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(19) (CA) **CANADIAN PATENT** (12)

(54) Internally Pressurized Envelope

(72) Rudy, Marion Franklin, U.S.A.

(73) Same as Inventor

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ABSTRACT OF THE DISCLOSURE

An internally pressurized envelope according to the present invention has spaced inner and outer surfaces characterized by a load deflection curve having a first and second region. The first region reflects the compliance upon initial application of a load and the second region reflects the compliance after the initial application of the load. The curve is such that the compliance of the first region of the curve is less than the compliance of the second region of the curve. The envelope is particularly useful as a cushioning layer and can be used in shoes.

INTERNALLY PRESSURIZED ENVELOPEField of the Invention

This invention relates to internally pressurizable multi-layered envelopes, and more particularly, to an improved multi-layered pressurized and gas containing envelope which is particularly adapted for use as a cushioning device such as an insole or other component in footwear.

Background of the Invention

Previously, considerable difficulty had been experienced in providing internally pressurizable multi-layered envelopes wherein the envelope was a flat or uniformly contoured supporting surface, with the capacity of being pressurized to relatively high levels. Previously much of the absorbed, re-distributed, and stored impact/shock energy was lost and not

1 returned in a useful form because of the requirement to
2 encapsulate the unit in a viscoelastic foam acting as a
3 moderator to develop the desired smooth or contoured surface.
4

5 It was simply not possible to provide a product wherein
6 much (greater than 60%) of the load supporting material of the
7 product was a gas under pressure. With the former product,
8 less than 40% of the energy of impact on the structure was
9 returned in a beneficial, efficient and comfortable manner,
10 the balance of the energy being absorbed and dissipated as
11 heat. The present design is capable of returning, in a useful
12 form, up to 92% of the otherwise wasted energy. In addition,
13 superior cushioning and compliance are also provided, which
14 significantly reduces damaging impact shock loads to the foot
15 and legs to levels under 12 G's.
16

17 The new product was developed because difficulty had been
18 experienced with the prior products in producing light weight,
19 long-life, high-pressure inflated structures for use in foot
20 wear and the like which possessed a high degree of resilience
21 and compliance wherein the shock energy absorbed,
22 redistributed and stored at impact is efficiently returned as
23 useful energy in a smooth manner, at a rate equal to or
24 greater than the rate at which the applied load is removed
25 from the devices. Success of this new product depended upon
26 solving several basic problems: 1) separation (delamination)
27 between the tensile element (fabric layer with drop threads)
28

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1 and the gas containing barrier layer, when subjected to high
2 loads with long-term cyclical fatigue conditions, 2) crushing,
3 abrasion, and bending fatigue failure of the drop-threads, 3)
4 hydrolytic degradation failure of the drop threads, 4) fungus,
5 bacteria and hydrolytic stress fracture of the barrier
6 material, 5) unravelling of the tensile-elements immediately
7 adjacent to the cut edges of the cloth, when subject to high
8 loads and bending and flexing, 6) puncture and abrasion
9 failure of the barrier film, 7) leakage of the pressurizing
10 gas at the perimeter seal, caused by fiber filaments extending
11 from the sides of the tensile cloth being trapped in, and
12 bridging the perimeter barrier seal so as to create minute
13 leakage paths through which pressurizing gas could slowly leak
14 out.

15
16 In addition to the above problems, one of the more
17 difficult challenges was the provision of a sealed,
18 permanently inflated cushioning device with flat surfaces, as
19 contrasted to tubular or rounded chambers, and which could be
20 made relatively thin so as to achieve 100% air support and
21 cushioning and which possessed sufficient fatigue resistance
22 to withstand millions of compression cycles in use. In the
23 case of consumer items, especially footwear, a useful life of
24 several years is essential. Furthermore this product must
25 maintain the unique and beneficial cushioning properties,
26 without significant degradation throughout its full lifetime.
27 As is apparent, a significant loss or gain of pressure over a
28

1 period of time is not acceptable, especially in consumer
2 products. It is also desirable to provide an inflated product
3 capable of withstanding relatively high localized loads
4 without bottoming out, such as the loads typically encountered
5 in athletic activities.
6

7 For example, in running or other sport events which
8 involve running or jumping, there are substantial localized
9 loads during heel strike or push off. If the cushioning
10 device bottoms out, then the entire purpose of the cushion is
11 compromised. For most conditions encountered, to prevent
12 bottoming out, the inflated product either may be made
13 sufficiently thick or highly pressurized or both. Another
14 desirable approach is to use smaller chambers inflated at
15 lower pressures, and positioned under the load bearing surface
16 so that there is little or no accumulator volume into which
17 the gas may escape. Relatively high pressurization of the
18 prior art inflated devices with rounded tubular chambers
19 produced an uncomfortable feel, unless encapsulated with foam,
20 or used with some other type of surface/contour moderator
21 element.
22

23 The load/deflection curve of this tensile product
24 achieves totally new, unique and beneficial cushioning
25 characteristics never before possible with other prior art
26 load cushioning devices.
27
28

1 The load deflection characteristics of my earlier
2 inventions, Patent No. 4,183,156, provided a very soft
3 cushioned support under light loads. Then, with progressively
4 heavier loads, the supportive force increased either in a
5 linear or in an exponential manner. This type of
6 load/deflection characteristic is suitable for many
7 applications. However, there are other uses where it is very
8 desirable that the pressurized pneumatic cushioning device
9 initially exhibit a very firm cushion support under light to
10 moderate compression loads, a degree of support greater than
11 the product of the area of the applied load times the internal
12 working pressure. Then, when greater compression loads are
13 applied, the device automatically, at a predetermined load,
14 changes from the firm, board-like cushioning support and
15 exhibits a soft, relatively consistent and gradual increasing
16 level of cushioned support throughout the full, available
17 displacement of the inflated device.

18
19 This type of cushioned support embraces substantially
20 different, new novel technology from the prior art. New,
21 novel and highly useful products are now possible that were
22 impossible using the prior art.

23
24 Thus, a need exists for an improved essentially
25 permanently pre-pressurized product which has advantages over
26 the prior art inflated products. It is also apparent that
27 there are the practical considerations of being able to
28

1 manufacture such products relatively inexpensively, at
2 relatively high volume and of a very high quality which
3 assures that the product will be free of leaks and have an
4 acceptable service life even when built as a permanent and
5 integral part of the footwear. It is also an advantage to be
6 able to provide a gas pressurized load bearing cushioning
7 member which may be formed in various shapes, thicknesses, and
8 contours.

9
10 Brief Description of the Invention

11
12 These and other difficulties of the prior art have been
13 overcome according to the present invention. The present
14 invention provides a gas pressurized and inflated structure
15 which comprises an hermetically sealed outer covering barrier
16 layer which is securely bonded, as will be described,
17 substantially over the entire outer surfaces of a double
18 walled interior fabric structure. The double walled fabric
19 structure comprises first and second outer fabric layers which
20 are normally spaced apart from one another at a predetermined
21 distance. Drop-threads, (or more appropriately drop-yarns)
22 preferably in the form of multi-filament yarns comprised of
23 many individual fibers extend internally between the proximal
24 or facing surfaces of the respective fabric layers. The use
25 of multi-filament drop-yarns is unique to this product. The
26 filaments of the drop yarns form tensile restraining means and
27 are anchored to the respective fabric layers. The restraining
28

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1 means or drop yarns may be arranged nominally perpendicular to
2 the first and second fabric layers, or they may be arranged in
3 a triangular arrangement. It is noted that the yarn
4 comprising the drop threads or restraining means may be
5 separate and distinct from the yarn of the first and second
6 fabric layers, i.e., the yarn used for the first and second
7 fabric layers may be completely different from the yarn of the
8 drop threads or restraining means, depending an the
9 application and the use environment. These restraining means
10 function to maintain the general flat or contoured planar form
11 of the pressurized and inflated structure, and the bonding of
12 the outer covering to the distal sides or exposed outer
13 surfaces of the respective fabric layer prevents the outer
14 covering from peeling away or separating from the distal
15 surfaces and forming an aneurysm. The drop yarns which extend
16 from one fabric layer to the other, function in pure tension
17 as the preferred restraining means and are present in
18 quantities sufficient to hold the structure in the desired
19 planar form without offering substantial resistance to the
20 compression of the two outer layers towards one another. That
21 is, the restraining means have very little compressive
22 strength and very substantial tensile strength and thus do not
23 provide any significant compressive support to externally
24 applied loads and thus exhibit a very considerable fatigue
25 life. It is the pressurized gas component that provides 100%
26 of the cushioned support for the very heavy, life-time cyclic
27 compression loads. The pressurized gas has literally an
28

1 infinite fatigue life. Thus, by separating the compression,
2 and tension load carrying components of the device in this
3 manner, a very unique and beneficial result is achieved. The
4 resulting product has a fatigue life many times greater than
5 is otherwise possible. The region between the proximal
6 surfaces of the fabric layers is of sufficient openness to
7 allow movement of the pressurizing gas throughout the
8 pressurized chamber.

9
10 The hermetically sealed outer barrier layers, which
11 operate to contain the gas, preferably are composed of a
12 composite elastomeric semi-permeable material which is
13 substantially impervious to those gases which are essentially
14 non-polar and that may additionally have very large molecular
15 sizes. The outer barrier layers also can control the rate of
16 inward and outward diffusion of N₂ and O₂ and other component
17 gases of the ambient air by means of the percentage
18 composition of the crystalline component within the
19 elastomeric component of the barrier layer. Therefore, this
20 outer barrier layer provides a very important secondary
21 function of being slightly permeable to some other gases such
22 as oxygen. With this material, a selective inward diffusion
23 of oxygen occurs from the ambient air which, by means of
24 partial pressures, tends to increase the total pressure within
25 the already pressurized enclosure. This is described in some
26 detail in, for example, Rudy U.S. Patent No.4,340,626 patented
27 July 20, 1982; Rudy et al, U.S. Patent No.4,183,156 patented
28

1 July 15, 1980; Rudy et al, U.S. Patent No.4,271,606 patented
2 June 9, 1981; and Rudy et al, U.S. Patent No.4,219,945
3 patented September 2, 1980. Attention is respectfully invited
4 to these patents

5 for a description as to the barrier film, the
6 pressurizing gas and the physical phenomenon which are
7 involved in diffusion pumping and the activated diffusion of
8 gas through the semi-permeable barrier layer.

9
10 The structures according to the present invention are
11 particularly unique and suited for use where they are required
12 to absorb and cushion an impact load within a limited space
13 and then return this otherwise wasted energy in a useful
14 manner. This structure has a further advantage because it has
15 a substantially reduced mass as compared to the prior art
16 structures, thus providing pressure constraining walls or
17 elements which have a low hysteresis energy loss when flexed.
18 Gas(s) pressurized to at least 2 psi and preferably more than
19 15 psi, functions well to provide excellent and comfortable
20 cushioning and then to return the stored energy in a
21 resilient, efficient life-like and beneficial manner. When
22 the structure of the present invention is pressurized to a
23 level in excess of 40 to 50 psi the structure gives back as
24 much as 92% of the energy of an impact.

