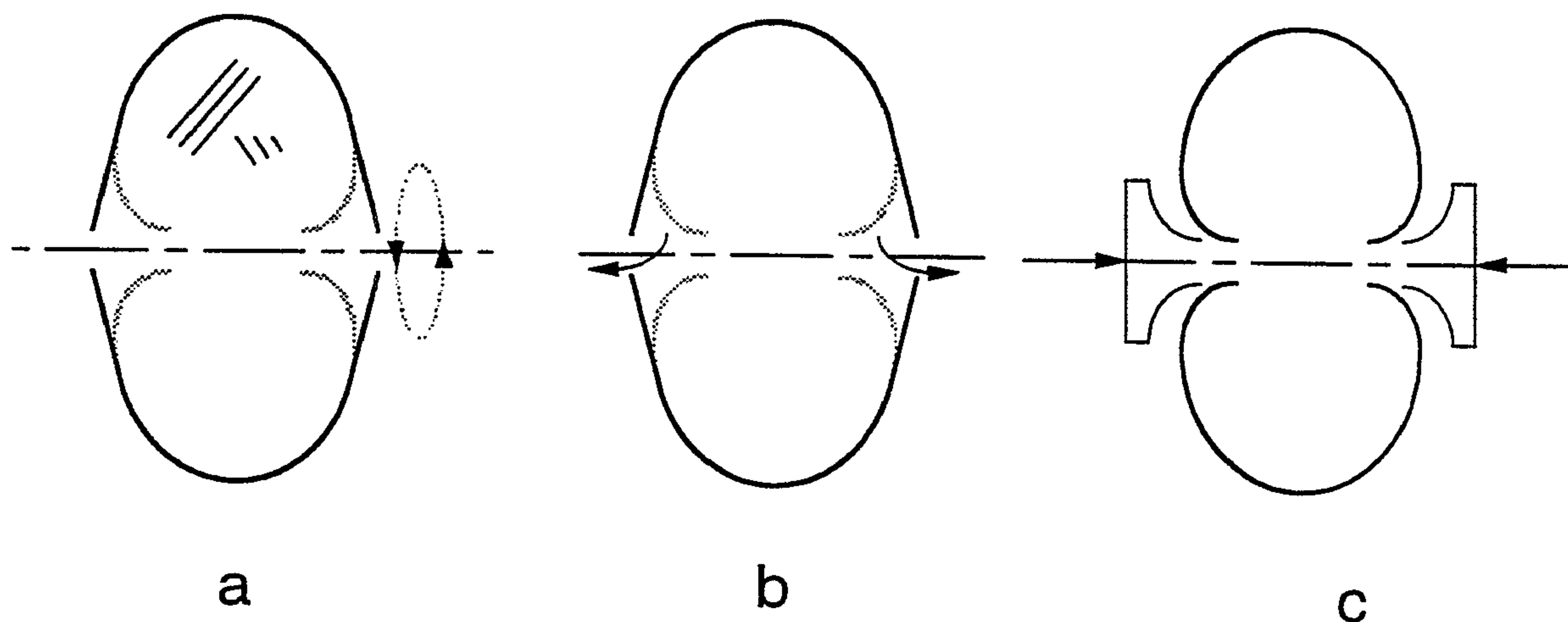




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 (72) Inventeurs/Inventors:
 BEUKERS, ADRIAAN, NL;
 DE JONG, THEO, NL
 (73) Propriétaire/Owner:
 ADVANCED LIGHTWEIGHT CONSTRUCTIONS
 GROUP B.V., NL
 (74) Agent: BORDEN LADNER GERVAIS LLP

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(57) Abrégé/Abstract:

The invention is directed to a wheel-shaped pressure-resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber-reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.



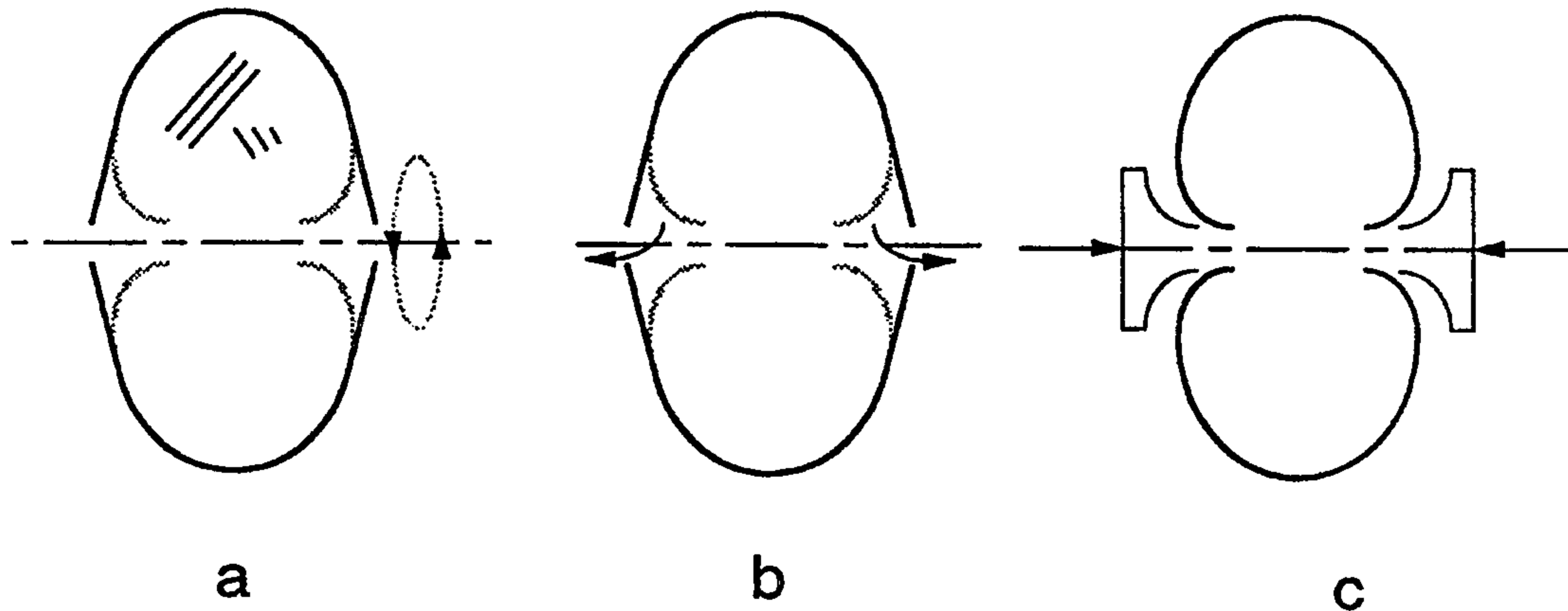
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(54) Title: PRESSURE-RESISTANT VESSEL



