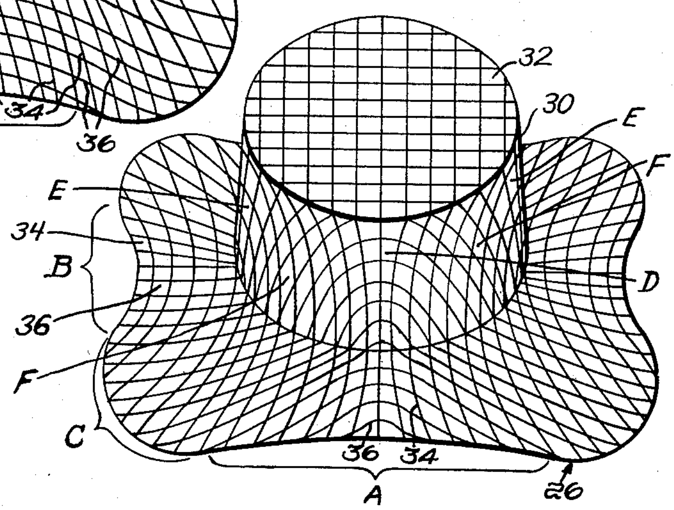

Fig. 12.

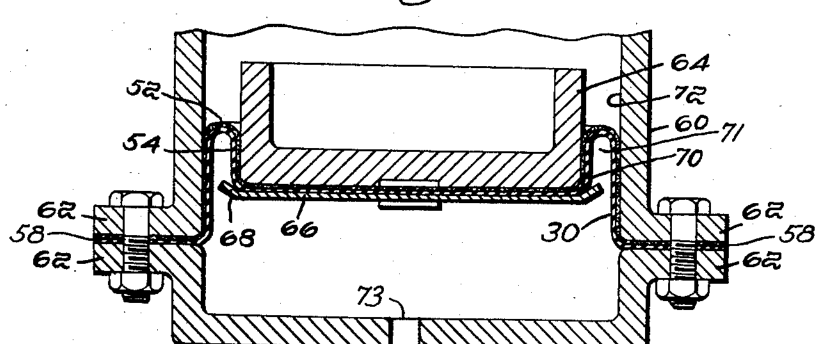

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Fig. 9.

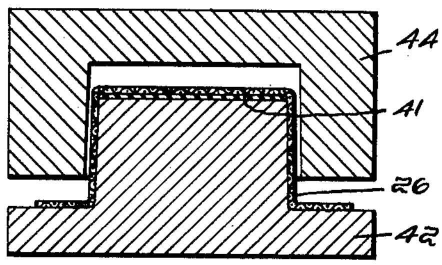


Fig. 11.

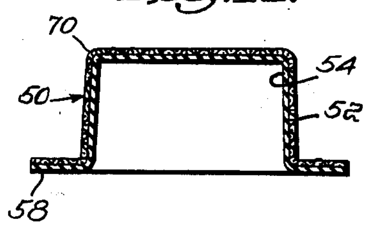
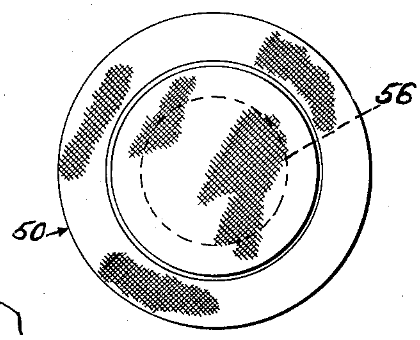


Fig. 10.



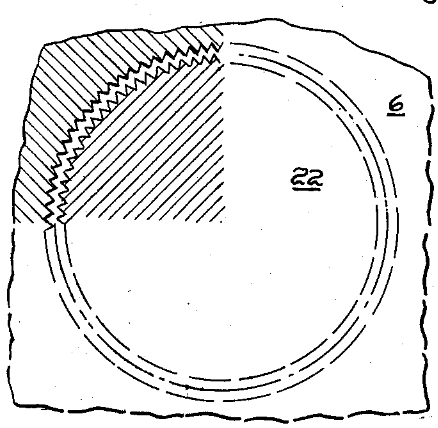
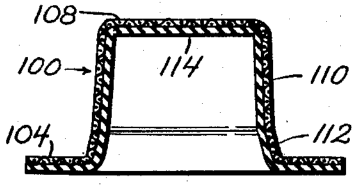


Fig. 14.