25
26 Therefore, if a weight having the shape, mass, and
27 velocity of a representative human foot at heel-strike, is
28

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1 dropped from approximately two feet height on to a properly
2 designed structure in accordance with the present invention,
3 which is pressurized to a level of approximately 55 psig., the
4 weight will first be well cushioned from the force of impact,
5 such that the G forces on the weight will be in the range of 9
6 to 12 G's. Then nearly all of the impact energy that is
7 absorbed, redistributed and stored in the device during the
8 downward compression portion of the cycle (i.e., about 92%)
9 will be very efficiently returned to the weight, causing it to
10 rebound to approximately 92% of the original drop height, or
11 22 inches. The word compliance is used to express the
12 combination of these two factors: i.e., cushioning and
13 resilience. A product simultaneously exhibiting maximum
14 cushioning and maximum useful energy return, or resilience, is
15 considered to have good compliance. Poor compliance would, of
16 course, be the opposite.

17
18 The present invention is uniquely suited to footwear and
19 other similar cushioning applications where high style and/or
20 maximum cushion comfort, support and shock protection are to
21 be achieved in a minimum of thickness and space (.e., low
22 profile). Thicker devices as disclosed in Rudy Patent
23 4,183,156, were, in large measure, poorly suited for this type
24 of application. The hills and valleys of the earlier product,
25 coupled with the need for some type of foam encapsulation or
26 moderator device to provide a smooth, comfortable support
27 surface, created a product that was relatively thick and
28

1 clumsy for this type of application.

2
3 The flat or contoured planar load bearing surfaces of the
4 present invention achieves a completely new and unique degree
5 of 100% floating on air cushioned, resilient support, comfort
6 and protection never before possible. This invention
7 eliminates the need for foam encapsulation. However, in
8 certain circumstances it may be desirable to use foam in order
9 to build the unit into a midsole, to absorb moisture and to
10 increase further the service life of the gas pressurized
11 product. The use of foam can also control or eliminate the
12 tendency of the subject cushioning product from buckling, when
13 bent in a sharp radius.

14
15 In the present invention the formation of one or more
16 aneurysms constitutes failure. Aneurysms can develop either
17 when there is delamination of the barrier material from the
18 distal or outer surfaces of the double-walled fabric, or by
19 failure of the drop yarns. Such drop yarn failure can be
20 caused by bending fatigue and/or abrasion of the drop yarns,
21 normally referred to as a fibrillation-type failure.

22 As discussed later, the present invention solves these
23 problems for the life of the product.

1
2 The use of drop yarns in a double walled structure acting
3 in tension to constrain and shape the barrier surfaces has
4 been proposed previously. An example of the aneurysm which
5 can develop when the drop yarns are of insufficient strength
6 or are deliberately severed, is illustrated for example in
7 Cross, U.S. Patent No. 3,205,106 patented September 7, 1965.
8 There the product functions completely as a structural device,
9 it does not produce a cushioning function; nor does it solve
10 the problems inherent in a cushioning product such as does the
11 present invention. Cross does not address the problems that
12 must be solved in order to achieve permanent inflation nor
13 does he attempt to use or control diffusion pumping in a
14 useful and unique manner as described in this present
15 invention.
16

17 The use of drop yarns and filaments as structural
18 compressional cushioning or stiffening members in double
19 walled structures has been proposed, for example, by Tungseth,
20 U.S. Patent No. 3,616,126 patented October 26, 1971 and Giese
21 et al, U.S. Patent No. 4,005,532 patented February 1, 1977.
22 These prior structures are comprised of a single heavy (i.e.,
23 large .003 to .025 inch diameter) plastic monofilament strand
24 woven into a stiff three-dimensional, compression load
25 supportive mat. The Tungseth '126 patent describes a product
26 of this type that relies completely on the buckling
27 characteristics of select diameter plastic monofilaments in
28

1 the woven structure and which are placed in compression in
2 order to absorb compression shock loads. In Tungseth '126, no
3 pneumatic support is provided at all.
4

5 The Giese patent '532 likewise is a stiff compression
6 load supporting mat woven from a .010 of an inch diameter
7 plastic monofilament strand in order to form a thermal
8 insulation insert for articles of footwear; wherein it is
9 stated "The separating material"(i.e., plastic monofilaments)
10 "are of such a strength as to prevent deformation of the mesh-
11 like fabrics toward each other when subjected to the weight of
12 the wearer of the shoes." This is identical to Tungseth. The
13 embodiment calls for the mat to be covered with a barrier
14 material and closed to form a hermetically sealed chamber. In
15 one form, air may be left within the chamber to form an
16 insulative dead-air space, while in other forms, the air may
17 be evacuated from the chamber or, replaced with a gas such as
18 CO₂ in order to achieve a thermal coefficient of heat transfer
19 that is lower than the ambient air. These structures are very
20 poor shock absorbing devices returning little, if any, of the
21 impact energy to the user and thus wasting and dissipating the
22 energy away as internal frictional heat. Our tests reveal
23 rapid fatigue failure of these large diameter, compression
24 load supporting plastic monofilaments which thus create sharp,
25 protruding plastic splinters that easily puncture the envelope
26 film, resulting in a loss of vacuum or loss of special low
27 thermal conductive gas. The sharp splinters likewise
28

1 penetrate, irritate and puncture the skin of the foot,
2 resulting in pain, discomfort and possible infection.
3

4 Other prior patents include U.S. Patent 4,409,271 issued
5 to Pehr on October 11, 1983 and which relates to a lightweight
6 construction element. The Pehr structure is composed of an
7 untrimmed velvet fabric having a vertical pile between the
8 upper and lower webs. The fabric is rendered impermeable to
9 air by a rubber coating which is vulcanized and the fabric is
10 joined together by a seam. The Pehr product may be filled
11 with a gas, liquid or foam. The Pehr product is not intended
12 to be used as a cushioning or shock absorbing device, as is
13 the case with the present invention.
14

15 Similar to Pehr is United States Patent 2,743,510 issued
16 to Mauney et al on May 1, 1956. There, however, fabric is
17 used which has not been tensilized so that when exposed to
18 heat and tension, the fabric will stretch.
19

20 U.S. Patent 3,205,106 of September 7, 1965 issued to
21 Cross also discloses a structure in which drop cords are
22 present. The drop cords are severed in order to increase
23 stiffness in the product by providing a convex section. This
24 effectively produces an aneurysm, the very situation which the
25 present invention seeks to avoid.
26

27 Also of interest, but describing an entirely different
28

1 product from that here disclosed is U.S. Patent 4,261,776 of
2 April 14, 1981, issued to Lea et al and the patents therein
3 discussed. The Lea et al product is a self-inflating air
4 mattress.

5
6 In the present invention the drop yarns consist of many
7 very fine, texturized or bulked separate filaments (not a
8 single monofilament as in the above prior art) each having a
9 high tensile strength and being of a very small cross-section
10 diameter in comparison with the prior art such that they
11 cannot act as Euler column compression members and are
12 completely incapable of supporting any significant compression
13 load by themselves. Should filaments become broken, the
14 resulting product does not create a sharp splinter that could
15 puncture or otherwise damage the barrier envelope. Thus, the
16 load supporting mechanism of the present invention is
17 completely different from the prior art, and with greatly
18 superior high pressure containment, load carrying capability,
19 shock absorption, fatigue life, resiliency, long term
20 permanent inflation and beneficial life-like energy storage
21 and return characteristics that are not even remotely possible
22 with the above stated prior art.

23
24 Various gas containing foam materials have previously
25 been sealed in flexible air-tight compartments, see for
26 example, Rosenberg, U.S. Patent No. 4,590,689 patented May 27,
27 1986 and Striegel, U.S. Patent No. 3,914,881 patented October
28

1 28, 1975. Foam products of this type pressurized even with
2 supergas (Rudy U.S. Patent 4,183,156) have not been successful
3 because of several problems; (1) the tensile strength of even
4 the best open-cell foam materials is not sufficiently strong
5 and reliable to support the necessary inflation pressures over
6 the life of a product to be used in this manner in footwear;
7 (2) under heavy cyclic compression loads, typical of the foot
8 strike when walking or running, the walls of the individual
9 cells constituting the foam structure abrade and tear as they
10 move against one another and thus rapidly fail, resulting in
11 an aneurysm and/or a subsequent loss of pressure.

12
13 It is known that the highest possible quality foam, when
14 used as a cushioning load supportive, compression member
15 (i.e., mid halfsole or insole) in athletic footwear such as
16 running shoes, loses a substantial percent of its original
17 cushioning properties within just a few miles of running, and
18 at about 150 miles approximately 75% of the initial cushioning
19 properties have been lost. The loss of cushioning is the
20 result of internal breakdown of the cell walls of the foam as
21 described above. In this usage, the footwear does not become
22 unusable because of the described breakdown of the foam. The
23 user simply is exposed to reduced cushioning (and poorer foot
24 support) and thus much greater shock forces. However, with a
25 pressurized structure, breakdown of the foam structure results
26 in formation of a protruding aneurysm or bulge under the foot.
27 Even the smallest failure of this type (i.e., diameter) makes
28

1 the product painful under the foot and therefore unusable.

2
3 The relatively high pressures which are required to
4 provide the desired and necessary degree of support and
5 springiness present very substantial problems with the peeling
6 or delamination of the outer barrier film away from the distal
7 or outer surfaces of the double-walled fabric. It is thus
8 important, in accordance with this invention, to provide a
9 strong bond between the outer surface of each of the layers of
10 the fabric and the facing surface of the envelope or barrier
11 layer. In other words, the peel strength or the force needed
12 to delaminate the bonded layers must be very high throughout
13 the life of the product.