(57) Abstract

The invention is directed to a wheel-shaped pressure-resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber-reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.

Title: Pressure resistant vessel

The present invention is directed to a pressure vessel for gaseous, liquefied or liquid materials and the like.

Pressure resistant vessels have been in use for numerous applications, one of them being the use as LPG-container for automotive purposes. LPG being an interesting fuel for automotive purposes, i.a. due to the low price and low emission of environmentally harmful substances, the use thereof has increased substantially over the last decades. However, LPG is a material that has been liquified through pressurisation, with the consequence that the requirements for safety are very high. In view of their relatively low costs, generally steel pressure tanks are used for storage of LPG, said pressure tanks generally being substantially cylindrical and having torispherical domes.

A distinct disadvantage of these LPG containers is their weight and the amount of space they require in a car. In the smaller (compact) cars this weight and especially the amount of space required makes the use of LPG as fuel rather unattractive.

It is an object of the invention to provide a pressure vessel having a relatively low weight, and a shape which makes it better suitable for automotive applications. An other object is to provide a pressure vessel which may be used by a person carrying the vessel, for example on the back.

The invention is based on the development of a wheel shaped vessel, which vessel may have the size of a spare car wheel and which will fit in the area provided for said spare wheel.

The invention is accordingly directed to a wheel shaped pressure resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber

reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell.

5 A preferred embodiment of the invention provides a wheel shaped pressure resistant vessel, comprising a substantially continuous shell of a fiber reinforced elastomeric resin having a central opening, a gas tight, substantially rigid inner lining and an axial member, said substantially
10 continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell and is attached to the rims of the central opening, thereby closing the said central opening.

The shell is comprised of a fiber reinforced resin body.
15 The fibers have been wound along substantially geodetical lines, and the shape of the vessel is designed so that the load is substantially equal everywhere in the fibers (more or less isotensoid). Preferably a combination of relatively stiff fiber re-inforcement and flexible matrix material is chosen,
20 resulting therein, that the design, production and use of the vessel is very tolerant for deviations and stress-concentrations. Deviations of geodetics and/or continuity becomes possible to a certain extent, provided the structural integrity is maintained.

25 The so-called "netting" theory has been used for this design. This theory assumes that in case of the use of stiff fibers in a non-rigid (such as elastomeric) matrix, the influence of the matrix may be discounted for calculating the forces in a system of fibers of a wound construction. This
30 theory is valid when the stiffness of the matrix is negligibly small compared to the stiffness of the fibers. A theoretical report on the development of pressure bodies using the netting theory can be found in the report of the Technical University of Delft, The Netherlands, report VTH-166.

35

Winding the substantially continuous fiber reinforcement along a substantially rotation symmetrical body results then

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in an equilibrium shape that is non-spherical, preferably approximately elliptical, and determined by the form parameter q as defined in the said report. In view of the applicability of analytical methods, such as the netting theory to the present invention, which is justified by the difference in stiffness between the fibers and the matrix, the use of continuous fibers for the winding of the body will lead to the situation where the tension in all the fibers is substantially equal throughout the body (isotensoid).

The shape and size of the vessel is determined by the following differential equation (See also figure 1)

$$\frac{dX}{dY} = \pm \frac{\sqrt{a^2(Y^2 - 1) - (Y^3 + kY)^2}}{Y^3 + kY}$$

wherein

$$X = \frac{x}{y_0}, \quad Y = \frac{y}{y_0}, \quad a = \frac{nF}{\pi p y_0^2}, \quad k = \frac{K}{\pi p y_0^2}$$

F Tension force in the fibres
 K axial load on the poles of the vessel
 X, Y dimensionless co-ordinate axis
 x, y co-ordinate axis
 a constant; describes relation between internal pressure and number of fibres
 k constant; describes relation between internal pressure and polar load
 n number of yarns in cross-section
 p internal pressure
 y₀ polar opening radius

An inflatable body of a somewhat comparable shape has been disclosed in EP-A 626,338.

The essential differences between this known body and the present invention are, among others, the requirement of a rigid shape, preferably provided by the lining and the axial member.

3a

Fig.1 shows the principle equation for designing a pressure vessel according to the present invention;

Figs. 2a-2c show the principle of preparing the shell of the vessel;

Fig. 3 gives the x-y relation of the wound and final shapes; and

Fig. 4 shows the construction of part of the assembled vessel.

The vessel of the present invention may have different constructions, depending on the materials used and the actual requirements on the size, shape and strength.

5 An essential requirement is that the vessel is rigid. This means, that either the shell is rigid, or that the inner lining is rigid. In this context the term rigid is understood to mean, that without internal pressure, the shape of the vessel is substantially maintained.

10 The shell, prepared from fiber reinforced resin, can either be rigid or flexible. In a preferred embodiment the shell is prepared from an elastomeric resin, such as a vulcanised or thermoplastic rubber.

