United States Patent [19]

Bauer

[11] **3,895,746**

[45] ***July 22, 1975**

[54] **POSITIVE EXPULSION TANK**

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[73] Assignee: **Textron Inc.,** Providence, R.I.

[*] Notice: The portion of the term of this patent subsequent to Feb. 10, 1987, has been disclaimed.

[22] Filed: **Aug. 6, 1969**

[21] Appl. No.: **866,049**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 571,938, Aug. 11, 1966, Pat. No. 3,494,513.

[52] **U.S. Cl.** **222/386.5;** 60/39.48

[51] **Int. Cl.** **B67d 5/42**

[58] **Field of Search** 222/386.5; 60/39.48, 259

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Primary Examiner—Samuel Feinberg
Attorney, Agent, or Firm—Bean & Bean

[57] **ABSTRACT**

The telescoped annular bands of a ductile metal bladder are subjected on one side to fluid pressure and caused to unroll along the folds at the ends of the bands so that the bladder is extended into elongate form to expel a usable fluid from a container. The folds are of small radius so that the bands are nested or telescoped in close proximity to each other and those bands subjected to axial and radial compressive forces incidental to the extension of the bladder are stabilized to prevent buckling thereof. The stabilization of intermediate bands subjected to compression is effected mechanically by at least partial support thereof from next inner bands subjected to tension whereas the innermost band, which cannot be thus supported, is stabilized either by forming it so as to be subjected to axial and hoop tension or, if formed to be subjected to compressive forces, either by limiting its length or by reinforcing it with an external rigidifying member.

3 Claims, 9 Drawing Figures

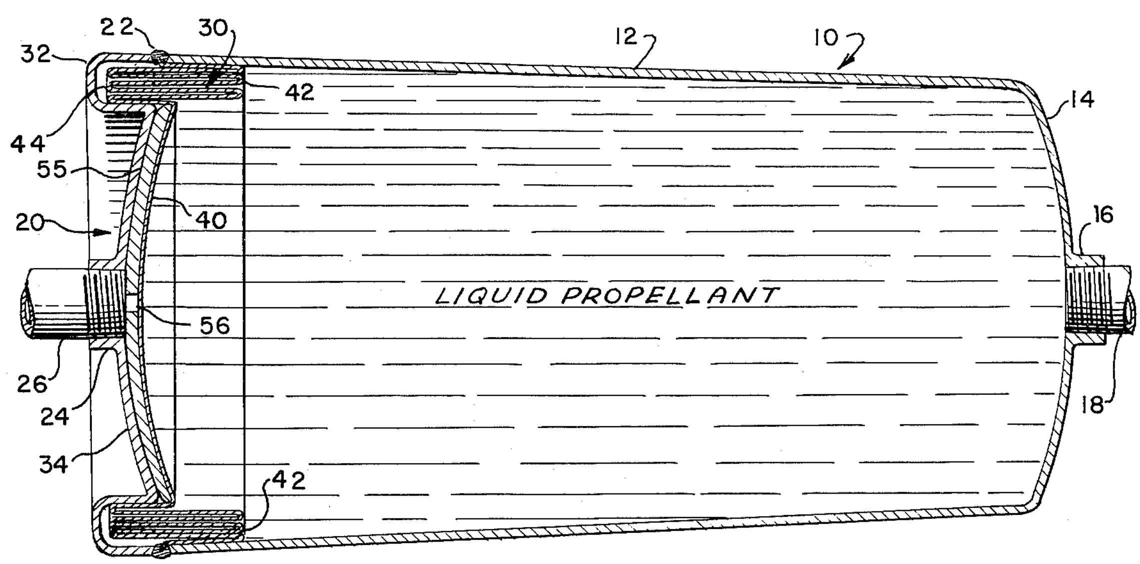

Fig. 1.

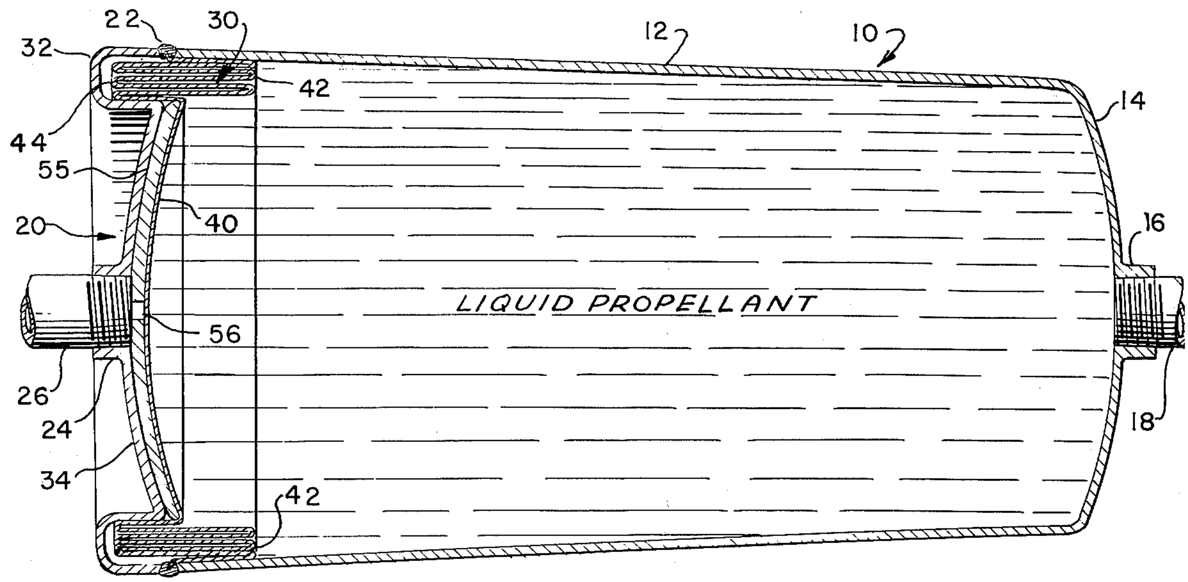

Fig. 2.