14
15 It has been found, in accordance with this invention,
16 that if the yarn which is used to form the double-walled
17 fabric and which creates the fiber interface reinforcement of
18 the barrier layer, is in some way bulked, texturized or
19 flannelized or made from at least 20% discontinuous
20 filaments, so that there is a large degree of openness to the
21 yarn and there are numerous loops and/or spirals of small
22 diameter tendrils or other tendrils and projections of
23 filamentary material extending slightly from the distal
24 surfaces of the fabric layers, greatly improved bonding can be
25 achieved. Actually, the tendrils extend from the larger
26 diameter yarns from which the fabric material is formed. The
27 texturizing can be provided for example, by abrading the
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1 distal surfaces of the double-walled fabric, by crimping the
2 individual filaments which go to make up the yarn, by using a
3 false twist or air bulk heat-set texturizing step in
4 manufacturing the yarn, and the like. Such a surface or bulk
5 treatment is referred herein as a FIRTEC (Fiber Interface
6 Reinforcement Technology) surface treatment. It is also
7 desirable to use a yarn wherein the filament surfaces are dull
8 or semi-bright, as contrasted to bright. Therefore, in a
9 preferred embodiment, the yarn from which the double-walled
10 fabric is constructed is treated so that in the final product
11 there is a large degree of openness to the yarn, and the
12 distal sides of the respective fabric layers present a great
13 many tiny loops or outwardly projecting. The individual
14 filaments may be continuous in nature in the preferred
15 embodiment so that the loops are anchored at both ends.
16 Crimped filaments when combined into a yarn are also suitable
17 for use according to the present invention. In some cases it
18 may be desirable to have a yarn core of straight fibers
19 surrounded by texturized fibers. Also, fibers, other than
20 fibers of circular cross-section, may be useful to increase
21 the surface area for bonding purposes; such fibers are oval,
22 cruciform, dumbbell or Y-shaped in cross section. It has been
23 found that best results are achieved when the yarn is properly
24 heat set in the texturized/bulked condition.

25
26 The presence of a multiplicity of tendrils in the form of
27 loops and the like significantly increases the bond strength
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1 beyond that which has heretofore been achieved in the industry
2 to provide exceptionally strong bonding between the barrier
3 envelope material and the facing fabric layer. One of the
4 factors is that the presence of the tendrils significantly
5 increases the surface area of the anchoring components.
6 Another factor is the essentially uniform and widespread
7 dispersion of fiber inter-face reinforcement anchoring
8 components thus assuring strong bonds over the entire mating
9 surfaces of the fabric and the outer envelope component. Yet
10 another factor is that the openness of the yarn permits a
11 carefully controlled degree of penetration of the coupling
12 material into the facing cloth members.

13
14 The cloth or fabric structure which forms the tensile
15 load bearing portion of the inflated product may be
16 constructed according to any known procedures including
17 knitting, weaving, sewing, matting, etc. It is preferred that
18 the drop threads be securely anchored to the fabric layers,
19 for example by a lock stitch, whereby the tensile elements
20 remain in place to prevent ballooning along the edges of the
21 fabric layers. The double needle bar Raschel knit material is
22 particularly satisfactory to use according to the present
23 invention since it provides the lock stitching to the fabric
24 layers. Also material which is woven with a locking stitch is
25 suitable to use. A wide range of products having complex
26 contoured and/or tapered surfaces in many different shapes are
27 possible using high speed computer controlled, gang type
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1 sewing techniques where the length and angularity of each drop
2 thread or restraining means may be different from those
3 adjacent restraining means. The drop yarn or tensile elements
4 may extend perpendicularly from the fabric layer or may be at
5 shear force balancing angles. In some instances, where
6 lateral loads are involved, as contrasted to loads
7 perpendicular to the surface of the product, opposing and
8 balancing angular orientation of the tensile yarn has
9 advantages in supporting shear loads which, of course, cannot
10 be supported by the pressurizing gas. It is important that
11 the finished cloth or fabric structure be free of lubricants
12 or processing aids that would be detrimental to achieving a
13 strong bond between the filaments of the fabric and the
14 coupling material.

15
16 The yarn from which the drop thread linked double-walled
17 fabrics are constructed must be made of a high tensile
18 strength material which is stable under the intended
19 conditions of both manufacture and usage. A variety of
20 synthetic yarn materials may be used. However, because of the
21 bending and abrasion of the drop threads which occurs when the
22 two outer fabric layers move toward one another when cyclic
23 loads are applied for relatively long periods of time, it is
24 important to use fibers that have good abrasion properties and
25 bending fatigue resistance as discussed later.

26
27 In general the filaments utilized in the yarn according
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1 to the present invention have a denier per filament of from
2 about 1-20 with a preferred range of from about 2-5. The
3 individual filaments in general exhibit tensile strengths
4 (tenacity) of from 2 10 grams per denier with a preferred
5 range of from approximately 4-6 grams per denier. In general
6 the number of filaments per yarn ranges from about 1-300 with
7 the preferred range being from about 40-200. In general there
8 are from approximately 1-8 yarns per tuft or strand with the
9 preferred range being from about 1-3 yarns per strand. The
10 preferred fabric is knitted with from about 50-1000 strands or
11 tufts per square inch of fabric and preferably from about 400-
12 500 strands per square inch. The bulk density of the fabric
13 is therefore in general in the range of from about 5,000-
14 150,000 fibers per square inch.

15
16 It is important that the finished cloth (in addition to
17 the beginning yarn) be given a heat-set treatment so that in
18 the double-walled fabric the drop yarn will tend to stand up
19 so that a given point on one fabric layer will tend to remain
20 axially aligned with the same given point on the opposed
21 fabric layer. This is advantageous in construction. It is
22 preferable during the manufacturing procedure to have the drop
23 yarns standing up so that there is no significant mis-
24 alignment between the upper and lower surface fabric layers.
25 Texturizing of the drop yarn prevents the individual filaments
26 from acting as Euler column compression members under any
27 circumstance.
28

1
2 The construction of the internally pressurizable multi-
3 layer envelop according to the present invention begins with
4 the selection of an appropriate double-walled fabric which
5 incorporates drop threads extending between the proximal
6 surfaces of the respective fabric layers. The distal sides of
7 the respective fabric layers are impregnated with a carefully
8 metered quantity of coupling material. This may be done by
9 starting with large sheets or rolls of fabric material, then
10 applying the coupling material. The properly shaped article
11 can then be cut from these larger sheets or rolls of material
12 that have been pre-treated. This procedure has advantages to
13 be described later.

14
15 In general, the coupling material is a product which
16 will, 1) penetrate and bond to the material of the outer
17 fabric layers to a carefully controlled depth, not exceeding
18 the thickness of said surface cloth members, 2) act as a semi-
19 permeable elastomeric matrix, penetrating the yarn bundles and
20 tenaciously attaching to and joining together the fibers
21 constituting the outer fabric layer elements, and 3) also
22 forming a strong bond with the semi-permeable elastomeric
23 outer barrier material, or envelope.

24
25 The coupling material may be applied using conventional
26 application procedures including, for example, heated platen
27 presses, extrusion procedures, or calendering, spraying and
28

1 doctor blading.

2
3 In general, however, the preferred method application is
4 to provide the coupling material in a sheet form .002 to .008
5 inches thick, with .004 being the preferred thickness and to
6 melt and press the molten sheet material into the distal sides
7 of the fabric layers. The fabric is moved under an upper and
8 lower heated platen hot press with a sheet of coupling
9 material on top and on the bottom of the fabric and with a
10 sheet of release agent between the coupling material and the
11 heated platens of the press. Such sheets of a suitable
12 release agent (strippers) are used to prevent the sheets of
13 coupling material from sticking to the upper and lower heated
14 platens of the press. The stack of fabric and coupling
15 material sheets are subjected to relatively light pressure in
16 the press between the heated platens (approximately 5-3 psi)
17 for 6-25 seconds in the range of temperature of 340 to 400
18 degrees F. When thermoplastic polyurethane is used as the
19 coupling material, the temperature has to be high enough to
20 soften and melt the coupling material but not so high as to
21 damage or shrink the fabric. The feed system for this process
22 can be either a batch system (using in-and-out shuttles) or a
23 continuous process using rolls of fabric and rolls of coupling
24 material moved along on an intermittent basis by means of
25 suitable relaxer and indexer conveyor mechanisms. Platen
26 sizes are normally 14 inches x 18 inches, 30 inches x 30
27 inches or 36 inches x 36 inches, with platens ground flat and
28

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1 parallel within .002 of an inch. Temperature uniformity
2 should be plus or minus 5 degrees F of the set-point.
3 Structural deflection of the press should not exceed .002 of
4 an inch to .004 of an inch. The cold press used to freeze the
5 hot coupling material operates in the range of 60 to 120
6 degrees F. The up-and-down motion of the cold press is in the
7 same timed sequence as the hot press. Because some fabrics
8 tend to shrink somewhat when heated during this process, it
9 may be useful to use pre-shrunk fibers when knitting or
10 weaving the cloth. In some cases it is useful to apply
11 longitudinal or lateral tension to the fabric during
12 application of the coupling material. In this way a finished,
13 smooth surface is obtained on both top and bottom surfaces of
14 the fabric.

15
16 Accurate temperature, pressure and time control is
17 essential so as to achieve a good grip between the fabric and
18 coupling material while also avoiding driving the coupling
19 material all the way through the fabric which would impair the
20 flexibility of the drop threads or at worst, bond the opposite
21 fabric layers together so the product could not be inflated
22 and pressurized. In the preferred embodiment, the quantity of
23 coupling material available to penetrate the fabric is
24 controlled by controlling the thickness of the sheet of
25 coupling material which is applied to the fabric. Also, the
26 heat is very accurately controlled and regulated so that hot
27 spots do not occur and the depth of penetration does not vary
28

1 from one area of the fabric to another due to changes in the
2 fluidity of the coupling agent. A superior and preferred
3 procedure presently used follows in detail this coupling
4 material application step.

5
6 The outer surfaces of the fabric must have a controlled
7 and uniform degree of closeness or density of weave. The
8 density should be sufficiently uniform such that when the
9 fabric is held up to a light source it must not be possible to
10 detect penetration of discrete light rays. The density should
11 not be too loose in any areas. Also, the density should not
12 be too tight. Such control of density is achieved in several
13 ways: 1) number of yarns per square inch, 2) number of
14 filaments per yarn, 3) amount of the bulking, texturizing or
15 FIRTEC treatment, 4) tension in the Raschel machine during the
16 knitting process, for example. Thus the coupling agent can
17 penetrate both the yarn bundles and the cross section
18 thickness of the surface cloth elements only to a controlled
19 depth and can effectively join together the yarns comprising
20 the outer surfaces of the fabric.

21
22 Another factor to control during fabric manufacture is
23 the use of lubricants or processing aids in the manufacture of
24 fibers, yarns and fabric. Such agents can be detrimental to
25 the achievement of a strong bond. Particularly harmful are
26 silicone lubricants and polytetrafluoroethylene processing
27 aids. The use of such lubricants should be reduced to a
28

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1 minimum or eliminated completely during manufacture of fibers,
2 yarns and fabrics. If any such agents remain on the surfaces
3 of the fabric, the fabric should be washed (scoured) or
4 properly dry-cleaned prior to application of the coupling
5 agent.