15 The inner lining may also be rigid or thermoplastic. In case the shell is flexible it is essential that the lining is rigid. Otherwise the selection may be made based on criteria of construction and gaspermeability.

20 The axial member may have two functions in the pressure vessel according to the invention. In the first place this member may provide the necessary means for attachment of all accessories or appliances that are required for the actual use as a pressure vessel. It is for example possible to accommodate all said means inside the axial member, or on top thereof. In the second place, and this is much more important, the axial member provides the necessary axial reinforcement of the vessel, by providing a link between the two surfaces of the shell, thus closing the vessel, and pulling the two surfaces together. This latter effect is very important in terms of the shape of the vessel. Without the link the shape would become too much of a balloon to be suitable for use.

30 This axial member may be provided by a separate element, such as disclosed in figures 2^a and 4, or by winding the fiber reinforcement through the opening in the vessel.

35 According to a preferred embodiment the axial member does not extend beyond the planes defining the outmost surface of the shell of the pressure vessel. Thereby the rim of the central opening in the shell is pulled inward, thus creating an actual wheel like shape.

The vessel body has a geometrically continuous shape and substantially no stress concentrations occur, with the exception in the area where the axial reinforcement member holds the two surfaces together. The shape of the body contains substantially no discontinuities in the mathematical sense, with the exceptions discussed above.

To enable the vessel to hold gases or liquids, a gas-tight inner lining is present. This lining is preferably substantially rigid, thus providing the required shape to the pressure vessel. The material of the inner lining will be selected in relation to the intended application. Of course the material has to be gastight at the thickness used, which means that the amount of gas passing through it should not exceed the criteria of the applicable laws and regulations. Suitable values thereof are less than 10 ml/h, independent of surface area.

Furthermore the material must be resistant to chemical influences of the gas or liquid. Finally it must be able to withstand the external forces, that could be exerted on the vessel, such as crash-loads, penetration, indentation and the like. Suitable materials for the inner lining are i.a. the various non-elastomeric ethylene and propylene polymers, PVC and copolymers, as well as metals, such as steel or aluminium.

To protect the vessel against foreign objects, damage, wear, environmental influences, chemicals, such as oils, acids, lye, fats and the like, a protective outer lining may be used. Preferably this outer lining is able to withstand mechanical and thermal abuse without early collapse.

The pressure vessel according to the invention may be used as an LPG container for automotive use, as discussed hereinabove, but also for other applications wherein pressure vessels can be useful. Examples thereof are lightweight, crash resistant pressure vessels, for example for holding hazardous gases or liquids under high pressure, such as gaseous, liquefied or liquid propellants in the aerospace industry. Other applications can be the storage of oxygen or air for rescue workers, fuel for cooking or other equipment, cryogenic

storage (provided a suitable isolation is present, for example in the form of a foam between two walls in a double walled vessel), fire extinguishing liquids or gases, and the like.

5 The vessel can be fire proof by the choice of the materials of construction thereof, or by the use of suitable fire proofing additives or barriers therein.

10 The pressure that the vessel can withstand depends on the construction thereof, and more in particular on the fiber density in the shell. Generally the vessel can withstand pressures from little above atmospheric to more than 100 bar, for example up to 400 bar.

15 The fabrication of the fiber reinforced resin body can take place in various ways. A suitable method is winding a pre-impregnated fiber around the rotation symmetric core (for example the rigid inner lining), optionally followed by further impregnation of the final fiber reinforcement with the resin and solidification and/or vulcanization. However it is also possible to apply a resin matrix to the substantially rotation symmetric core prior to the winding of the fibers and/or after the winding of the fibers. After the fiber reinforcement has been wound around the core, the core is removed. This can be done by using a core that collapses in parts, by a temporary core composed of loosely bound solids, a core of hardened glass, which may be broken and removed after production, or an inflatable core.

20 In order to provide the required shape in the area of the inner rim of the shell, the shape of the lining preferably deviates somewhat from the theoretical equilibrium shape. As has been shown in figure 3 the surface extends somewhat outwardly, thus enabling the attachment of the axial member, after the extending part has been inverted inside.

35 After the fiber reinforcement body has been wound, woven or braided it can be incorporated in a resin matrix. It is also possible to wind resin-impregnated fibers, which results in the forming of the resin matrix. In a preferred embodiment the shell is produced by first applying a layer of resin material on the body, preferably an elastomer, subsequently

winding one or more layers of fibers (strands) around this body, preferably two layers, and finally again applying a final layer, a resistance layer, over the final layer of fibers.

5 The matrix can then be solidified, for example by vulcanisation.

The fiber reinforcement can be constructed from various materials, generally comprising natural or synthetic organic or inorganic fibers, although the well-known aramid fibers, such as Kevlar (TM) and Twaron (TM) are a suitable choice. Those fibers provide sufficient tensile stiffness in combination with strength. Other suitable fibers are all those fibers with a high tensile strength and/or stiffness, like sisal, carbon fibers, E-, R- and S-glass fibers, and those
10
15 polymeric fibers which are suitable in the environments where the vessels are used, such as the high molecular weight polyethylene fibers, polyester fibers and other fibers from high quality plastics (engineering plastics).

The matrix resin material of the shell may be
20 elastomeric, or rigid. Preferably the shell is prepared from a fiber reinforced resin selected from the group of elastomeric, thermoplastic elastomeric, thermosetting and thermoplastic, non-elastomeric resins. As the elastomer matrix any suitable elastomer can be used, although it is preferred that a high
25 quality elastomer having a good resistance against environmental degradation, such as ozone resistance, is used. Suitable elastomers are for example the isoprene, polyurethane, styrene-butadiene, butadiene-nitrile, EP(D)M, polybutadiene and silicone elastomers, which are optionally
30 vulcanised after the body has been shaped. The most preferred elastomer, especially for use as an LPG container is chloroprene rubber.

The invention is elucidated on the basis of the following figures, without being restricted thereto.