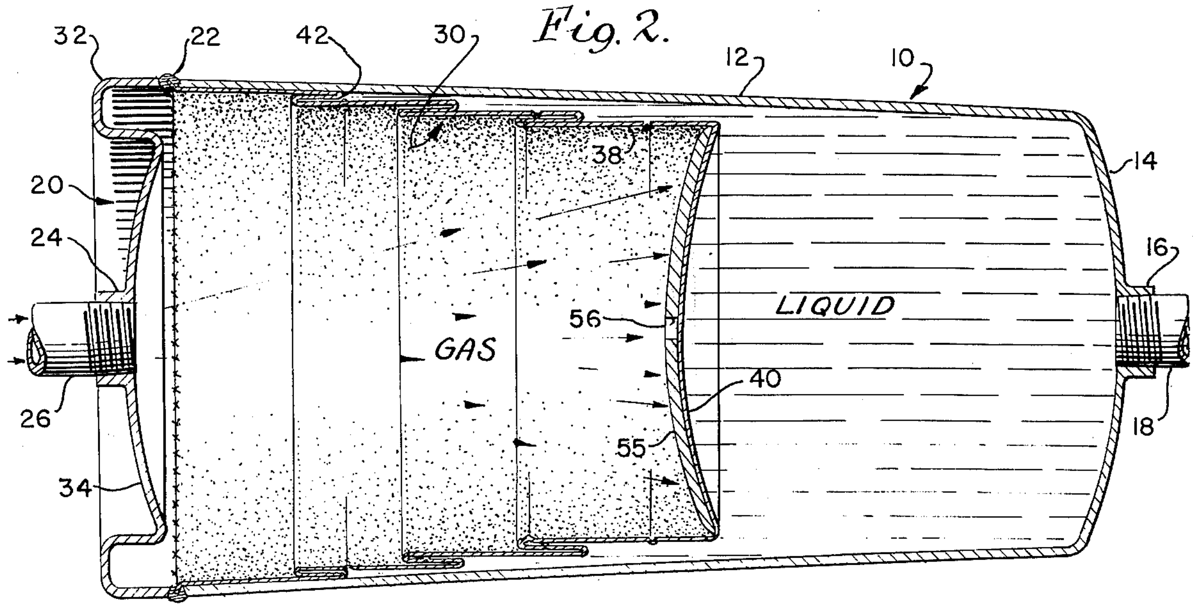

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Fig. 3.

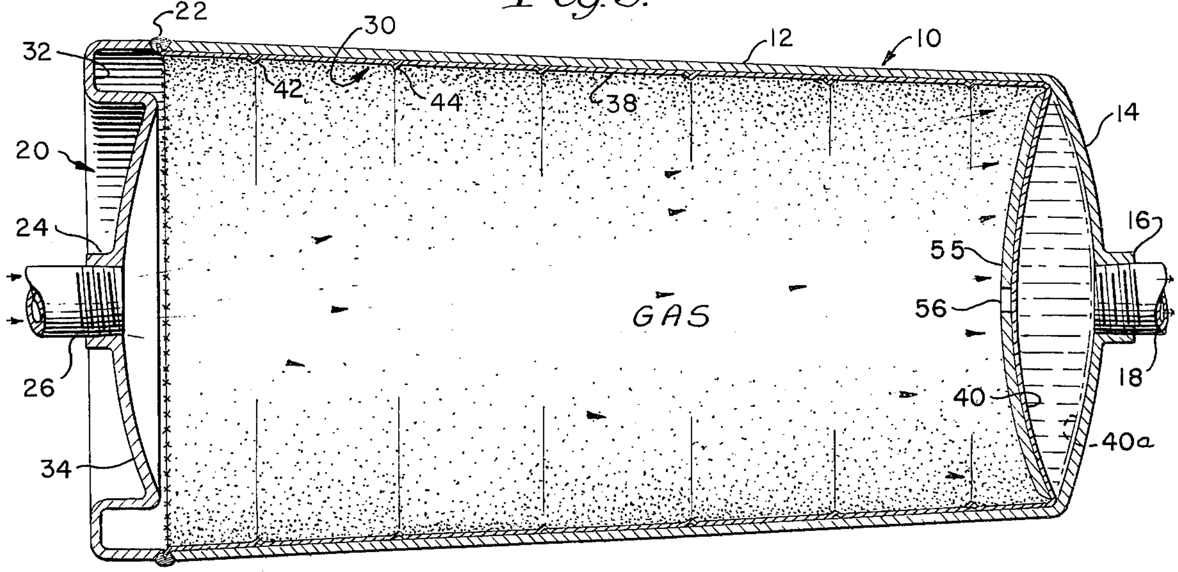

Fig. 4.