6
7 One of the advantages of prefixing the coupling material
8 to the fabric is that it virtually eliminates free and
9 laterally extending fibers when the bonded fabric subassembly
10 is die cut. The absence of such lateral fibers is important
11 in the subsequent sealing operation in which the barrier is
12 joined together in the appropriate areas at the perimeter of
13 the product so as to create an enclosure that can be
14 pressurized with a gas. In effect, the absence of laterally
15 extending fibers prevents leakage paths in the region of the
16 perimeter seal joint or in the portion of the envelop
17 laterally of the edge of the fabric. The presence of small
18 fibers or even one small fiber extending laterally and
19 bridging the perimeter seal forms a potential leak area which
20 is so small that it is extremely difficult to find in the
21 usual quality control inspection. The result is a very slow
22 and virtually undetectable leak which results in loss of
23 pressurization in a period of two to three months.

24
25 The coupling material may also be extruded as a semi-
26 molten viscose film and driven into the surface fabric
27 layer(s) using heated, and cooling, rollers on a continuous
28

1 feed process.

2
3 Still another method of applying the coupling material,
4 is to apply by extrusion or spraying a properly formulated-
5 polyol-isocyanate mixture as a viscose partially cured liquid
6 to the surface fabric layer followed by a doctor blade
7 treatment and thus with rollers and release material to drive
8 the coupling material, also referred to as a coupling agent,
9 to the necessary carefully controlled depth. This is not a
10 preferred technique because the residual reactivity of the
11 mixture is likely to react with the tensile yarn so as to
12 weaken and embrittle it. Also the bond strengths with this
13 technique are generally much poorer than can be achieved with
14 the heated platen approach described above.

15
16 The coupling material impregnated fabric is next cut into
17 the desired shape, being careful that the cut is free of
18 laterally extending fibers or filaments. The coupling
19 material impregnated fabric is then placed within the semi-
20 permeable elastomeric outer membrane envelope, and the semi-
21 permeable membrane is securely bonded to the distal surface of
22 the coupling material impregnating the upper and lower fabric
23 layers, preferably by radio frequency heating. The
24 temperature of the dies which are used to effect these
25 laminations are preferably adjusted so that melting occurs at
26 the interface between the coupling material and the inner
27 surface of the barrier membranes and not otherwise. The radio
28

1 frequency power setting, pre-seal, seal, and cooling cycle and
2 die temperatures and die heat sinks are preferably selected so
3 as to minimize the amount of heating to the fabric and the
4 barrier film. At this point the outer membrane perimeter seal
5 is not yet been made.

6
7 Another approach that can be used to bond the barrier
8 film to the fabric (impregnated with the coupling material)
9 utilizes a radiant heat source, such as infra-red heaters, and
10 atmospheric pressure to apply the needed bonding pressure.
11 This can be accomplished by sealing the two layers of the
12 barrier film (using a suitable clamping mechanism) around the
13 edges of the fabric, and then drawing a vacuum within the
14 sealed envelope. The pressure of the ambient atmosphere is
15 thus utilized to apply the appropriate laminating/bonding
16 pressure to the external surfaces of the barrier layers as
17 they become molten and flow into the cloth layers.

18
19 The part which results from the bonding of the semi-
20 permeable outer membrane to the distal sides of the coupling
21 material impregnated surface fabric members, is uniformly
22 attached by a bond which is enhanced by a multiplicity of tiny
23 connection sites comprising loops or tendrils of the yarn, so
24 that the attachment of the semi-permeable membrane to the
25 fabric is substantially continuous throughout the upper and
26 lower surface fabric members, completely free of yarn fibers
27 or filaments that may bridge (from the inner to the outer
28

1 surfaces), through the barrier envelope. The outer barrier
2 must also be completely free from pin-holes. The peel
3 strength exhibited by this structure is high; i.e., in excess
4 of 20 pounds per linear inch and generally exceeding the
5 ultimate tensile strength of the tensile yarns when subjected
6 to a typical Instron type tensile test procedure.
7

8 The cushioning device is completed into a pressurizable
9 product by welding or otherwise sealing the appropriate
10 portions of the outer membrane envelope material where the
11 material extends beyond the impregnated inner (cloth) member.
12 If the outer membrane material constitutes two sheets of film,
13 then a weld is made adjacent to the entire perimeter of the
14 inner impregnated cloth member. If the barrier envelope is
15 partially pre-formed such as in extrusion, blow molding,
16 vacuum/heat forming, thermal set casting, or vulcanizing, the
17 perimeter seal may have been partially or fully completed
18 during a previous step.
19

20 Perimeter sealing may be conveniently accomplished by
21 conventional techniques such as radio frequency welding
22 thermal impulse sealing, cementing, ultrasonic welding,
23 magnetic particle sealing, vulcanizing and the like. It is
24 here that the absence of laterally extending fibers becomes
25 important. If such fibers exist, they tend to be sealed into
26 the perimeter weld during the perimeter sealing operation and
27 form a potential leakage path. If the fiber extends all the
28

1 way to the outer periphery, it more than likely will leak
2 slowly and undetectably. If it extends only partly, it
3 constitutes a weak area where a leak may take place,
4 especially under relatively heavy and cyclic loads. By
5 applying the coupling material, as described, the subsequent
6 cutting operation is a clean cut which eliminates the
7 possibility of free laterally extending fibers.

8
9 Although not presently a preferred method of manufacture,
10 vulcanizable and/or thermal-set elastomers may be used, rather
11 than the thermal plastic urethane elastomers described above,
12 still requiring, however, the same precise degree of control
13 of the depth and quality of penetration of the elastomer into
14 the upper and lower cloth or fabric layers.

15
16 As a final step, the chamber, which is now defined
17 between the walls of the double-walled fabric, is pressurized
18 with a suitable gas, preferably a large molecular non-polar
19 gas such as supergas. In a preferred form, the gas is
20 conveniently injected through the use of a needle with the
21 injection port (which may be free of any cloth or fiber
22 material) being sealed after the pressurization is completed.
23 It is also possible to use an inflation/deflation valve. The
24 physical phenomenon which occur with inflation and diffusion
25 are described for example in Rudy U.S. Patent No.4,340,626
26 patented July 20, 1982 and attention is respectfully invited
27 to this patent disclosure.
28

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1
2 As mentioned earlier, the present device provides a novel
3 and important means for controlling the rate of diffusion
4 pumping. One objective of such control is to maintain the
5 product at design inflation pressure for longer periods of
6 time than would otherwise be possible. Because in many
7 applications the device is thin, the contained volume of
8 inflatant fluid is small. Therefore, the ratio of surface-to-
9 volume is very high. This can contribute to rapid loss in
10 pressure through diffusion. However, the addition of the
11 crystalline gas barrier elements within the barrier layer
12 serve a very unique and valuable function of metering and
13 controlling the rate of both inward and outward diffusion,
14 particularly as it applies to the O₂ and N₂ molecules in the
15 ambient air.
16

17 There is a further advantage to the incorporation of
18 crystalline gas barrier materials within the elastomeric
19 envelope of the device. Most of the millions of conventional
20 multi-chamber gas pressurized footwear components (U.S. Patent
21 4,183,156) that have been manufactured in accordance with my
22 earlier patents, and used throughout the world are normally
23 made from ester base polyurethane film, because this
24 formulation has lower gas permeability when inflated with one
25 of the supergases than does the ether-base polyurethane
26 formulation. However, ester-base film in contrast with the
27 ether-base film, has the disadvantage that it is adversely
28

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1 affected by moisture and humidity (hydrolytic instability that
2 can damage physical properties) fungus and bacteria especially
3 at temperatures above 100-110 degrees F. Therefore, such
4 conventional gas pressurized products for footwear are
5 protected by encapsulating them into a foamed midsole, which
6 is costly; and the foam attenuates and detracts from the
7 beneficial resilient properties of pressurized footwear
8 product. On the other hand, the device of the present
9 invention can utilize the desirable characteristics of the
10 more gas permeable ether-base film, and, by imbedding
11 crystalline elements in the outer barrier layers of the
12 structure, control the outward diffusion rates to acceptably
13 low levels while still benefiting from the very slow inward
14 diffusion of the ambient air nitrogen and oxygen molecules
15 which off-set any loss of the supergas so as to achieve a
16 useful life of three or more years. Foam encapsulation is
17 therefore not necessary. Air-cushions performance is greatly
18 improved, and cost and weight minimized.

19
20 As a corollary, it is sometimes advantageous to use
21 either thin films or low modulus of elasticity films for the
22 outer barrier layer of the product. This modification will
23 provide a softer, more compliant feel with greater overall
24 flexibility. By controlling or varying the modulus of
25 elasticity, the load deflection characteristics of the final
26 product may be varied. The lower modulus materials provide
27 increased comfort, while the higher modulus materials provide
28

1 better energy return qualities. The more rapid diffusion rate
2 that may exist when using such materials, can likewise be
3 offset by the addition of the distorted crystalline fibers of
4 the fabric. In some cases softness of feel can also be
5 enhanced using elastic (two-way stretch) fibers as the backing
6 yarns in the outer surfaces of the fabric.

7
8 Because the volume of the device cannot grow
9 significantly under pressure (the thickness is constrained and
10 maintained essentially constant by the tension in the pile, or
11 interface, yarns), diffusion pumping of air into the device
12 can readily over-pressurize the product during the initial 2-
13 12 months of inflation. This is a potential problem with the
14 product and of the present invention as applies to the
15 diffusion of N_2 into the pressurized device and requires a
16 solution. This potential problem is solved or eliminated in
17 accordance with the present invention by the presence of
18 crystalline gas barrier yarns or particulate elements imbedded
19 within the semi-permeable elastomeric barrier layers of the
20 pressurized enclosure. This technique can limit, reduce and
21 control the inward diffusion of the partial pressure of
22 nitrogen, which is about 12 psi, from the ambient air to
23 nearly zero over a two year period, and greatly reduce and
24 precisely control the inward diffusion of the partial pressure
25 of oxygen from the ambient air.

26
27 There are practical limits to the control of diffusion
28

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1 pumping. Even with a very tight weave of the backing yarns in
2 the outer surface of the fabric, some diffusion will occur,
3 and permeability cannot be reduced to zero. However, for the
4 best construction, it is practical to form an effective
5 control for diffusion of most gases of interest, including
6 nitrogen. However, oxygen can diffuse much more rapidly than
7 nitrogen. Using this diffusion control technique, oxygen can
8 diffuse into the enclosure over an extended period of four to
9 twelve months (after inflation and sealing at the factory).
10

11 The partial pressure of oxygen within the ambient air
12 atmosphere is about 2 psia (out of a total pressure of 14.7
13 psia). Thus, reverse diffusion of oxygen into the enclosure
14 can only raise the total pressure within the enclosure by an
15 increment of 2 psi, as a maximum. If desired, this can be
16 offset by initially under-inflating slightly with supergas (or
17 either a mixture of supergas and nitrogen gas or a mixture of
18 supergas and air). However, in some cases such under
19 pressurizing is not necessary; an increment of 2 psi is within
20 the allowable tolerance of inflatable pressure specifications.
21 Furthermore, with age and use, the device does increase
22 slightly in volume. The added partial pressure of O_2 is
23 nearly perfect in order to compensate for this small increase
24 in volume of thus provide an unusually uniform inflation
25 pressure throughout the life of the product.
26

27 If cost is of major importance, the inflatable gas can be
28

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1 100% nitrogen; and the same diffusion inwardly of oxygen will
2 occur, assisting in the maintenance of design inflation
3 pressure to offset the slow outward diffusion of nitrogen. A
4 mixture of air and nitrogen can be used in some cases where a
5 large percentage of the cross section of the outer layers of
6 the device contains crystalline material. This can be quite
7 advantageous, as the cost of nitrogen is about 1/10 that of
8 hexafluoroethane (supergas) and the weight of nitrogen is
9 about 1/5 that of the supergases.