35 In figure 1 the principle equation for designing the vessel, together with a schematic drawing showing some of the variables is given. In figures 2^{a-c} the principle of preparing

the shell of the vessel is shown. Figure 3 gives the X-Y relation in the wound (equilibrium) shape and the final shape, after insertion of the axial member.

In figure 4 the construction of part of the assembled vessel with separate axial member is given. The end plate 1, provided with valve 2, is attached by means not shown to axial reinforcement member 3 and to end ring 4. Thereby a cylindrical enclosure is formed inside the central part of the shell, the rims of which are held in place between the end plate 1 and end ring 4.

CLAIMS:

1. A wheel-shaped pressure resistant vessel for gaseous, liquid or liquefied material having a substantially rigid shape, said vessel comprising a substantially continuous shell of a fiber reinforced resin having a central opening, an inner lining and an axial member, said substantially continuous shell having a substantial mechanical equilibrium shape, whereby the axial member is present in the said central opening of the shell,
wherein said axial member is an axial reinforcement member, which is attached to rims of the central opening, thereby closing the said central opening.
2. The vessel according to claim 1, comprising a substantially continuous shell of a flexible fiber reinforced elastomeric resin and a gas tight, substantially rigid inner lining.
3. The vessel according to claim 1 or 2, wherein the axial member is attached to the shell in such way that the surfaces of the shell are pulled towards each other.
4. The vessel according to any one of claims 1 - 3, wherein the axial member comprises an inner member and two end plates, said end plates fixing the shell to the inner member.
5. The vessel according to any one of claims 1 - 4, wherein the said axial member is provided with means for filling the vessel with the pressurized material.
6. The vessel according to any one of claims 1 - 4, wherein the said axial member is provided with means for removing the said material from the vessel.
7. The vessel according to any one of claims 1 - 4, wherein the said axial member is provided with means for determining the pressure.
8. The vessel according to any one of claims 1 - 4, wherein the said axial member is provided with means for determining the filling degree of the vessel.

9. The vessel according to any one of claims 1 - 8, wherein the shell is prepared from a fiber reinforced resin selected from the group consisting of elastomeric, thermoplastic elastomeric, thermosetting and thermoplastic, non-elastomeric resins.
10. The vessel according to claim 9, wherein the fiber reinforced resin is chloroprene resin.
11. The vessel according to any one of claims 1 - 10, wherein the fiber reinforcement of the shell is selected from the group consisting of organic and inorganic fibers.
12. The vessel according to claim 11, wherein the fiber reinforcement is selected from the group consisting of polyamide fibers, carbon fibers, and polyolefinic fibers.
13. The vessel according to claim 12, wherein the fiber reinforcement is aramide.
14. The vessel according to any one of claims 1 - 13, wherein the ratio of the diameter of the central opening to the outer diameter of the vessel ranges from 0.1 to 1.
15. Use of a vessel according to any one of claims 1 - 14 as an LPG-container for automotive purposes.