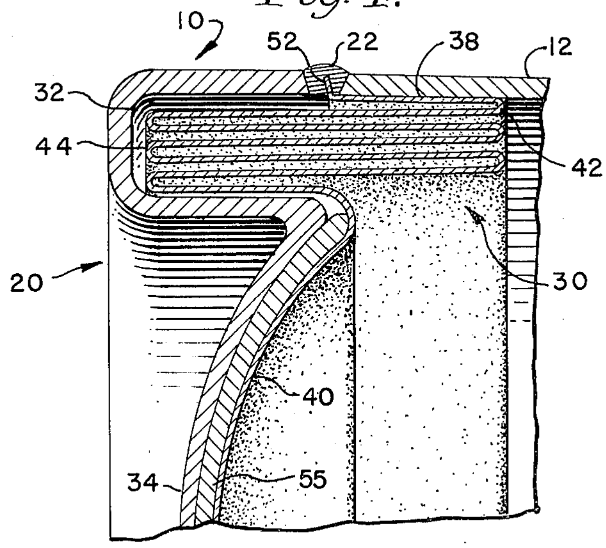

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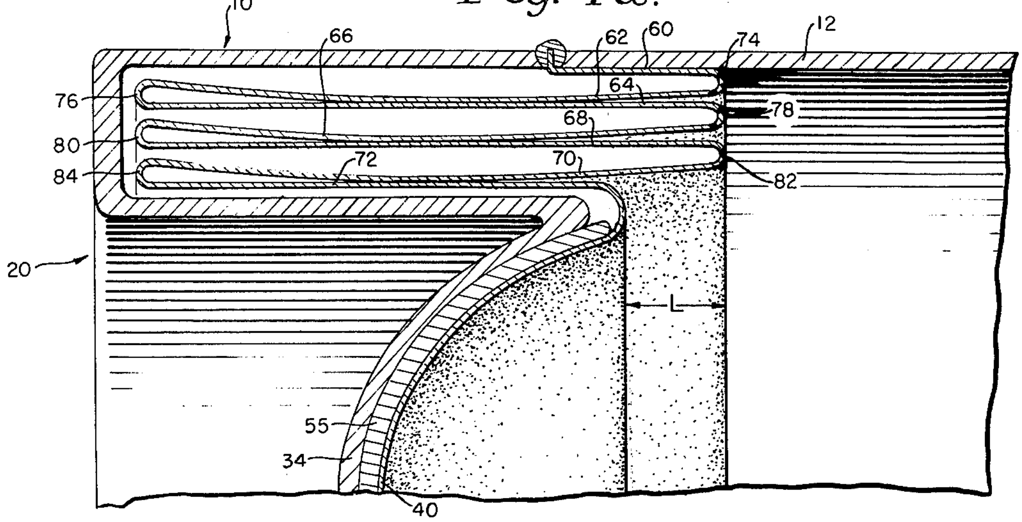
Fig. 4a.



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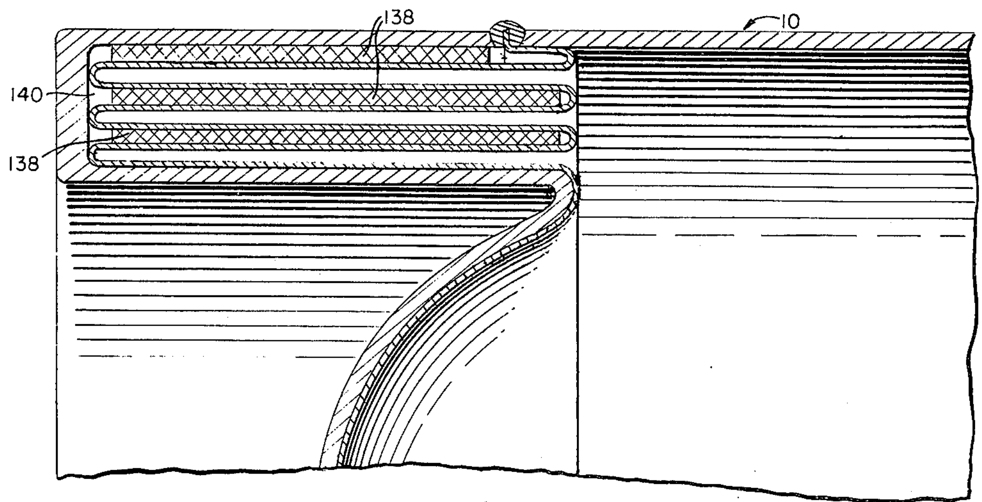

Fig. 5.