10
11 The pressurized structures according to the present
12 invention enjoy wide utility in all sorts and varieties of
13 footwear including boots, athletic shoes, every day casual and
14 leisure shoes, dress shoes, work shoes, prosthetic
15 shoes/devices, sockliners as well as in other devices
16 including helmets and protective gear (for football, hockey,
17 soccer, baseball, and equestrian endeavors). The invention
18 can also be used for recreational, military, marine,
19 industrial and aerospace applications, including bicycle
20 handle grips, handles for jack hammers, chain saws, hammers,
21 bats, etc. as well as other seat and saddle applications for
22 bicycles, motorcycle and equestrian purposes. Playing
23 surfaces, athletic mats, flooring, work station pads, gloves,
24 life jackets and the like are other markets for the invention.
25 Since supergas is both a superior electrical and thermal
26 insulator, this device is useful where cushioning needs to be
27 combined with electrical and/or thermal insulation. It is
28

1 further noted that cushioning products made in accordance with
2 this invention and inflated with supergas will have the unique
3 ability to selectively absorb and attenuate potentially
4 damaging high frequency acoustic energy, while simultaneously
5 transmitting low frequency energy waves.

6
7 The devices of the present invention are unique at least
8 in that:

9 (1) Essentially permanent inflation can be achieved by a new
10 and novel technique to selectively control the rate of
11 diffusion pumping emanating from the ambient air.

12 (2) The use of texturizing, bulking, loops, tendrils and/or
13 single free strands to greatly increases the attachment
14 between the coupling member and the fabric and in turn
15 attachment of the fabric to the associated elastomeric outer
16 envelope material, so as to achieve a bond peel strength
17 several times greater than is possible with other conventional
18 methods.

19 (3) The two step process for attaching the gas containing
20 envelope to the fabric to achieve the necessary high strength
21 bond by:

22 (a) Carefully controlled heat, pressure and cooling
23 (freezing) under pressure and timing, applied to the coupling
24 material in order to achieve the essential, precise degree and
25 quality of penetration of said coupling material into the
26 upper and lower facing fabric layers;

27 (b) Short duration, high power RF lamination of the inner
28

1 surface of the elastomeric semi-permeable outer envelope
2 material to the outer surface of the fabric material.

3 (4) The use of special yarns and fibers that have good
4 resistance to abrasion, fibrillation and bending fatigue and
5 of sufficient pile fiber bulk.

6 (5) The use of a coupling material on the cloth which
7 eliminates laterally extending fibers and thus precludes such
8 fibers from being trapped and sealed in the perimeter seal and
9 thus bridging the perimeter seal and acting as leakage paths
10 for the inflatant gas.

11 (6) The variety of unique cushioning products which can be
12 made, especially relatively thin and essentially flat or
13 contoured products, of a wide variety of shapes and
14 configurations.

15 (7) The provision of products that can have controlled surface
16 contours.

17 (8) The provision of inflated products having a high internal
18 pressure, great durability, longevity, and service life and
19 reliability, and excellent resistance to fatigue failure.

20 (9) The use of a fabric material comprising filaments made of
21 gas barrier materials securely imbedded within the semi-
22 permeable elastomeric envelope in order to reduce and
23 precisely control the inward diffusion of O₂ and N₂ from the
24 ambient air, into the relatively thin products which typically
25 have a high surface to volume ratio and thus are much more
26 sensitive to loss of pressure.

27 (10) Products that achieve the optimum level of cushioning and
28

1 energy return or resilience (i.e., compliance) within any
2 given package limitation.

3 (11) Products that are able to selectively attenuate,
4 convert and slow-down potentially damaging high frequency
5 acoustic vibrations while simultaneously transmitting lower
6 frequency acoustic vibrations.

7 (12) Products that simultaneously cushion and also provide
8 both excellent electrical and thermal insulation, even when
9 surrounded by a high moisture environment.

10
11 Other novel features will become apparent from the
12 present detailed disclosure.

13
14 Therefore, it is an object of this invention to provide
15 an improved air-cushion type of device which produces superior
16 comfort, more effective cushioning, attenuation of potentially
17 damaging shock loads, and storage and return of energy, in an
18 inflated device which may be relatively thin and which may
19 have essentially flat and parallel or contoured surfaces.

20
21 It is a further object of this invention to provide a gas
22 inflated air-cushion type of product of the type described and
23 which will have the needed degree of reliability, durability
24 and service life in application which require superior
25 structural and fatigue resistance properties when exposed to
26 repeated application of severe cyclical loads.

1 Another object of this invention is selectively to
2 control and slow down the outward flow of inflatable gas so as
3 to maintain uniform internal pressure within a sealed,
4 relatively high surface to volume ratio device at appropriate
5 inflation levels for relatively long periods of time, (i.e., 5
6 years or longer).

7
8 Another object is to slow down and precisely control the
9 reverse (inward) flow of ambient air into the air-cushion
10 during early stages of pressurization (2-12 months), thereby
11 eliminating the tendency of over pressurization of the product
12 which in contrast with my earlier invention, has essentially
13 zero volume growth when pressurized.

14
15 A further object of the invention is to permit the use of
16 more readily available, lower weight, less expensive inflatable
17 gases.

18
19 A further object is to provide a practical inflated
20 cushioning product which can be pressurized with air or
21 nitrogen, or combination thereof and still have an acceptable
22 service life of at least two years.

23
24 Numerous other advantages of the present invention will
25 become apparent from the following description, which should
26 be read with the foregoing, and which, taken together with the
27 accompanying drawings, describes and illustrates preferred
28

embodiments of the various forms of this invention.

An internally pressurized envelope having spaced inner and outer surfaces, according to the present invention, is characterized by a load deflection curve having a first and second region, where the first region reflects the compliance upon initial application of a load, the second region reflects the compliance after the initial application of the load, and the compliance of the first region of the curve is less than the compliance of the second region of the curve.

Brief Description of the Drawings

Figure 1 is a plan view of an insole for articles of footwear according to the present invention;

Figure 2 is an exploded view, partly in section and partly in elevation, of the components of the product of this invention prior to final assembly;

Figure 2a is a view similar to Figure 2 showing the structure in a partially assembled configuration with the coupling layer having been impregnated into the outer surfaces of the fabric layers;

Figure 2b is similar to Figure 2 showing the structure in the completely assembled configuration and represents a section taken along the line 2b-2b of Figure 1;

Figures 3a, 3b and 3c are similar to Figures 2, 2a and 2b and illustrate the product of the invention wherein the

restraining means or drop threads are positioned in a triangular arrangement;

Figure 4a is an enlarged view of a single fiber diagrammatically illustrating the tendrils and attachment sites;

Figure 4b is a view, partly in section and partly in elevation taken along the line 4b-4b of Figure 4a;

Figure 4c is an enlarged exploded diagrammatic view illustrating the bond between the fabric and the coupling

1 agent impregnated envelope in accordance with this invention;

2 Figure 5 is a view of a short length of flat,
3 untexturized yarn;

4 Figure 6 is a pictorial representation of a portion of
5 fabric knitted or woven from the flat yarn of Figure 5;

6 Figure 7 is a view of a short length of yarn which has
7 been texturized by a false-twist, frictional twist, stuffer-
8 box, edge-crimp, or similar type of texturizing;

9 Figure 8 is a pictorial representation of a portion of
10 fabric knitted or woven using texturized yarn as in Figure 7;

11 Figure 9 is an enlarged view of a short length of yarn
12 which has been texturized with a special method, i.e., the
13 air-bulked, heat-set method;

14 Figure 10 is a portion of fabric woven or knit using the
15 special texturized yarn of Figure 9;

16 Figure 11 is a portion of fabric having a flannelized
17 and/or abraded surface;

18 Figure 12 is a sketch of a short length of yarn which has
19 been spun using a combination of continuous and discontinuous
20 fibers with discontinuous fibers constituting approximately
21 30% of total fiber content;

22 Figure 13 is a view partly in section and partly in
23 elevation of the composite structure of this invention mounted
24 in a radio frequency sealing press and positioned between the
25 upper and lower set of laminating dies;

26 Figure 14 is a plan view and a longitudinal section of
27 full-length inflated element having variable inflated
28

1 thickness where the thick heel portion is joined to a thinner
2 fore-foot portion by means of a tapered shank portion, in
3 accordance with this invention;

4 Figure 14a is a sectional view taken along the line 14a-
5 14a of Figure 14;

6 Figure 15 is a plan view of a heel ped in accordance with
7 the present invention;

8 Figure 16 is a plan view of a form of cobra pad cushioned
9 rear foot stabilizer insert in accordance with this invention;

10 Figure 17 is a plan view of another form of cobra paid
11 insert in accordance with this invention;

12 Figure 17a is a view, partly in section and partly in
13 elevation, taken along the line 17a-17a of Figure 17;

14 Figure 18 is a view, partly in section and partly in
15 elevation, of a multiple layer, multi-chambered product in
16 accordance with this invention;

17 Figures 19 is a view of a heel ped where the enclosing
18 envelope is pre-formed by injection molding, blow molding,
19 roto molding and the like and wherein he fabric layer is
20 impregnated with coupling agent and then heat-sealed to the
21 inner surfaces of the pre-formed envelope, in accordance with
22 this invention;

23 Figure 19b is a view in perspective as seen from the left
24 of Figure 19;

25 Figure 19c is a sectional view taken along the line 19c-
26 19c of Figure 19;

27 Figure 19d is a sectional view taken along the line 19d-
28

1 19d of Figure 19;

2 Figure 20 is a graph comparing the force-deflection
3 characteristics of a standard tubular inflated element of the
4 prior art with the new cushioning device of the present
5 invention inflated to an average pressure level;

6 Figure 21 is a graph comparing the force-deflection
7 characteristics of a standard tubular inflated element of the
8 prior art with the new cushioning device of the present
9 invention inflated to a higher than average pressure ;