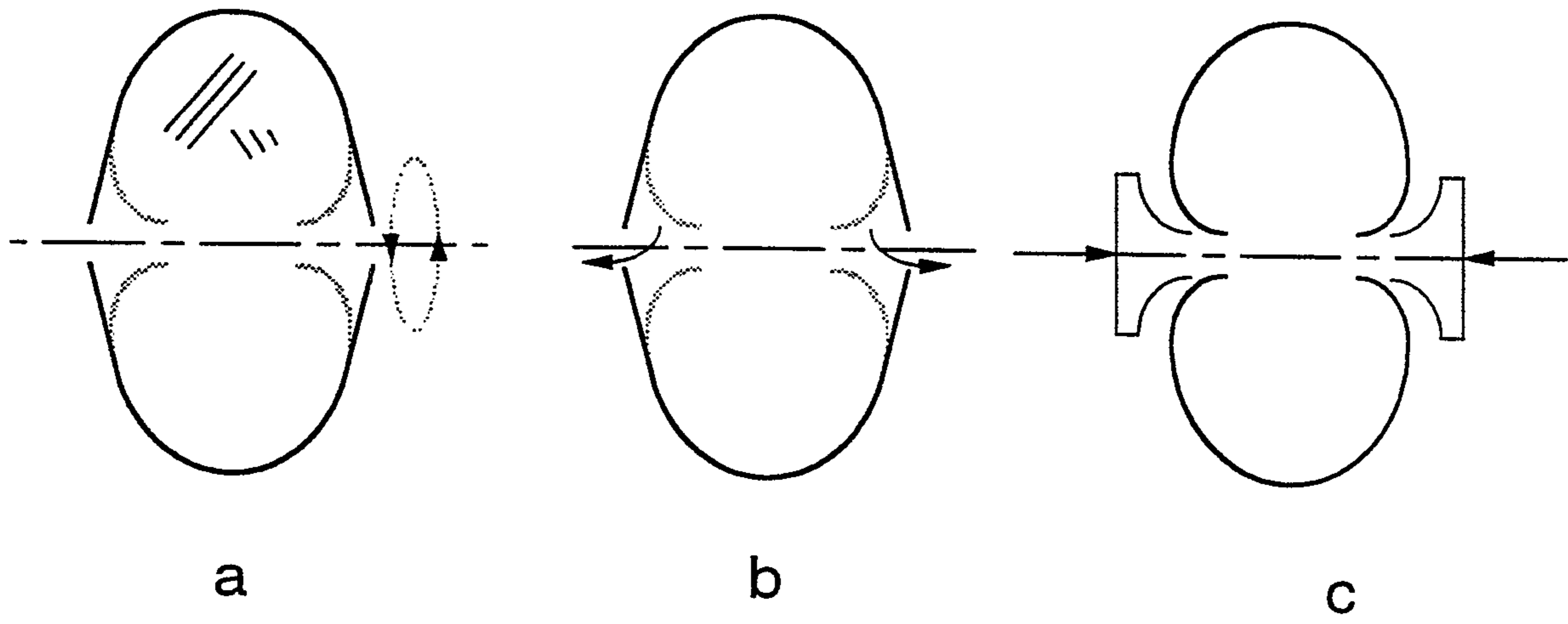
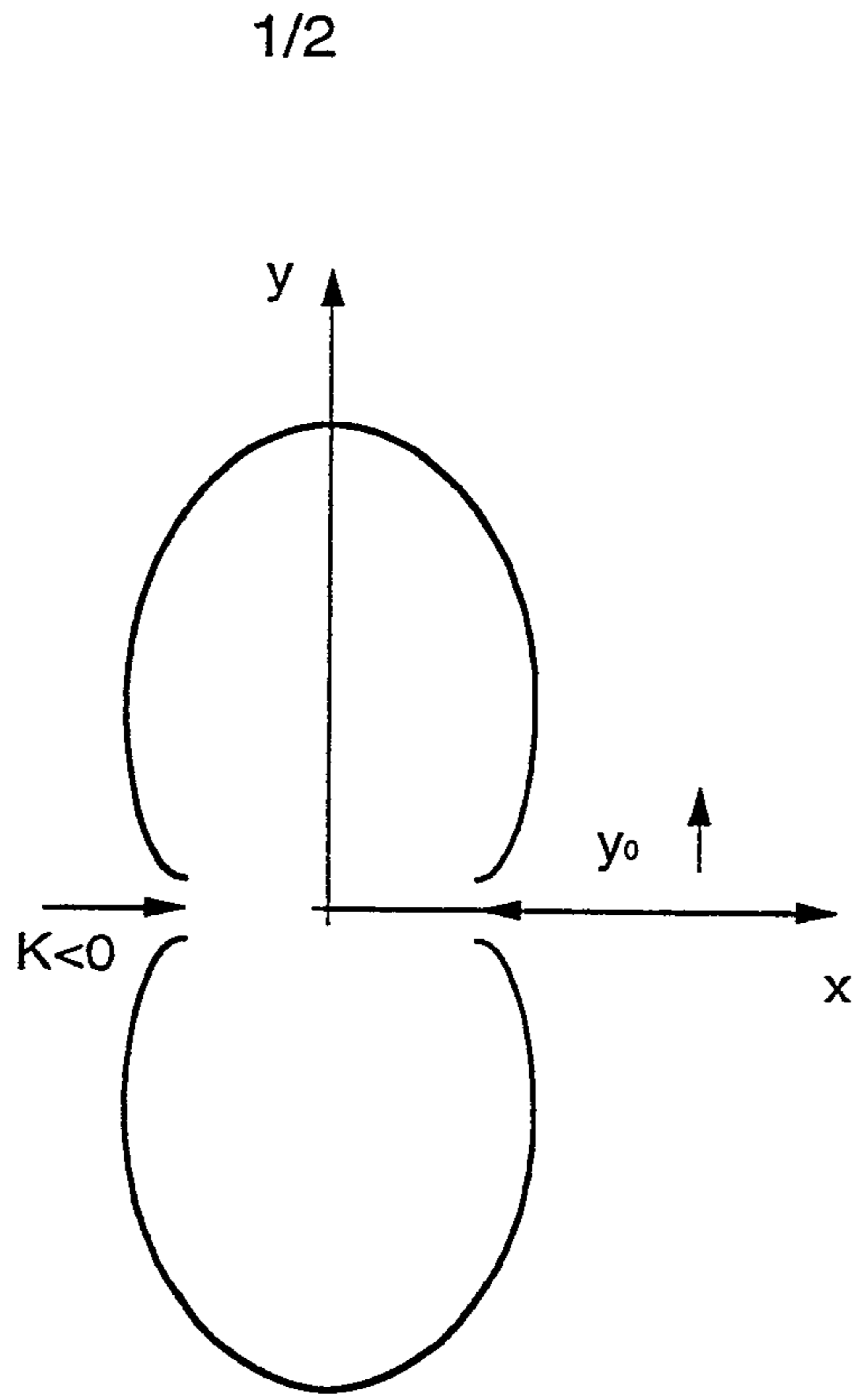