Fig. 13.



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2,849,026

FLEXIBLE FLUID SEALING DIAPHRAGM

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Application December 12, 1955, Serial No. 554,756
6 Claims. (Cl. 137—795)

This invention relates to diaphragms for use in pressure responsive systems and more particularly to diaphragms exhibiting high sensitivity and providing a uniform response to pressures applied thereto and so constructed and mounted as to provide a rolling-type seal whose mean effective area is constant as it is displaced.

Diaphragms have long been used for transforming a pressure into an actuating force for controlling a mechanism. However, application of diaphragms has been limited for various reasons, chief among these being (1) variations in the mean effective area of the diaphragm throughout the operating stroke, (2) difficulty in fully obtaining the desired stroke, (3) excessive wear, (4) reduced flexibility of the diaphragm because of attempts to strengthen the material to prevent it from rupturing, (5) introduction of a spring gradient when the material was preformed to a desired diaphragm shape, and, (6) excessive cost due to inefficient methods of manufacture.

Accordingly it is an object of this invention to provide an improved diaphragm that is free positioning with complete relaxation at all points within its operating stroke limits.

It is another object of this invention to provide a diaphragm of deep convolution construction that can be repeatedly moved through a relatively large stroke without excessive wear and which exhibits frictionless rolling action as it moves from piston to cylinder or vice versa when subjected to varying pressures.

Another object of this invention is to provide a diaphragm that can be doubled upon itself in a sharp bend or fold when installed in a linear pressure actuating mechanism and which when so mounted is sensitive to slight variations in pressure and permits achievement of a constant pressure-force ratio through the entire operating stroke of the mechanism.

A further object of this invention is to provide a diaphragm whose extensibility is predeterminately limited to provide a constant effective working area.

Another specific object of this invention is to provide methods of making diaphragms having novel structural characteristics permitting achievement of the foregoing objects. Method claims directed to subject matter disclosed herein are being prosecuted in my copending applications Serial Nos. 623,607 and 623,608, and in my divisional application entitled "Method of Making Flexible Fluid Sealing Diaphragm" and Filed April 4, 1958.

These and other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figs. 1 and 3 present sectional views in elevation of apparatus for molding diaphragms according to a first method;

Fig. 2 is a plan view of a fabric blank useable with the device of Figs. 1 and 3;

Fig. 4 is a plan view of the fabric blank after being molded by the device of Figs. 1 and 3;

Fig. 5 is an enlarged plan view similar to Fig. 4 showing how the threads of the fabric have been rearranged during the molding step;

Fig. 6 is an enlarged view in perspective of the same fabric after molding;

Figs. 7 and 8 illustrate a first method of coating the molded fabric to render it impervious to fluid;

Fig. 9 illustrates a second method of coating the molded fabric;

Fig. 10 is a plan view of the completed diaphragm;

Fig. 11 is a sectional view in elevation of a completed diaphragm;

Fig. 12 is a sectional view in elevation of a diaphragm constructed according to this invention mounted between a cylinder and a piston;

Fig. 13 is a sectional view in elevation of a modified embodiment of a diaphragm according to the invention and having a double frusto-conical wall;

Fig. 14 is an enlarged sectional view taken on the line 14—14 of Fig. 3 showing axial corrugations in the male and female members of the mold.

While diaphragms constructed according to the present invention are capable of several distinguishable embodiments as for example those explained hereinafter, nevertheless, several factors or characteristics are common to all of the particular embodiments herein described. Each such embodiment has the general shape of a hat, comprising a cylindrical or slightly conical wall having a flat head or flange portion extending transversely inwardly from the top thereof and a flange portion extending radially outward from the bottom of said wall. The flange portions or means referred to form diaphragm attaching means; in referring to flanges or flange means herein it is of course intended to refer to obvious equivalents even though such flange means may be of varying cross sectional shape. The flat head portion may be annular or entirely closing the circumferential wall. Each hat is formed of unseamed homogeneous fabric and through various novel expedients the cylindrical or conical wall has substantial dimensional stability longitudinally and predetermined dimensional extensibility circumferentially. Each hat, having a cylindrical or conical wall, is circular in cross section; as used herein the expression "circular cross section" refers to such embodiments, which are characterized by a single generally circular configuration in cross section. By way of contrast, in use these hat shaped diaphragms are bent over into a reverse configuration which would be characterized at certain cross sections thereof (see, for example Fig. 12) by an annular or ring-like rather than circular configuration. In addition each hat is treated to render it impervious to fluid under pressure. Generally this is accomplished by coating the fabric with an impervious elastomer.