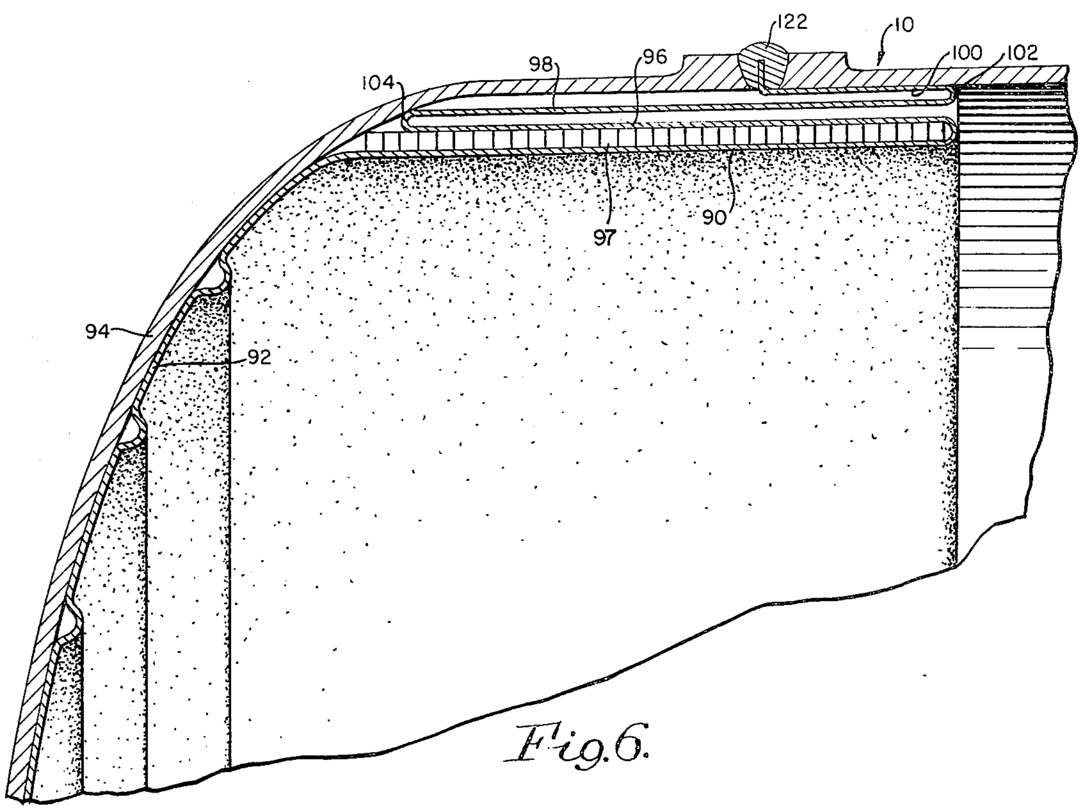

Fig. 6.

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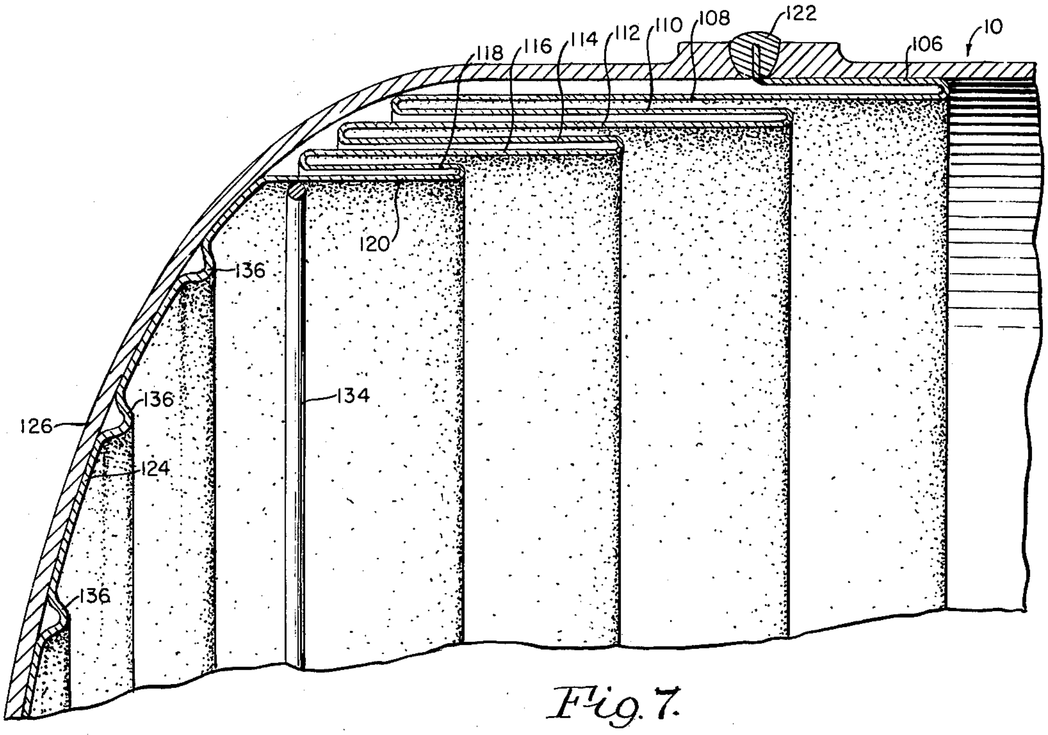

Fig. 7.

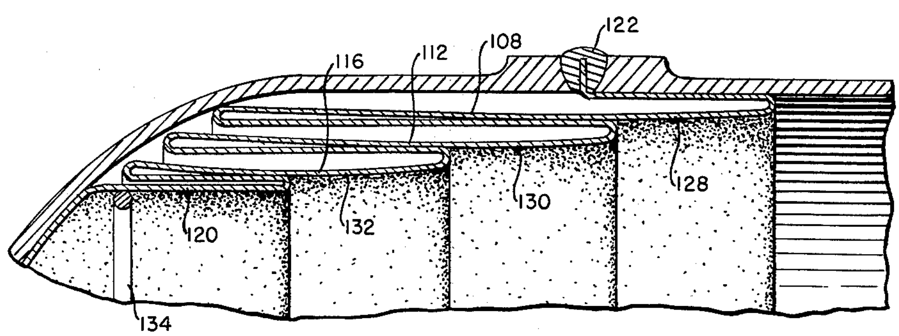

Fig. 8.

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POSITIVE EXPULSION TANK

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of my co-pending application Ser. No. 571,938 filed Aug. 11, 1966 now U.S. Pat. No. 3,494,513.