10 Figure 22 is a graph of the force-deflection
11 characteristics of the cushioning element of the present
12 invention showing the portion of the load supported by the
13 drum-head property of the device and portion of load supported
14 by the thermodynamic properties of the pressurized inflatable
15 medium;

16 Figure 23a is a schematic cross-section view with vector
17 force diagrams of the cushioning element of the present
18 invention being compressed by a load (as a foot) with the load
19 making initial contact;

20 Figure 23b is a schematic cross-section view with vector
21 diagrams of internal pressure forces and forces in the barrier
22 envelope of the cushioning device of this invention,
23 illustrating how the device performs to provide the unique
24 drum-head effect and the unique force-deflection
25 characteristics of this new cushioning element;

26 Figure 24 is a graph comparing the force-deflection and
27 compliance characteristics of a conventional foam
28

1 encapsulated, tubular cushioned and pressurized sole of the
2 prior art and a non-inflated midsole of foam, sorbathane, or
3 gels, etc., with the force-deflection and compliance
4 properties of the inflated element of this invention inflated
5 to average pressure;

6 Figure 25 is a graph showing how differences in inflation
7 pressure levels can affect the force-deflection
8 characteristics of the cushioning device of the present
9 invention;

10 Figure 26 is a graph showing how different mechanical
11 devices such as lugs, bars, etc. on the inner surface of a
12 moderator pad can affect and customize the force-deflection,
13 spring rate characteristics of the device of the present
14 invention,;

15 Figure 26a is a plan view of a product in accordance with
16 the present invention having lugs and the like;

17 Figure 26b is a sectional view taken along the line 26b-
18 26b of Figure 26a;

19 Figure 27a is a schematic cross-section of the device of
20 this invention mounted in a special Kim flex-test machine to
21 provide accelerated bending fatigue testing of the inflated
22 device, with the schematic showing the inflated element in a
23 partially flexed condition;

24 Figure 27b is a schematic cross-section of the device,
25 same as Figure 27a, with the inflated element in the fully
26 flexed, bottomed-out condition;

27 Figure 28a is a highly enlarged schematic representation
28

1 of three different types of fibers in tension 1) flat
2 untexturized fiber, 2) conventionally texturized fiber, and
3 3) special air-bulked, heat set fiber;

4 Figure 28b is a schematic representation of the same
5 three fibers of Figure 28a in a partially compressed, or
6 relaxed, condition;

7 Figure 28c is a schematic representation at 1,000 times
8 actual size of the same three fibers of Figure 28b after
9 several million cycles of flexing in the near-bottomed-out
10 condition;

11 Figure 29a is a plan view schematic representation of a
12 bundle of flat, untexturized fibers, as in a portion of yarn
13 bundle, being subjected to a transverse loading condition;

14 Figure 29b is a cross-section view of the fiber bundle of
15 Figure 29a;

16 Figure 29c is an enlarged cross-section of a single flat
17 fiber of the fiber bundle of Figure 29b showing how the
18 transverse loading condition can cause bundles (or groups) of
19 molecular chains within the single fiber to start to separate
20 and subsequently break apart, causing a fibrillation type
21 failure of a single fiber (see also Figure 30), after repeated
22 application of loading and unloading of a transverse load;

23 Figure 29d is similar to Figure 29a for the example of an
24 air-bulked, heat-set fiber bundle;

25 Figure 29e is similar to Figure 29a for the example of an
26 air-bulked, heat-set fiber bundle;

27 Figure 30 is a view of a scanning electron microscope
28

1 photograph at 1000 times actual size obtained of a single pile
2 interlock fiber after one of these tensile element fibers of the
3 present invention had experienced a fibrillation-type failure
4 resulting from approximately one million cycles of compression
5 and associated abrasion, and bending and flexural fatigue;

6 Figure 31 is a graph showing how differences in volume of
7 plan-form can affect the force-deflection, cushioning properties
8 of the inflated device of the present invention, with Figures
9 31a, 31b, 31c and 31d illustrating the geometry represented by
10 the graph;

11 Figures 32 and 32e include a plan view and cross-sectional
12 views of two inflated cushions illustrating the cushioning
13 characteristics through the use of an accumulative volume into
14 which an inflation gas may be mass transported from one portion
15 of the device to another upon application of the load;

16 Figure 33a is a plan view of a device in accordance with
17 the present invention having a composite hybrid design with load
18 proportional, dynamic, automatic longitudinal arch support;

19 Figures 33b and 33c are sectional views along the line 33B-
20 33B indicating the arch area with a zero load and with the arch
21 area in a loaded condition, respectively;

22 Figure 33d is a load deflection graph illustrating
23 comparing the load deflection characteristics of a conventional
24 product and one in accordance with the present invention;

25 Figure 34a indicates, partly in section and in partly in
26 elevation and multi-layered pressurized product in accordance
27 with this invention while Figure 34B is a similar view

1 indicating the relative configuration upon application of a
2 load;

3 Figure 35a is a plan view of a product in accordance with
4 the present invention incorporation a flex line extending a
5 laterally across the product while Figure 35b is a view in
6 section taken along the lines 35b-35b.

7 Figure 36a is a 20 times actual size plan view schematic
8 representation of a filament having been imbedded in a perimeter
9 seal when the perimeter seal was made in the barrier film;

10 Figure 36b is a view in cross-section of Figure 36a showing
11 the potential leakage path around the fiber through which the
12 inflatant gas can slowly leak out of the device of this
13 invention when improper manufacturing or quality control
14 procedures are used; and

15 Figure 36c is a schematic representation at 500 to 1000
16 times size of a cross-section of a group of fibers in the outer
17 layer of fabric of the device of this invention which have been
18 impregnated and surrounded with molten coupling agent material
19 which shrinks when it cools and develops a tight shrink fit
20 around each fiber thereby eliminating potential inflatant
21 leakage paths.

22 Detailed Description of the Invention

23 Referring particularly to the drawing, which show
24 preferred forms of this invention, there is illustrated in
25 Figure 1, generally at 10, an inflated product according to the
26 present invention which for the purposes of illustration

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1 may be an insole. As shown further in Figure 2, 2a and 2b,
2 insole 10 is composed of a composite structure in which an
3 outer semi-permeable elastomeric barrier layer 12 defines a
4 pressure tight sealed chamber in which a tensile load-bearing
5 structure which comprises a double-walled thread (yarn) linked
6 fabric indicated generally at 14 is positioned. The double-
7 walled thread linked fabric structure 14 is composed of a
8 first fabric layer 16, a second fabric layer 18 and drop
9 threads 20 (pile interlace yarns) which function exclusively
10 as tensile elements in that they are placed in tension when
11 the envelope is pressurized and sealed. The material of the
12 fabric layers may be different from that of the drop threads.
13 Also indicated in these Figures are layers 23 and 24 of a
14 coupling material, as well as the loops and tendrils 29 and 30
15 extending outwardly from the distal surfaces 32 and 34
16 respectively.

17
18 It is apparent that Figs. 2, 2a and 2b are progressive
19 views of the general sequence in fabricating the product of
20 this invention. As shown in Figure 2a and as will be
21 described in detail, the coupling agent 23 and 24 is bonded to
22 the outer exposed surfaces 16 and 18 of the fabric 14.
23 Thereafter, the barrier layer material 12 is assembled and
24 bonded to the coupling material and the underlying fabric 16
25 and 18 to form an assembled coupling layer 35, the barrier
26 layer being seam welded as indicated at 38 to form an envelope
27 enclosure. Thereafter, the envelope is pressurized with any
28

1 of the gases or combination of gases described.
2

3 The material of the envelope 12 is preferably one of the
4 elastomeric materials noted in the above Rudy patents.
5 Preferred materials are polyurethane materials such as
6 polyester or polyether based polyurethane elastomers, or
7 polyester elastomer, although the invention is not limited to
8 those specific materials. Depending upon the ultimate
9 environment in which the product is used, one of these
10 materials may be preferred over the other. For example, heat,
11 moisture and bacteria tend to create problems over a period of
12 time. If the product is not used in that type of environment,
13 a polyester urethane material operates quite well. If the
14 environment is such that heat, moisture and bacteria are
15 likely problems, the polyether urethane material is preferred.
16 The latter is somewhat more expensive and requires somewhat
17 greater care in the manufacturing process for the final
18 product. With the polyether urethane, the higher diffusion
19 rate with respect to supergas is not a serious factor in the
20 novel products of this invention for reasons to be discussed.
21 It is understood that the outside surface of the envelope may
22 optionally have a relatively thin fabric material bonded
23 thereto.
24

25 The fabric material which has been described may be a
26 polyamide, for example the nylon materials noted, or polyester
27 yarns or materials such as that available under the mark
28

1 DACRON.* Polyamide materials tend to have greater tensile
2 strength and greater abrasion and fibrillation resistance than
3 the other materials mentioned, but require more care in
4 production, especially if RF welding techniques are used. In
5 general, the use of high RF energy for a short periods of
6 time, as compared to the other types of heat sealing, is
7 satisfactory. It is of course well known that RF energy is
8 quite accurately controllable.

9
10 The peel strength between the facing yarn 16 and 18 and
11 the assembled coupling layer 35 and the semi-permeable
12 elastomeric barrier layers 12 of the envelope must be at least
13 18 pounds/linear inch. The preferred values are between 25/35
14 pounds/linear each. Conventional bonding techniques are able
15 to achieve maximum peel strengths of only 8 to 15
16 pounds/linear inch.

17
18 Figures 3a, 3b and 3c are similar to Figures 2, 2a and
19 2b, but illustrate a fabric 14a in which the drop threads 20a
20 are angularly oriented. In all other respects, the structures
21 are essentially the same.

22
23 One of the important features of the present invention is
24 the provision of a strong bond between the barrier material
25 and the facing fabric material.

26
27 Referring to Figures 4a and 4b, which illustrates a
28

*trade-mark

1 fragmentary section, the fabric layers 16 and 18 each includes
2 fibers 40 having the tendrils 42 and 46 extending therefrom.
3 It is preferred that the coupling material and the barrier
4 layers 12 be of the same material to form an optimum bond.
5 The coupling material 23 and 24 only penetrates the fabric
6 layer 16 (and 18) and does not penetrate into the tensile
7 elements 20. Thus, the coupling agent does not invade the
8 region between layers 16 and 18 that is occupied by the
9 tensile elements, thus permitting the tensile elements to
10 function freely and without any restraint. In addition, the
11 elastomeric coupling material 35 securely locks the tensile
12 yarn 20 within the facing layers 16 and 18 so they will not
13 pull loose and unravel adjacent to the cut edges of the fabric
14 when cut to the size and shape of the desired product. This
15 feature is particularly important when the drop tensile yarn
16 20 is not otherwise locked into the facing cloth layers 16 and
17 18, for example in a woven three dimensional fabric. However,
18 the preferred method of manufacturing of the three dimensional
19 cloth is double needle bar Raschel knitting.