Referring to the drawings, Figs. 1 through 11 illustrate a first type of novel diaphragm having the aforesaid characteristics and the preferred methods of making it. In this case the diaphragm is constructed from a blank of flat woven or loomed fabric 2 (Fig. 2). Such fabric is made up of interlocking fibers, as is also, for example knitted fabric. Preferably the blank is circular, but it may be otherwise. The minimum value of the diametrical dimension of the circular blank (or side dimension in the case of a non-circular blank) depends upon the size of the hat-shaped diaphragm desired to be formed. Preferably it is at least equal to twice the diameter of the cylindrical wall plus twice the height of said wall plus twice the width of the outwardly extending flange of the diaphragm. A blank cut to the proper size as determined by the foregoing formula is placed in a molding die 4 (Fig. 1), having a cylindrical or slightly conical cavity or hole 6 and a countersink 8. The diameter of cavity 6 is substantially equal to the outside diameter of the cylindrical wall of the hat to be formed. The diameter of countersink 8 is sufficiently large to receive blank 2. A plate 10 having a central opening 12 of diameter intermediate in value to the diameter of cavity 6 and countersink 8 is then placed on top of blank 2. Plate 10 has fingers 14 adapted to receive therebetween eye bolts 16 which are pivotally connected to peripheral extensions 18 of die 4. Bolts 16 are threaded to receive wing nuts 20 which cooperate with these bolts to clamp plate 10 to die 4. Nuts 20 are tightened to bring plate 10 into intimate contact with blank 2, i. e., until the spacing between plate 10 and countersink 8 is equal to or slightly less than the thickness of the blank before plate 10 is placed upon it. The pressure of plate 10 on the fabric blank is not however sufficient to prevent sliding movement of the blank when a suitable force is applied to the blank.

Thereafter a hot cylindrical male die 22 having a peripheral flange 24 is brought into engagement with blank 2 forcing it downwardly into cavity 6 into the position shown in Fig. 3. Male die 22 is identical in shape to cavity 6, but its diameter is less than the diameter of cavity 6, differing therefrom by an amount equal to twice the thickness of blank 2. This difference in diameter is critical. If, when as illustrated, a single blank is deformed, the difference in diameter between male die 22 and cavity 6 is more than twice the thickness of blank 2, the fabric will tend to double upon itself when forced downwardly into the constriction of cavity 6. If the difference is less than twice the thickness of blank 2, the fabric is forced into the cavity only with considerable difficulty and possible rupture. Peripheral clearance between the male and female dies is thus made as great in amount as possible while remaining still insufficient to allow the quantity of fabric deformed therebetween to double upon itself. During this operation the blank is drawn by the male die into the cavity and, under the influence of the heat and pressure applied thereto by the male die, its central portion assumes the shape of the space between male die 22 and the cavity 6.

As stated hereinabove plate 10 is clamped against blank 2 only to the extent necessary to keep the fabric flat while still permitting it to be drawn radially inward toward cavity 6. This factor in combination with the critical spacing between cavity 6 and male die 22 causes the fibres of blank 2 to be rearranged in a unique manner by the dies.

The blank, which was initially circular as in Fig. 2, is molded into the shape of a hat 26 which as seen in Figs. 4, 5, and 6, now has a substantially rectangular peripheral flange 28, a cylindrical, tubular or conical portion 30, and an end portion 32. In Figs. 5 and 6, the warp and filling threads have been widely spaced for ease of illustrating the behaviour of the threads as the hat is formed. It will be understood, however, that the blank 2 is a closely woven fabric and that all the threads therein follow the pattern assumed by the illustrative threads 34 and 36 of Figs. 5 and 6.