BACKGROUND OF THE INVENTION

In a spacecraft the fluid propellants are conventionally stored in tanks provided with internal bladders or diaphragms against which pressured gas is applied to expand and displace the bladders, thereby expelling the propellants from the tanks. Basically, it is a problem to provide such systems so that substantially the entire interior of the tank may be occupied with propellant and that substantially all of the stored propellant may be expelled therefrom for its intended use, regardless of attitude in space and/or gravity effects thereon; and also that the pressured bladder parts be chemically compatible with the gas and liquid materials coming in contact therewith.

BRIEF SUMMARY OF THE INVENTION

The present invention relates to a ductile metal bladder or diaphragm initially disposed in telescoped condition and which is subjected on one side to the pressure of a pressurizing fluid to expel the contents of the propellant container. The telescoped annular bands of the ductile metal bladder are alternately subjected to compressive and tension forces. The alternate bands which are subjected to compressive forces are so subjected under the action of axial compressive forces due to the resistance of the metal to the unrolling action and to radial buckling forces due to the pressure of the pressurizing fluid. The construction is such as to assure that the two compressive forces do not exceed the resistance of the bladder material to buckling, whereby the annular bands of the bladder may be extended into cylindrical side wall form so as to expel the propellant with maximum volumetric efficiency.

Stabilization of the bladder to permit its full extension and thus achieve maximum volumetric efficiency is effected. The maximum permissible length of an unsupported portion of an annular band subjected to compressive forces is a function of the diameter of the band, the material thickness and physical properties, and the pressure required to overcome the rolling resistance of the bladder. I have found that when any portion of a compressively loaded band is exposed beyond the next innermost band and is unsupported, its unsupported length must be less than

$$\frac{.56E}{P} \sqrt{Rt} \left(\frac{t}{R}\right)^2 + .657 \sqrt{Rt}$$

where R is the radius of the band in question, t is the material thickness, E is the modulus of elasticity, and P is the required rolling pressure. The outermost band is disposed so as to be in tension while intermediate compressively loaded bands are supported at least in part by their next innermost bands which are in tension. The innermost band may be disposed to be in tension and will thus require no additional stabilization, but the innermost band also may be disposed to be in compression, in which case it either must be of a length less than that described above or provided with external rigidifying means.

The bladder extends or unrolls as a result of a constant axial force, the magnitude of which is a function of the band diameter, wall thickness, material properties and fold radius. From purely stress consideration, it is desirable to make the roll radius large which results in a low rolling pressure. On the other hand, it is necessary to keep the fold radius as small as possible to maintain a high tank volumetric efficiency. It is also critical to select a fold radius which will satisfy the aforementioned requirements and will at the same time minimize the plastic strain requirement of the bladder material during extension, thereby assuring adequate plastic strain margin for any subsequent radial expansion of the bladder. I have found that the minimum practical radius for the folds along which the bladder unrolls is approximately 1.5 times the wall thickness. For those applications where the bladder must expand radially after extension only the outermost fold can tolerate a $1.5t$ minimum radius; a practical limit for the succeeding inner folds having been determined to be approximately 3 times the wall thickness.

BRIEF DESCRIPTION OF THE DRAWING FIGURES

FIG. 1 is a longitudinal section taken along an assembly constructed in accordance with the present invention and illustrating the bladder in its initial condition;

FIG. 2 is a view similar to FIG. 1 but showing the bladder partially extended;

FIG. 3 is a view similar to FIGS. 1 and 2 but showing the bladder in its fully extended position;

FIG. 4 is an enlarged view showing details of the bladder in its initial condition;

FIG. 4A is a view similar to FIG. 4 but showing the effects of the pressurizing fluid on the bladder assembly;

FIG. 5 is a view similar to FIG. 4 but showing a modification of the invention;

FIG. 6 is a view similar to FIG. 5 but showing a further modification of the invention;

FIG. 7 is a view illustrating a still further modification of the invention; and

FIG. 8 is a view similar to FIG. 7 but illustrating the effect of the pressurizing fluid on the bladder construction.

DETAILED DESCRIPTION OF THE INVENTION

As illustrated herein by way of example, the liquid storage and positive expulsion package of the invention may comprise a generally cylindrically shaped tank **10** having a rigid cylindrical wall section **12** closed at one end by a bell-shaped end wall **14** which is fitted with a liquid outlet portal **16** into which a delivery conduit **18** is connected. At its other end the tank **10** is closed by means of an end cover wall **20** which is welded to the cylinder wall **12** as indicated at **22** as will be explained hereinafter. The end bell **20** is formed with a gas inlet portal **24** to which connects a pressured gas supply conduit **26**.

The tank **10** is provided interiorly thereof with a special rolling-telescopic type bladder as indicated generally at **30**, which is formed of sheet metal or the like as will also be more fully explained in detail hereinafter. When in extended form the device is of a closed-end cup-shaped configuration dimensioned so as to fit into and closely conform to the inner cylindrical wall and discharge end wall portions of the tank. Thus, as illustrated at FIG. 3, when the open end lip portion of the bladder **30** is fixed to the intake end of the tank wall structure and the bladder is extended, it comprises a lining device closely hugging the interior of the tank. The end wall member **20** of the tank structure includes a perimetrically located annular recess portion as indicated at **32**, surrounding the dish-shaped main body portion **34** thereof. The recess **32** accommodates in nested relation therein the bulk of the bladder structure when the latter is compacted into inoperative position as shown in FIGS. **1** and **4**, as will also be explained more fully hereinafter.