Fig. 2

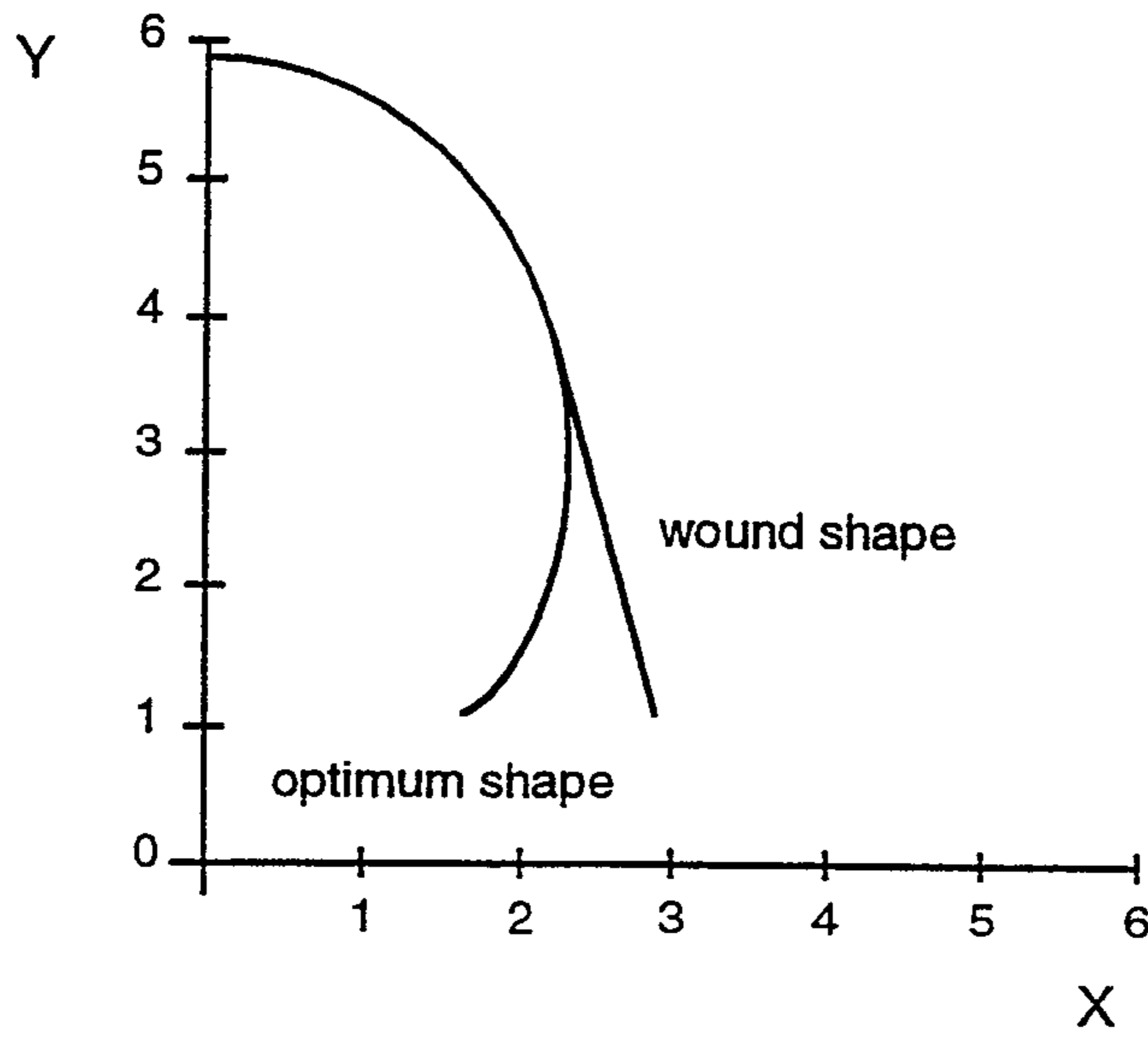


Fig. 3

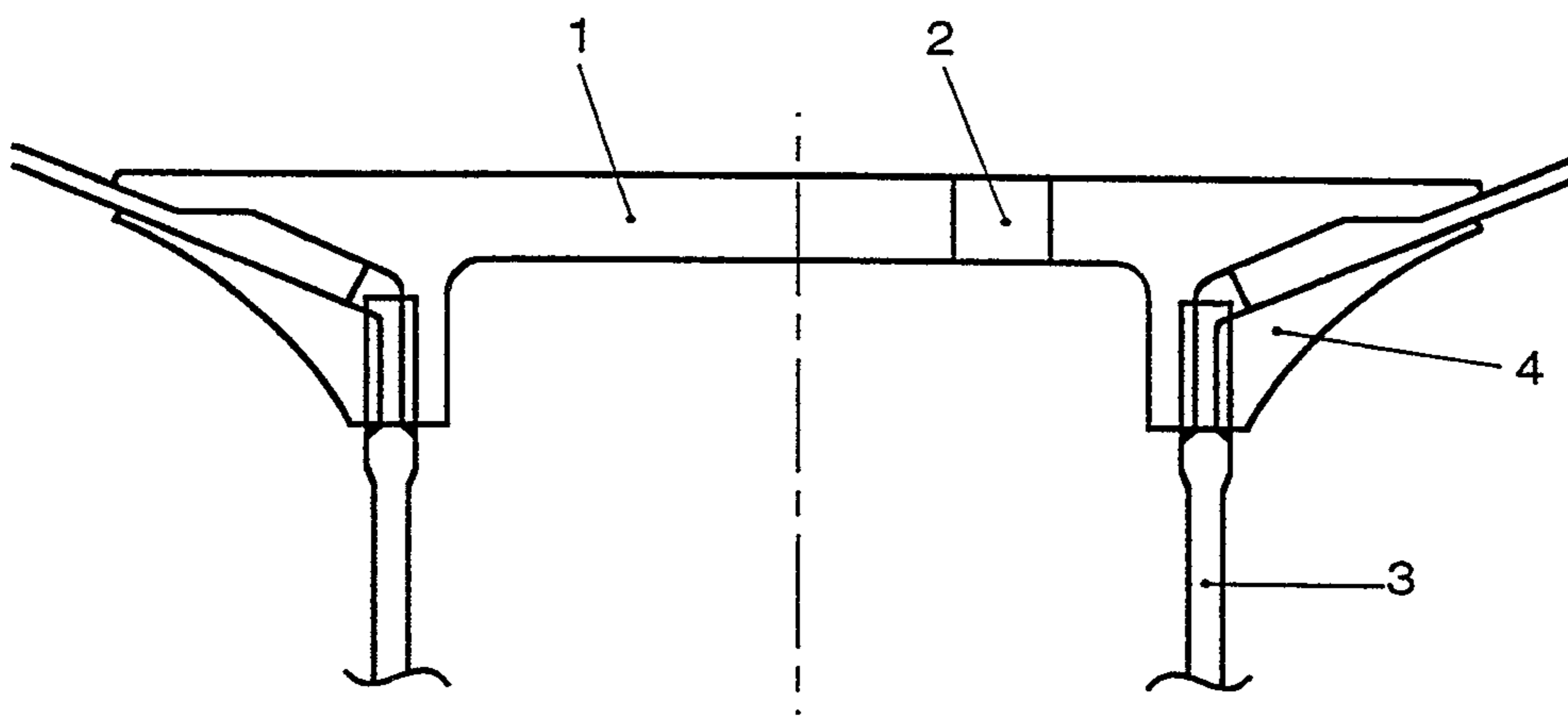