The configuration of the hat is a result of rearrangement of fibres and not because of stretching of the individual fibres. The latter situation is carefully avoided to allow the fibres to retain their inherent resiliency so as to be able to withstand rapid and large fluctuations in pressure.

The circular blank has been use as it illustrates most plainly the rearrangement of the fibres. Of course, blanks of other starting shapes may be used in practice for the initial rim configuration is immaterial and is removed by subsequent trimming.

Referring to Figs. 5 and 6 it is seen that the peripheral flange portion 28 of the hat formed from flat circular blank 2 has the general configuration of a square with its sides slightly bowed inwardly at their midpoints. This configuration is due to the fact that the proximity of the male and female dies causes the blank to be stressed in a direction parallel to the axis of cavity 6 and compressed circumferentially of cavity 6 thereby producing rearrangement of the fibres. Since the fabric comprising the cylindrical portion of the hat has been circumferentially compressed and axially extended by rearrangement of the fibres, the warp threads 34 at A are substantially straight, having been axially dislodged to only a slight degree while the filling threads 36 at A are curved, having been rearranged by circumferential compression of the cylindrical part of the fabric, and now lie at an oblique angle to the warp threads. When the expression "in compression" is used herein, there is always referred to the condition described generally in this paragraph, involving forcing fabric between simple male and female dies.

For this reason the flange at A and the cylindrical part at D is substantially non-stretchable in the direction of the warp, but extensible in the direction of the filling.

A similar situation exists at B substantially 90° removed from A. In this case, it is the filling threads 36 that have been maintained in their original linear relationship and the warp threads 34 that have been bowed or rearranged by compression. Consequently, the flange at B and the cylindrical part at E is extensible in the direction of the warp and substantially non-stretchable in the direction of the filling.

A slightly different situation exists at C. Here the fabric has been stressed by a force axially of cavity 6 and compressed by a force circumferentially of cavity 6, pulling both the warp and filling threads from their normal mutually perpendicular arrangement to a new biased, mutually oblique arrangement to form a generally diamond-shaped pattern, as shown in both Figs. 5 and 6. Here again the flange and the cylindrical part at F is non-extensible radially and axially but expansible circumferentially.

In summary, with respect to the cylindrical or slightly conical wall 30 of the hat, it is seen that the warp and filling threads comprising the cylindrical or slightly conical wall have also been rearranged from their original mutually perpendicular arrangement in the flat blank 2. The portion of the wall D comprises substantially straight warp threads and bowed filling threads. The reverse situation exists in the portion of the wall E where the filling is straight and the warp bowed. In the biased portion F the warp and filling threads are obliquely arranged, having been stressed axially and compressed circumferentially. Consequently the cylindrical wall 30 is stretchable circumferentially but not axially. The extensibility of the wall is a minimum adjacent the top and a maximum adjacent the rim.

Referring now to the top or end portion 32 of the hat, it is seen that it differs substantially from the flange and wall portions. The top or end of the hat comprises warp and filling threads which are still in their original mutually perpendicular arrangement. Consequently, the top or end of the hat will be non-extensible in all the directions as the axial forces to be applied along the wall portion will be equal, thus to hold the end portion undeformed. The circumferential extensibility of the flange portion of the hat is likewise not objectionable. The reason for this is that the diaphragm when mounted in a suitable actuator device is clamped at its peripheral flange and end portion, leaving the circumferential wall portion free to respond rapidly to fluctuations in pressure.

After the fabric hat 26 has been formed from blank 2, it is treated with a suitable material to render it impervious to fluids. Preferably, this is accomplished by separately forming a similar hat 40 of a suitable elastomer. Thereafter, as shown in Figs. 7 and 8, the elastomer hat 40 is positioned on the upstanding plug of a heated mold 42. The fabric hat 26 is placed over the elastomer hat, and a complementary mold 44 having an internal cavity

46 is brought into engagement with the fabric hat clamping it and the elastomer hat tightly against the heated mold 42. Due to the heat and pressure of the molds the elastomer flows into the interstices of the fabric and sets. Thereafter, the diaphragm is removed and its outwardly extending flange trimmed to the required size. The finished diaphragm, designated generally at 50, appears as shown in Figs. 10 and 11 ready for use. The numerals 52 and 54 designate the cloth and the elastomer sides of the diaphragm respectively and 58 designates the finished rim. If desired a circular hole may be cut in the end of the hat as shown by the dotted line 56 in Fig. 11 so as to leave an inwardly extending annular flange.