The bladder **30** may be fabricated by the impact extrusion process, explosive forming or other well-known methods of seamless construction thus forming the walls **38** and the head piece **40** of one piece. The head portion **40** is then pressed through the center of the cylindrical wall portion **38** until the traveling perimetric fold line between the pressed-in portion and cylindrical wall portion **38** arrives at a position such as indicated at **42**, FIGS. **1**, **4**. The press operation is then reversed whereby the closed end section **40** of the bladder is again pushed through the center thereof but in opposite direction, until such time as the newly formed traveling fold line reaches a position such as is indicated at **44**, FIGS. **1**, **4**. Thus, as accordion-pleated appearing (in section) folding of the cylindrical wall portion of the bladder is initiated; and this operation is repeated until such time as all of the side wall material of the bladder is compactly pleated as shown in FIGS. **1** and **4**. The material of the bladder structure will of course be appropriately annealed from time to time as the operation indicates the need.

To assemble the device of the invention the bladder **30** is first prepared in fully pleated form as explained hereinabove and is then slip-fitted into the open end of the tank **10** prior to welding of the end cover **20** thereon. It is preferred to "spin" the extreme lip portion of the bladder device into an outwardly flared configuration as best illustrated at **52** (FIG. **4**) whereby the bladder device is precisely positioned incidental to assembly relative to the tank structure. Also, it will be appreciated that when the end cover **20** is then moved into position for welding to the tank cylinder wall **12**, the end lip **52** of the bladder will be sandwiched therebetween to become incorporated in the weldment **22** which thereupon interconncts the parts in fluid-tight pressure-resistant relation. Prior to such assembly of the end cover **20** on the tank a substantially rigid dish-shaped head member **55** is set loosely in place against the central inside surface of the cover member **20** between the bladder and the cover **20**. The head member **55** is centrally apertured as indicated at **56**.

Referring now more particularly to FIG. 4a, the outermost band is indicated by the reference character **60** therein whereas the next innermost band is indicated by the reference character **62**, the next band by the reference character **64** and so on for the bands **66**, **68** and **70**, the innermost band being indicated by the reference character **72**. The successive fold lines leading from the outermost band **60** successively to the innermost band **72** are indicated successively by reference characters **74**, **76**, **78**, **80**, **82** and **84**. It will be appreciated that axial and radial forces are acting on each of the bands due to the pressure of the pressurizing fluid, one such force being due to the resistance of the folds to unrolling and producing the axial forces and the other being produced by the pressure of the pressurizing fluid acting against the exposed surfaces of the bands. Thus, in the configuration shown in FIGS. **1–4**, and as is illustrated in FIG. **4***a*, the innermost band **72** will be subjected to axial tension and hoop tension and the outermost band **60** will likewise be so subjected to axial and radial tension. The alternate inwardly disposed bands **64** and **68** will likewise be subjected to axial and hoop tension whereas the remaining bands **62**, **66** and **70** are subjected to axial compression and radial compression causing these remaining bands **62**, 66 and 70 to deform inwardly in the fashion illustrated in FIG. 4a under the action of the pressurizing fluid. It will be noted that a portion of the band **70** is exposed beyond the innermost band **72** as indicated by the reference character L and I have found that the length of this exposed portion of any band which is otherwise unsupported must not exceed about

$$\frac{.56E}{P} \sqrt{Rt} \left(\frac{t}{R}\right)^2 + .657 \sqrt{Rt},$$

where R is the radius of the band in question, t is the material thickness, E is the modulus of elasticity, and P is the required rolling pressure. If this length is exceeded, the band in question may deflect inwardly sufficiently to prevent the next innermost band from unrolling therepast and a localized buckling and overlapping of interlocked metal layers will result which prevents the diaphragm from attaining its fully extended length, and thus will detract from the volumetric efficiency of the device. Thus, insofar as FIG. **4***a* is concerned, the exposed portion of the band **70** is unsupported whereas the remaining portion thereof is stabilized by the rigidity of the tensioned innermost band **72** which mechanically supports it. The innermost band **72**, on the other hand, is stabilized by virtue of the tension forces existing therein due to the pressure of the pressurizing fluid and the same is true for the bands **68** and **64**, both of which latter bands because they are coextensive in length with the compressively loaded bands **62** and **66**, mechanically support same throughout their lengths and prevent destructuve buckling thereof.

It will also be evident from FIG. 4a that the bands **60**, 64, 68 and **72** which are subjected to tension forces are unrolled along the respective fold lines **74**, **78** and **82** thereby to elongate at the expense of the intermediate bands **62**, and **66** and **70** which are compressively loaded. Thus, the compressively loaded bands become progressively shorter in length from their initial condition so that if they are properly stabilized in their initial state, they will remain so throughout the operation of the extension of the diaphragm. It is important to note that no rolling takes place along the fold lines **76**, **80** and **84** and, for this reason, their radii may be as sharp as is practical to form. To limit the pressure required to unroll along the fold lines **74**, **78** and **82**, however, the minimum radius should be about $1.5t$, where t is the thickness of the material. Larger radii will result in less pressure required to unroll along the fold lines, but volumetric efficiency of the system suffers. Thus, the radii of the traveling fold lines should be about $1.5t$ except in cases where the bladder may expand appreciably into contact with the tank. Since the outermost band will not be required to expand, its radius along the traveling fold will still be made about $1.5t$. For the remaining traveling folds, the radius should be about $3t$ to prevent rupture of the material due to exceeding the plastic strain capabilities thereof. Thus, a tapered tank as shown in FIG. 1 may utilize radii of $1.5t$ for all of the traveling fold lines since little outward expansion of the bladder may occur, whereas a cylindrical tank may require one or more of the inner bands to be formed with traveling fold line radii in the order of $3t$.