21 The texturized and kinked geometry of the individual
22 fibers causes them to act like miniature coil springs. Thus
23 applied loads are more evenly distributed across all of the
24 fibers of the yarn such that the ultimate tensile strength of
25 the yarn is approximately equal to the ultimate tensile
26 strength of the individual fibers times the number of fibers
27 in the yarn; in the non-texturized yarn the ultimate tensile
28

1 strength is only a small fraction of the ultimate tensile
2 strength of the individual fiber times the number of fibers
3 per yarn. This is because of the "Domino Failure" action of
4 the most highly stressed individual fibers.
5

6 Special finishes on the polymer filaments should be used
7 other than a polished finish, (i.e., semi-dull, dull, etc.).
8 This will increase the bond strength and thus peel strength of
9 the semi-permeable elastomer coupling matrix 35. However,
10 this must be used with caution with the pressurized product of
11 this invention, because this process weakens both the tensile
12 strength and abrasion strength of the drop thread tensile
13 fibers 20.
14

15 Bonding agents such as Dow Corning Silane Q1-6106 or PAPI
16 50 can also be used; however tests to date showed less than a
17 15% improvement in the peel strength when used on non-
18 texturized polyester or nylon 66 cloth.
19

20 Filaments having a cross-section other than round (i.e.,
21 cruciform, dumbbell, etc.) may also be used to improve bond
22 strength of the coupling layer 35, but may result in lower
23 tensile strength and abrasion resistance if used for the drop
24 tensile yarn, and they tend to be more costly. Flat ribbon
25 type filaments are more effective in controlling the activated
26 diffusion process.
27
28

1 The fiber-interface-reinforcement (facing yarns imbedded
2 into the coupling layer) is essential in order to achieve a
3 bond resistant to fatigue delamination failure. This is
4 achieved by flannelizing, abrading, or texturizing. Various
5 methods of texturizing are available, i.e., false twist,
6 friction twist, stuffer box, edge crimp and air bulk. False
7 twist and heat set air bulk are preferred, with heat set air-
8 bulk the superior of the two as explained later.

9
10 The essential characteristic of the outer surfaces of the
11 backing yarns and pile yarns in the facing layers 12 of cloth
12 are as follows: the individual filaments of the texturized
13 and/or flannelized strands of yarn must be kinked or bent, or
14 formed into loops, and/or selectively broken and protruding
15 from the yarn surface. The basic flat yarn is thus expanded
16 in diameter and volume which creates an external surface on
17 both upper and lower facing cloth members wherein spaces that
18 normally exist at the overlapping intersections of the strands
19 of the cloth are filled-in and/or covered over by the loops,
20 strands, or distorted filaments.

21
22 Thus it is important to note that appropriate texturizing
23 both the yarn that constitutes the upper and lower facing
24 cloth member and the yarn that constitutes the drop or tensile
25 yarn is essential in being able to achieve the required
26 durability and fatigue strength of the product as explained
27 elsewhere herein. It is likewise important, however, not
28

1 essential that both the texturized yarn and also the finished
2 three dimensional cloth be properly heat-set.

3
4 The surface characteristics as described above are very
5 important. In addition, it is important that the coupling
6 material of the elastomeric coupling layer 35 have a high
7 molecular weight (100,000 to 500,000, ideally 170,000-350,000)
8 and a long-chain molecule. Further, it is essential in the
9 preferred method of applying the polyurethane coupling member
10 into the upper and lower facing fabric, that the heat input be
11 uniform across the entire surface, and that the surface
12 temperatures of the heated platen be carefully controlled
13 within specified limits (350 degrees to 390 degrees F for
14 polyurethane). Accurate control of the time and heat input
15 assures that the coupling material will have the correct
16 viscosity when either mechanical or atmospheric pressure is
17 applied to drive it into the upper and lower layers 16 and 18
18 of the fabric. If the viscosity is too high, the material
19 will not penetrate sufficiently into the cross-section depth
20 of the strands of yarns. If the viscosity is correct, the
21 semi-permeable coupling material will move into the upper and
22 lower facing fabric and encompass, surround and adhere to the
23 individual filaments comprising each yarn and simultaneously
24 block and limit the penetration of the coupling material to a
25 depth not to exceed the total thickness of either the upper
26 or lower facing cloth members 16 and 18. It is extremely
27 important that the coupling layer 35 penetration not extend to
28

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1 the inside surfaces of the facing layers of the fabric, such
2 that it would interfere with the free movement of the drop
3 yarn tensile elements 20. This can happen if: 1) the coupling
4 material is not of sufficiently uniform high molecular weight,
5 2) the temperature of the coupling agent is not at the correct
6 point on the temperature-viscosity curve, and 3) the external
7 surfaces of the fabric are not structured properly as
8 described in the paragraph above, (as well as in the further
9 discussion which now follows in describing the Figures), 4)
10 the time at temperature is incorrect, 5) the applied pressure
11 is incorrect, 6) the composite product is not frozen (cooled)
12 to approximately room temperature before the release paper is
13 removed. This construction of the facing cloth 16 and 18
14 effectively constitutes a coupling agent penetration-control
15 mechanism. The high molecular weight, long chain molecules of
16 the semi-permeable coupling material drape around the very
17 fine filaments of the texturized and flannelized yarn, the
18 latter forming a filter for controlling and limiting the depth
19 of penetration of the coupling material 35 into the upper and
20 lower facing cloth layers 16 and 18.

21
22 At this point in the discussion it is important to
23 discuss further the needed characteristics of the surfaces of
24 the fabric. Figure 5 illustrates an individual flat yarn 50
25 (non-texturized) where the individual fibers or filaments are
26 essentially straight and lie together in a relatively compact
27 bundle. There is very little open space between the
28

1 filaments. The material of the coupling layer 35 cannot
2 penetrate into the cross-section of the yarn, and thus
3 attaches only to the outer surfaces of the yarn bundle. This
4 is not acceptable because (1) the bond is too weak. (2) the
5 open yarn bundle accelerates the process of outward activated
6 diffusion, instead of restricting and controlling it.

7
8 Figure 6 illustrates the additional problem with fabrics
9 having flat yarns. Open spaces 52 exist between the various
10 overlapping yarns of the completed three dimensional fabric
11 which permits the coupling material to flow essentially
12 unobstructed through the facing layers 16 and 18 of the cloth
13 into the pile area of the fabric. The pile (tensile) yarns 20
14 thus become glued together and the air-cushion will not
15 inflate uniformly to the proper thickness. In extreme
16 situations, the upper and lower facing cloth layers 16 and 18
17 are cemented together such that no inflation is possible.

18
19 Figure 7 shows a typical individual texturized yarn.
20 Loops, tendrils and filament ends 54 protrude from the surface
21 of the yarn. Individual fibers are kinked or coiled and are
22 not straight. The yarn is fluffed-up or bulked and of larger
23 diameter than a comparable flat yarn. Fibers do not lie
24 together in a compact configuration. There is substantial
25 space and openness between the individual fibers to permit
26 penetration of coupling material into the yarn. The coupling
27 material can easily penetrate the entire cross-section of the
28

1 yarn, thus locking the individual high-strength fibers
2 together within the elastomeric, semi-permeable matrix
3 (polyurethane) to form an extremely strong composite material.
4 The peel strength between the yarn and the elastomeric matrix
5 is extremely high because of the kinked geometry of the fibers
6 and the full-depth penetration of the elastomer between the
7 fibers.

8
9 Figure 8 diagrammatically illustrates a fabric 55
10 constructed with a texturized yarn as in Figure 7. This
11 fabric has no open spaces between the overlapping yarn
12 elements 55a and 55b that would permit excess penetration of
13 the polyurethane coupling material 35 as would be the case in
14 the fabric of Figure 6 made using a flat yarn. Even with a
15 texturized yarn, it is necessary to follow proper procedures
16 when knitting or weaving the fabric to insure proper (not
17 excessive) tension on the yarn during the knitting or weaving
18 process and to provide uniform density of the fabric surface
19 through all portions of the fabric. In this way, the macro-
20 molecular filter/penetration control technique is preserved and
21 is very effective in achieving the desired precise degree of
22 penetration of the coupling material 35.

23
24 Figure 9 is a pictorial representation of a single yarn
25 60 that has been texturized with a very special process. This
26 is an air-bulked yarn. Not only is this yarn bulkier than
27 other texturized yarns, but it is much more permanently heat-
28

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1 set during the texturizing process. The heat-setting
2 operation locks in the loops, tendrils and kinks 56 so that
3 even after being stretched out straight under tension and
4 relaxed many times such as during knitting or in the finished
5 product they will return to their texturized state when the
6 tension load is removed. This permanent spring-like property
7 can exist even after several million cycles of tension and
8 relaxation of tension which greatly adds to the bending
9 fatigue resistance and abrasion resistance of the pile
10 (tension) fibers 20. This will be discussed in more detail
11 later. For now, it is sufficient to say that air-bulk heat
12 set texturizing is also a very satisfactory method for
13 assisting in the macro-molecular penetration control of the
14 coupling material 35.
15

16 Figure 10 illustrates a fabric 65 which has been
17 constructed using the air-bulked yarn of Figure 9. The
18 advantages of such a fabric are superior to these of Figure 8.
19 As is apparent, it is important that the fabric layers be free
20 of any direct unobstructed passages or path ways to the core
21 or center portion of the fabric layers.
22

23 Other methods of treating the surface of the fabric to
24 add to bond strength can be used, although they are not
25 preferred approaches. These include abrading the surface or
26 flannelizing the surface of the fabric to create loops or
27 tendrils or protruding broken strands. The possible open
28

1 spaces between the overlapping yarn is thus covered by these
2 tendrils and broken filament loops to achieve at least a
3 partial macro-molecular penetration control of the coupling
4 material, as seen Figure 11.

5
6 Another less preferred approach is to use a discontinuous
7 fiber which has been spun into a yarn containing at least 70%
8 continuous filaments. Thus, the discontinuous fibers or
9 tendrils extend from the yarn surface, and the opposite ends
10 are locked into the yarn/fiber bundle, as illustrated in
11 Figure 12.

12
13 Again referring to Figure 2, because of structure of
14 filaments and yarns just discussed, as is seen, the distal
15 sides or outer surfaces 32 and 34, respectively, of the fabric
16 layers are populated with a multiplicity of tiny tendrils or
17 loops which form attachment sites or points 29 and 30. These
18 are shown as extending outwardly from the distal surfaces in
19 Figure 2 for the purpose of illustration, it being understood
20 that they are later bound within the coupling material as
21 shown in Figure 4c wherein the same reference numerals
22 previously used are again used. These attachment sites are
23 provided by the tendril members which are part of the
24 filaments from which the fabric is constructed.