Instead of coating the fabric hat by forming a similar hat of a suitable elastomer and thereafter molding them together, as illustrated in Figs. 7 and 8, a different procedure can be followed, as shown in Fig. 9.

A small elastomer slug or pellet 41 is placed on the post of mold 42, and a fabric hat 26 constructed as previously explained is placed over the pellet. Thereafter heated female die 44 is brought into engagement with the fabric hat. The heated molds soften the elastomer, causing it to run down the sides of the post and into the interstices of the fabric. It is allowed to set. When removed and trimmed, the finished product is as shown in Figs. 10 and 11.

Fig. 12 illustrates how the diaphragm is used. The outwardly extending flange 58 of the hat shaped diaphragm is clamped between complementary flanges 62 of the cylinder 60 of a pressure actuator unit. The central head portion of the hat is secured against a piston 64 by a plate 66 which preferably has a peripheral flange 68 to hold the diaphragm against the piston. The fabric or convex side 52 of the diaphragm is mounted adjacent the piston and the elastomer or concave side 54 of the diaphragm is mounted against the plate. At the portion 70 of the head and cylindrical portions, the hat is reversed so that the cylindrical portion is now 180° removed from its original position relative to the head portion, thus permitting the formation of a deep convolution as at 71.

Since there is no preformed convolution there is essentially no spring gradient in the diaphragm when working through its operating stroke. The air or other fluid pressure entering the cylinder through opening 73 forces one side of the convolution against the piston and the other side against inner wall 72 of the cylinder, filling the intervening space with fluid. This arrangement substantially eliminates all friction as the piston moves with respect to the cylinder except the internal friction of bending the diaphragm at its fold, which is either so slight as to be negligible, or capable of being compensated for in calibrating the actuator. Because the wall portion 30 of the diaphragm is circumferentially expandible, as the piston carying the inner portion of the diaphragm moves relative to the cylinder carrying the outer portion, material is payed off by a rolling action from the inner cylindrical portion to the outer in one direction of piston movement and vice versa in the other. Because the diaphragm is expandible only in a circumferential direction, the mean effective area of the diaphragm remains constant during the operating stroke so as to create a force which varies in direct proportion to the differential pressure thereacross regardless of the particular position of the piston in the stroke.

The pressure upon the diaphragm is sustained for the most part by the wall and head of the piston and the wall of the cylinder. The rest of the pressure is sustained by the diaphragm at its fold or convolution 71. Consequently the only place that the diaphragm is under a pressure tending to stretch or rupture it is at its fold. This stress is very slight, being a function of the radius of the convolution. For this reason the diaphragm thicknesses are ordinarily kept small in the order of .016–.018". Since the wall thickness is small the area of the convolution is small with consequent low fabric stress.

The unsupported area of a typical diaphragm constructed and mounted, as explained hereinabove, is an annular ring only .1" across the convolution, i. e. the radius of curvature of the convolution is approximately .05". Obviously the diaphragm is still subjected to some stress at its unsupported area. However, the diaphragm is well able to sustain it, even when the radius of curvature of the convolution is larger than .05" since as explained hereinabove, the fibres of blank 2, when the blank is molded by the dies, are rearranged but not stretched, to a position of axial non-extensibility. Consequently, the fibres retain their natural resiliency and, not having been stretched to or near their elastic limit and set at that point, they are well able to withstand the pressures applied thereto at the unsupported area.

Diaphragms constructed as explained hereinabove have been found to have a controlled area that is constant within 0.1% or less, have essentially an unlimited life under normal design conditions, have substantially frictionless rolling action, and withstand temperature variations from minus 65° F. to plus 600° F. and variations in pressure from zero to 500 p. s. i.