In the modification shown in FIG. 6, it will be appreciated that the innermost band 90 of the bladder is not stabilized by the pressure of the pressurizing fluid inasmuch as this innermost band, because of its disposition as shown, will be subjected to axial and radial compressive forces and it will also be appreciated that its length is sufficiently great as to assure that the device ordinarily would buckle due to the pressure of the pressurizing fluid. However, such an arrangement as is shown in FIG. 6 may be beneficial under many circumstances inasmuch as it will appear from the showing that the diaphragm or bladder is very compactly arranged within the container 10 inclusive of the head wall portion 92 thereof which very closely fits the end wall or dome 94 of the container. Stabilization in the case of FIG. 6 is achieved by an annular ring or band of rigidifying material indicated by the reference character 97 and which may take any convenient form, preferably of light weight, and for that reason may be constructed of honeycomb material. The rigidifying or stabilizing band 97 is brazed or otherwise affixed to the outer surface of the innermost band 90 and lends sufficient rigidity thereto as to withstand the axial and radial compressive forces acting thereupon due to the pressure of the pressurizing fluid as to allow the head wall portion 92 to completely reverse itself and pass through the next outermost band 96. In the configuration of FIG. 6, the band 96 will be under tension due to the axial and radial loads thereon whereas the next outermost band 98 will again be in compressed condition with the outermost band 100 again being under tension. Thus, in FIG. 6, the fold line 102 will unroll to shorten the compressed band 98 while correspondingly lengthening the tension bands 100 and 96. At the same time, the head wall portion 92 will tend to reverse itself and in the process will peel away the securement between the rigidifying band 97 and the innermost band 90, the head wall portion 92 ultimately taking a curve opposite to that shown in FIG. 6 when the bladder assembly is fully extended. It will be appreciated from FIG. 6 that the innermost band 90 in this case is stabilized solely by the presence of the rigidifying band 97 whereas the only other band shown which is under compressive forces, the band 98, will be stabilized by virtue of the fact that it is supported by the band 96 which is under tension.

In the modification according to FIG. 7, a combination of pressure and mechanical stabilization is employed for the various bands of the diaphragm system which are subjected to compressive forces by the action of the pressurizing fluid. In the modification shown, the successive bands beginning from the outermost band are indicated by reference characters 106, 108, 110, 112, 114, 116, 118 and 120. It will be appreciated that the volume of propellant which may be displaced by the diaphragm or bladder between its initial and extended positions is a function not only of the diameter thereof but also of the total length of the cylindrical side wall of the extended bladder represented by the accumulative lengths of the individual annular bands thereof. Furthermore, as is shown in FIG. 7, and as is employed to some degree or another in all of the previously described Figures, the point of attachment at 122 of the open free end portion of the bladder along the length of the container 10 also determines the volume of propellant which may be displaced. With the arrangement shown in FIG. 7, the point of attachment 122 may be shifted forwardly a significant amount while the telescoped bands occupy as little space as is possible and define as little volume to the left thereof, in FIG. 7, as is practicable, the head wall portion 124 of the diaphragm according to FIG. 7 again lying in close proximity to the end wall 126 of the container 10. The unsupported length of the innermost band 120 is less than the critically mentioned relationship above mentioned so that this band is inherently stabilized by this relationship but it will be appreciated that the other three bands shown, 108, 112 and 116 which are subjected to compressive forces are of total length materially greater than this critical relationship. However, in each of these cases, the unsupported length thereof as indicated respectively by the reference characters 128, 130 and 132 in FIG. 8 are less than the critical relationship mentioned. The remaining portions of each of these bands is, as is shown in FIG. 8, supported by the next innermost tensioned band in each case.

A rigidifying ring 134 may be provided as shown for the purpose of further rigidifying the innermost band 120 and the end or head wall portion 124 may be provided with a series of concentric deformations 136 to resist localized buckling of the head wall portion 124, a similar arrangement being shown and employed in the FIG. 6 modification.

Regardless of the type of stabilization employed, it may be desirable under some circumstances to provide bands of material such as those indicated by the reference character 138 in FIG. 5 which are not attached physically to the diaphragm or bladder assembly but which are merely slipped between adjacent bands thereof as shown to preserve the integrity of the bands and particularly the folds in the event that a pressure reversal takes place across the diaphragm. That is to say, it is possible that during long periods of storage the propellant contained within the container 10 may be subjected to variations in temperature and the like which would increase its pressure so as to exceed that in the space 140, correspondingly tending to reverse the relations of tension, or compression, of the individual bands. The separating bands 138 will prevent deformation of the bands in this reverse direction and will also serve to damp vibrations which may be imparted to the bladder assembly.