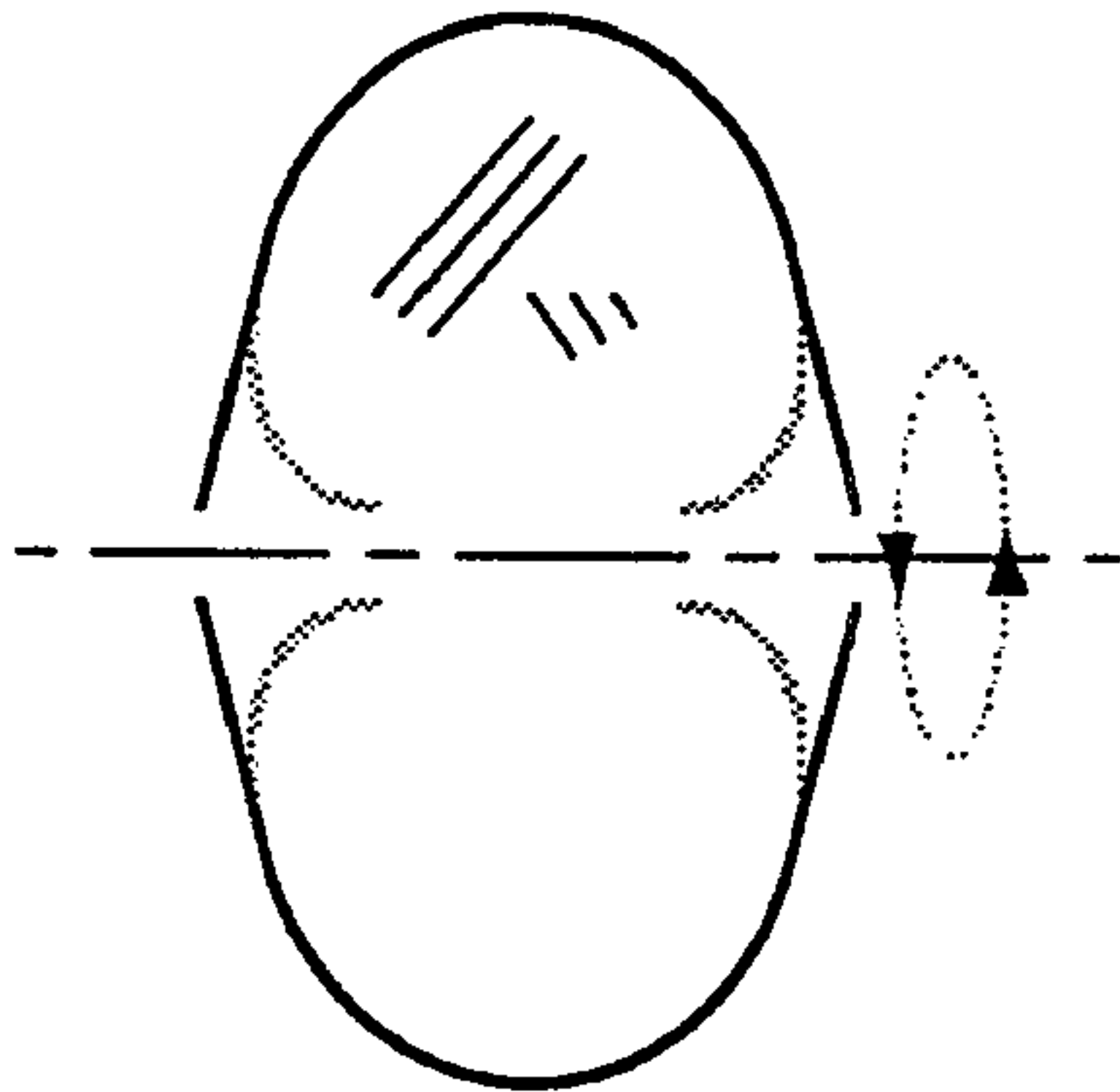
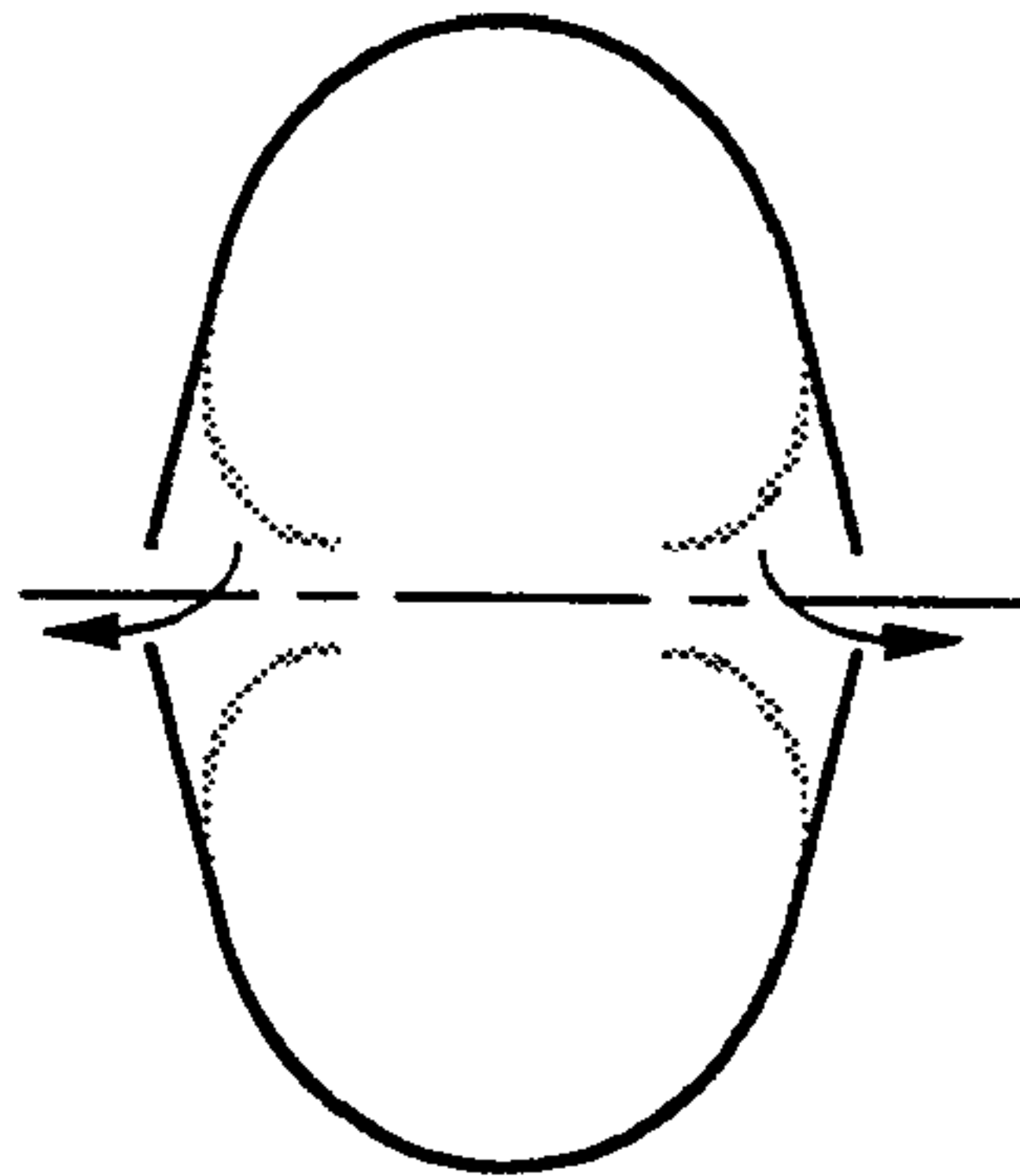