While preferably the fabric hat is so formed that its free circumference is sufficiently large to fit around the cylinder of the actuator without substantial stretching of the cords thereof, it should be understood that it may be formed with a circumference smaller than the cylinder bore by providing fine axial surface corrugations in the male and female members 22 and 6 of Figs. 1 and 3 (see Fig. 14). Thus the finished hat by virtue of the added corrugations which run parallel to the longitudinal axis, has more circumferential stretchability than the previously described construction.

Fig. 13 illustrates a modification in which the wall is double conical, being made up of two integral frustums of cones 110 and 112, the frustum 110 connecting with the frustum 112 at the largest diameter of the former and the smallest diameter of the latter, the frustum 110, being the portion of the wall in which most rolling action will take place, having a lesser taper than the frustum 112, since circumferential expansion takes place more easily than circumferential compression.

Preferably the diaphragms constructed according to the present invention are made from nylon when designed to be used below temperatures of 210° F. In the temperature range of 210° F. to 260° F., Orlon fabric is preferred. At higher temperatures glass cloth is used, the maximum temperature being limited in this case by the elastomer. Diaphragms constructed of glass cloth coated with a Silastic elastomer are satisfactory for sustained operation up to a temperature of 500° F. and operate satisfactorily when exposed for a brief period of time to temperatures as high as 600° F.

It will also be understood that any ballooning of the diaphragm at the convolution area is precluded by the presence of the circumferentially extending threads which act to stop any incipient separation of the longitudinally extending threads before unbalanced forces can develop against the elastomer.

The term "elastomer" is used herein to denote any material such as rubber, synthetic rubber, or like materials capable of rendering the fabric impervious to fluids while at the same time permitting the diaphragms to be rolled into a deep convolution which is free positioning in response to variations in applied pressure.

Obviously other materials well known to persons skilled in the art may be employed, the primary consideration being that the fabric have sufficient tensile strength and resiliency to withstand continued and large variations in pressure and temperature and that the coating material be impervious to fluids and elastic.

I claim:

1. A rolling seal diaphragm with a flexible, fluid-tight

wall portion having a substantially circular cross section, comprising, a layer of fabric of the type having interlocking fibers and having adherent thereto a fluid-tight layer of elastomer, said layer of fabric being non-extensible longitudinally of said wall and in compression circumferentially thereof to provide limited extensibility circumferentially thereof, said wall having a transversely inwardly extending wall adjacent one end and flange means adjacent the opposite end forming diaphragm attaching means, whereby said wall may roll from an inner surface onto a surrounding outer surface of larger perimeter with respect to which said inner surface is axially relatively movable, said fabric layer giving support at the upper limit of said limited extensibility against further stretching, and said fabric layer nowhere in said wall presenting more than a single thickness, whereby said wall is free of mechanically weakening overlapping pleats.

2. The diaphragm of claim 1 in which said fabric layer is cross woven fabric.

3. The diaphragm of claim 1 in which said fabric layer is knitted fabric.

4. The rolling seal diaphragm of claim 1 in which said wall and fabric are circular in cross section, in which said fabric is woven fabric circumferentially in compression, and in which warp threads extend longitudinally of said wall at two places 180 degrees apart and fill threads extend longitudinally of said wall at two other places each 90 degrees away from each of said longitudinal warp threads, warp threads on each side of each longitudinal warp thread being at an angle to longitudinal increasing to a maximum 90 degrees away, at the intersection with a said longitudinal fill thread, and fill threads on each side of each longitudinal fill thread being at an angle to longitudinal increasing to a maximum 90 degrees away, at the intersection with a said longitudinal warp thread, whereby warp threads toward a longitudinal fill thread are arched with respect thereto, fill threads toward a longitudinal warp thread are arched with respect thereto, and intermediate each longitudinal warp and each longitudinal fill thread is an area at which fill and warp threads are oblique to each other to form a generally diamond-shaped pattern.

5. The diaphragm of claim 1 in which said wall is double frusto-conical, comprising a pair of integral frustums of cones, the largest diameter of one frustum corresponding to the smallest diameter of the other frustum, the first mentioned of said frustums having a lesser taper per inch than the second mentioned.

6. The diaphragm of claim 1 in which said fabric layer is characterized by a multiplicity of axial corrugations, whereby said wall is given additional circumferential extensibility.

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