What is claimed is:

1. An expulsion tank assembly comprising, in combination,

a cylindrical container having a portion closed at one end wall and having a storage space therein for a usable fluid to be expelled therefrom,

a telescoped ductile metal bladder defining one end of said storage space and adapted to be extended thereinto to conform closely with the inner surfaces of said container thereby to displace the usable fluid therefrom with high volumetric efficiency, said bladder when extended being of cylindrical form having a cylindrical side wall open at one end and closed at its other end by a head wall portion, said bladder being sealingly secured peripherally around its open end to said container and said side wall of the bladder being initially disposed to present a series of telescoped annular bands, the bands being disposed in close proximity to each other so that the bands successively lead into each other along annular folds of small radius facing alternately toward and away from said storage space and with the innermost band being joined directly to said head wall portion of the bladder, said small radius being set so as not to exceed the ultimate plastic strain capability of the bladder material during expulsion,

means for introducing pressurizing fluid against that side of said bladder facing away from said storage space and at a pressure sufficient to unroll said side wall along those folds facing said storage space to extend said bladder as aforesaid, whereby alternate bands are subjected to axial tension and hoop tension while the remaining bands are subjected to axial compression and hoop compression due respectively in each case to the resistance of the metal to unrolling and the radial pressure of said pressurizing fluid,

each of said bands subjected to axial and hoop tension initially overlapping a next outermost band at least along a length thereof which would not expose a length of such next outermost band therebeyond which is greater than

$$\frac{.56E}{P} \sqrt{Rt} \left(\frac{t^2}{R}\right) + .657 \sqrt{Rt},$$

where R is the radius of the band in question, E is the modulus of elasticity, t is the material thickness, and P is the required rolling pressure,

means for stabilizing said innermost band during extension of the bladder whereby the bladder may attain its fully extended state

the fold line leading from said innermost band to the next outermost band facing away from said storage space whereby said means for stabilizing is constituted by the rigidity of said innermost band as effected by the axial and hoop tension forces acting thereon; and

each of said bands subjected to compressive forces having a portion thereof exposed on said storage space side beyond the next innermost tensioned band.

2. An expulsion tank assembly comprising, in combination,

a cylindrical container having a portion closed at one end wall and having a storage space therein for a usable fluid to be expelled therefrom,

a telescoped ductile metal bladder defining one end of said storage space and adapted to be extended thereinto to conform closely with the inner surfaces of said container thereby to displace the usable fluid therefrom with high volumetric efficiency, said bladder when extended being of cylindrical form having a cylindrical side wall open at one end and closed at its other end by a head wall portion,

said bladder being sealingly secured peripherally around its open end to said container and said side wall of the bladder being intially disposed to present a series of telescoped annular bands, the bands being disposed in close proximity to each other so that the bands successively lead into each other along annular folds of small radius facing alternately toward and away from said storage space and with the innermost band being joined directly to said head wall portion of the bladder, said small radius being set so as not to exceed the ultimate plastic strain capability of the bladder material during expulsion,

means for introducing pressurizing fluid against that side of said bladder facing away from said storage space and at a pressure sufficient to unroll said side wall along those folds facing said storage space to extend said bladder as aforesaid, whereby alternate bands are subjected to axial tension and hoop tension while the remaining bands are subjected to axial compression and hoop compression due respectively in each case to the resistance of the metal to unrolling and the radial pressure of said pressurizing fluid,

each of said bands subjected to axial and hoop tension initially overlapping a next outermost band at least along a length thereof which would not expose a length of such next outermost band therebeyond which is greater than

$$\frac{.56E}{P} \sqrt{Rt} \left(\frac{t^2}{R}\right) + .657 \sqrt{Rt},$$

where R is the radius of the band in question, E is the modulus of elasticity, t is the material thickness, and P is the required rolling pressure,

means for stabilizing said innermost band during extension of the bladder whereby the bladder may attain its fully extended state

the fold line leading from said innermost band to the next outermost band facing toward said storage space whereby said innermost band is subjected to axial and hoop compression forces, said means for stabilizing comprising a structural band surrounding and joined to said innermost band.

3. An expulsion tank assembly comprising, in combination,

a cylindrical container having a portion closed at one end wall and having a storage space therein for a usable fluid to be expelled therefrom,

a telescoped ductile metal bladder defining one end of said storage space and adapted to be extended thereinto to conform closely with the inner surfaces of said container thereby to displace the usable fluid therefrom with high volumetric efficiency, said bladder when extended being of cylindrical form having a cylindrical side wall open at one end and closed at its other end by a head wall portion,

said bladder being sealingly secured peripherally around its open end to said container and said side wall of the bladder being initially disposed to present a series of telescoped annular bands, the bands being disposed in close proximity to each other so that the bands successively lead into each other along annular folds of small radius facing alternately toward and away from said storage space and with the innermost band being joined directly to said head wall portion of the bladder, said small radius being set so as not to exceed the ultimate plastic strain capability of the bladder material during expulsion,

means for introducing pressurizing fluid against that side of said bladder facing away from said storage space and at a pressure sufficient to unroll said side wall along those folds facing said storage space to extend said bladder as aforesaid, whereby alternate bands are subjected to axial tension and hoop tension while the remaining bands are subjected to axial compression and hoop compression due respectively in each case to the resistance of the metal to unrolling and the radial pressure of said pressurizing fluid,

each of said bands subjected to axial and hoop tension initially overlapping a next outermost band at least along a length thereof which would not expose a length of such next outermost band therebeyond which is greater than

$$\frac{.56E}{P}\sqrt{Rt}\left(\frac{t^2}{R}\right)+.657\sqrt{Rt},$$

where R is the radius of the band in quesion, E is the modulus of elasticity, t is the material thickness, and P is the required rolling pressure,

means for stabilizing said innermost band during extension of the bladder whereby the bladder may attain its fully extended state

means interposed between and separating at least some of the adjacent bands for preserving their integrity in the event of pressure reversal across said bladder.

* * * * *