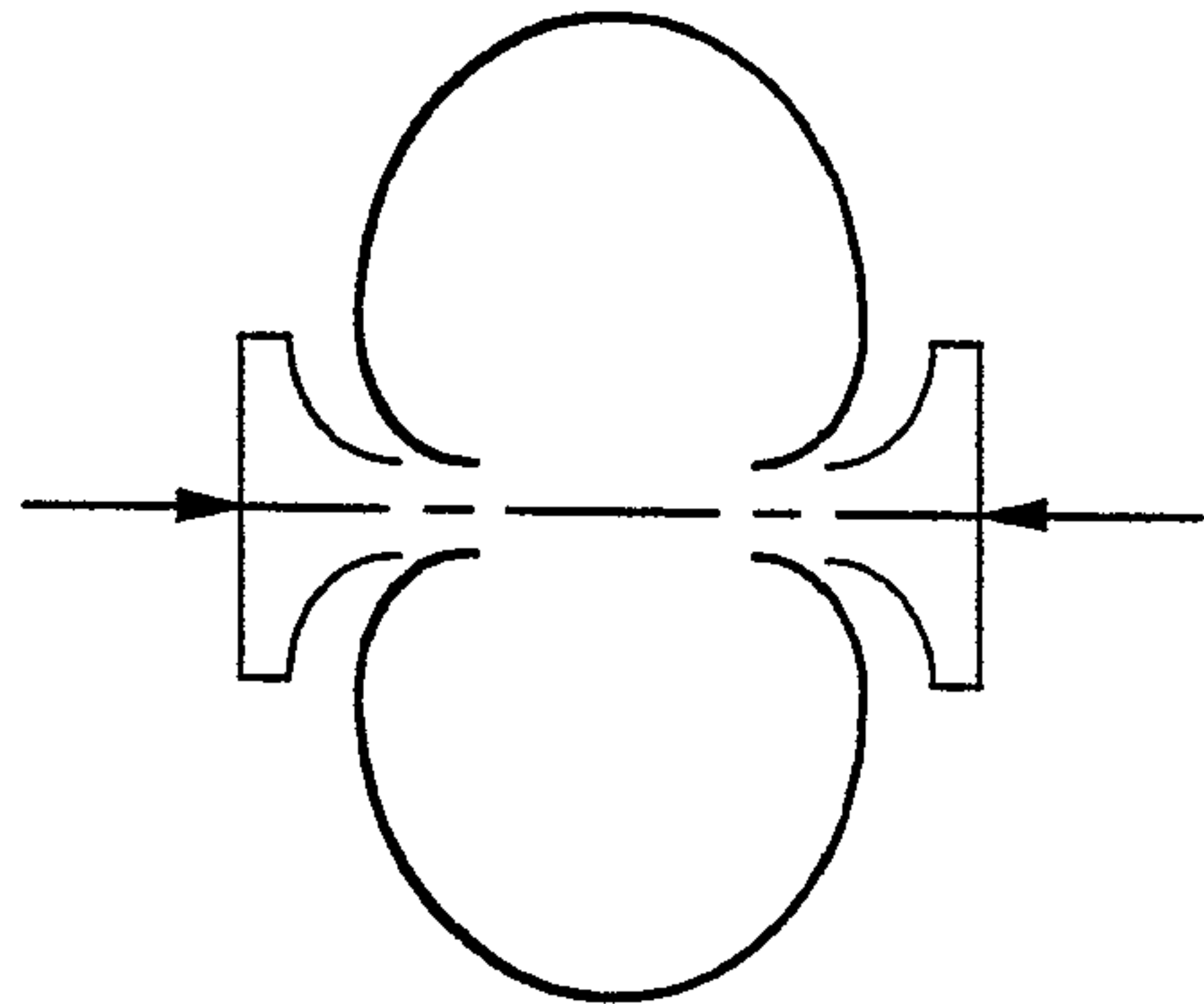
Fig. 4



a



b



c