25
26 Referring once more to Figures 4a and 4b, the yarn strand
27 40 includes a plurality of tendrils 42 which extend from the
28

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1 surface portion of the yarn strand. The tendrils may be loops
2 44 or fragmented fiber strands 46 or both. The procedures for
3 forming such tendrils has already been described. The
4 tendrils function to increase substantially the surface area
5 for attachment, as described. The tendrils extend in various
6 directions, depending upon the procedure used to form them.
7 As shown, there are tendrils at the upper surface of the fiber
8 strand and preferably around the entire surface area of the
9 yarn strand.

10
11 In the completed structure indicated for example in
12 Figure 4c the inner surfaces 68 of the outer semi-permeable
13 barrier layer 12 are rendered molten for the purposes of
14 bonding with the coupling agent 23, for example, which is also
15 rendered molten at the interfacing plane at 69. The
16 application of heat to the envelope during manufacturing is
17 preferably controlled so that molten zone at 35 and the
18 corresponding region of the coupling agent within the
19 respective fabric layers are the only parts of the structure
20 which become molten. This molten layer is very limited in
21 depth, both within the barrier layer and the coupling agent
22 layer (i.e., .001 of an inch to .002 of an inch deep).
23 However, in this process very strong bonds are obtained.

24
25 Radio frequency, dielectric heating (in combination with
26 heat sinks) is particularly useful in selectively focusing
27 heat input and controlling what gets hot and what does not get
28

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1 hot. The set-up which has been very effective in controlling
2 the lamination of the barrier film 12 to the coupling agent at
3 35 is shown in Figure 13. The upper and lower laminating dies
4 70 and 71, which may be configured to match the perimeter of
5 the die-cut fabric, are made of solid brass and are water
6 cooled. These dies are 1 inch to 2 inches in height to focus
7 the zone of maximum RF energy input at the horizontal center
8 plane of the fabric. Because the fabric has low dielectric
9 constant, it does not get hot. On the other hand, the
10 material of the barrier film 12 and the coupling layers 23 and
11 24 are highly polar and are quickly heated at the interface by
12 RF energy. The cooled laminating dies provide a heat-sink to
13 draw heat away from the outer surface of the barrier film.
14 The result is a sharp focus of heating at the localized
15 interface between the inner surface of the barrier film 12 and
16 the coupling material layers. This area quickly heats up to
17 approximately 350 degrees to 390 degrees F. as is seen in the
18 temperature scale of this Figure 19. At this temperature, the
19 barrier film and the coupling layer are molecularly locked
20 tenaciously together under the pressure of the laminating
21 dies. This process is best achieved with maximum practical RF
22 energy input of shortest possible time duration.

23
24 Upon joining of the envelope layer 12 (Figure 2b) to the
25 coated fabric material surface, as described, the material of
26 the coupling layer tends to merge or fuse with the envelope
27 material as one cohesive structure in which the fibrils are
28

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1 securely anchored. Since the envelope material is joined to
2 the coupling material and the latter effectively surrounds or
3 covers or encapsulates and penetrates substantially all of
4 both the relatively large yarn and the comparatively small
5 fibers and fibrils, the bond strength is exceptionally high
6 and much higher than could be achieved solely through the use
7 of coupling agents. Significantly, separation as a result of
8 the internal gas pressure does not appear to be at the
9 interface between the two materials, but rather due to
10 fracture or pulling of the fibers and tendrils with respect to
11 the coupling material 35. In other words, the separation
12 above the relatively high peel strengths noted is not
13 delamination of two distinct layers as may be the case of two
14 sheet materials adhesively bonded or laminated together.

15
16 The barrier layer 12 is hermetically sealed by means of a
17 weld 38, Figure 2b, which extends entirely around the
18 periphery of the structure to achieve a pressure tight
19 enclosure. It is preferred that the periphery of the
20 structure at the weld be about one-half the original cross-
21 sectional thickness of the two sheets of barrier material.
22 The weld 38 is normally made as close as possible to the edge
23 of the double-walled fabric 14 without trapping any of that
24 fabric material or strands thereof in the weld itself. Any
25 filaments trapped in the weld will probably cause the device
26 to leak, as will be described in detail. As earlier noted the
27 elimination of fabric or strands in the weld area may be
28

1 achieved by first applying the coupling material to the fabric
2 material. In certain instances, however, it is desirable to
3 position the weld a given distance from the edge of the cloth,
4 to create a stabilizer and pressure accumulator tube(s) or
5 section. (Figure 32, 33a-c). If a fabric material is applied
6 to the outer surface of the envelope, the surface other than
7 that which forms the perimeter weld, then none of that portion
8 of the fabric or covering cloth can be positioned in the weld.
9

10 If desired, the distal sides of the fabric may be treated
11 with chemical bonding agents such as silanes or silastic
12 materials DOW Q1-6106) to improve adhesion. It has been
13 found, however, that chemical bonding agents are not adequate
14 alone to provide the necessary peel strength.
15

16 In a less preferred procedure the distal sides of the
17 fabric 14 are flame treated so as to oxidize the surface and
18 provide a multiplicity of mechanical attachment sites. It has
19 been found, however, that flame treatment may reduce the
20 strength of the fabric beyond a satisfactory level.
21

22 Structures according to the present invention having
23 inflated thicknesses in the range of .100 of an inch to .500
24 of an inch have been successfully inflated to over 180 psi and
25 have retained those pressures for several months without
26 failure. It is also possible in accordance with this
27 invention to provide products that have variable inflated
28

1 thicknesses by having a controlled surface contour, i.e.,
2 thinner fabric at one portion and thicker at another portion.
3 Figures 14 and 14a illustrate and insole 75, for example,
4 wherein the fabric 76, already described, is knitted or woven
5 to have successively thick 77 (heel portion) and thin portions
6 79 (fore-foot portion) separated by and joined to a tapered
7 ramped section 80. In this form, an inflation/deflation
8 device 81 is also illustrated. The fabric is coated with the
9 coupling material and then die cut with the thick fabric
10 forming the heel portion, the thin fabric the forefoot portion
11 and the tapered section comprising the shank area of the
12 pressurized product.

13
14 In general the preferred barrier film material is
15 polyurethane as described in the above identified prior Rudy
16 U.S. patents the other elastomeric barrier films as identified
17 in the previously referred to patents are also applicable.
18 The coupling material is conveniently the same urethane
19 material which is used as the outer barrier layer. The fabric
20 is composed of heat set filaments so that the fabric layers
21 remain in accurate registry with respect to one another during
22 handling and fabrication. Very satisfactory results have been
23 achieved using filament shaving a denier 3, a tensile strength
24 of 3 grams per denier, approximately 40 filaments per yarn and
25 its 1 to 3 yarns per tuft or strand with the fabric being
26 composed of approximately 440 strands or tufts per square
27 inch. When radio frequency heating has been utilized to bond
28

1 the semi-permeable elastomer layer to the coupling agent
2 coated distal sides of the double-walled fabric it has been
3 found that heating the dies to between approximately 100 and
4 150 degrees Fahrenheit and utilizing a radio frequency of
5 27.12 megahertz, achieves the desired bonding without
6 impairing the rest of the structure.

7
8 The preferred inflatable gas is supergas, although the
9 invention is not limited thereto. The rate of diffusion of
10 air into the envelope and the reduced rate of diffusion of the
11 supergases out of the envelope are related to the surface area
12 through which diffusion may occur. It is again useful to
13 refer in somewhat more detail to the construction described in
14 Figures 2, 2a and 2b, for example. As can be seen, a large
15 percentage of the cross-section of the outer layers of the
16 device is occupied by fibers, comprising the distal surfaces
17 of the fabric, which are imbedded in the elastomeric materials
18 of the coupling substance 35 as well as the elastomeric
19 barrier (pressure enclosing envelope) film 12. The fibers of
20 the fabric are made from highly distorted crystalline gas
21 barrier materials (polyester or nylon, for example).
22 Diffusion rates are very low through such materials.
23 Therefore, the presence of such a large amount of distorted
24 crystalline polymers within the outer composite coupling
25 barrier layers of the product forms an effective control or
26 block to movement, by the activated diffusion process, of
27 gases either in or out of the inflated article. The rate of
28

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1 diffusion, and diffusion pumping, can be controlled by varying
2 the construction or density of the fabric outer surfaces,
3 i.e., the fibers and yarns which make up the backing portion
4 of the fabric. If desired, the construction of the backing
5 surfaces of the fabric can be changed independently of the
6 pile (interlace) portion 20, which extends between and
7 connects the outer surfaces of the fabric. Thus this novel
8 arrangement can retain the desirable and needed properties of
9 the elastomeric materials of the enclosure while at the same
10 time enjoying the benefits of control of diffusion rates, and
11 diffusion pumping, through the selective incorporation of
12 crystalline elements within the coupling layer and elastomeric
13 enclosure. The immediate effect is that in the case of
14 supergas, there is a substantial reduction in what is already
15 a comparatively low rate of diffusion out of the envelope.
16 The practical effect is that the supergas is retained for a
17 much longer period. This is especially important in thin
18 devices in accordance with this invention and which have high
19 surface to volume ratios. For example, the surface area of
20 thin devices in accordance with this invention can have
21 greater than 40 units of surface area for gas diffusion
22 compared to each corresponding unit of contained gas volume.
23 This is approximately 4 times greater than the typical
24 tubular, bulbous air-cushions of the previously identified
25 Rudy patents and thus the problem of maintaining the desired
26 uniform inflation pressure in the product for the stated life
27 expectancy is four times more severe.
28

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1
2 The secondary effect is to permit the use of gases other
3 than supergas or a greater amount of the other gases during
4 the initial inflation. For example, it is known that oxygen
5 has a high rate of diffusion through the elastomeric barrier
6 material. Nitrogen gas has a much lower rate of diffusion and
7 the supergases have still a much lower rate of diffusion.
8 Since the fabric operates to reduce the available elastomeric
9 gas passage area for diffusion, the slower diffusing gases may
10 be used as the inflatant, i.e., those gases having a diffusion
11 rate less than oxygen. Because air includes about 78%
12 nitrogen and about 21% oxygen with the balance being other
13 minor gases, air may be used as the inflatant in a properly
14 constructed part, since the diffusion of nitrogen is
15 relatively slow due to reduced surface area for diffusion, and
16 the relatively high rate of diffusion of oxygen represents
17 only 21% (2.5 psia) of the gas component. Thus, by initially
18 inflating at a relatively high pressure with air, the pressure
19 loss over time is relatively small. It is apparent that the
20 use of air or other gases having an effective diffusion rate
21 less than oxygen offers practical advantages. The diffusion
22 barrier properties of the fabric material relate to the
23 material of the fabric being distorted and stressed
24 molecularly as well as being highly crystallographic. In
25 either case the cohesive energy density is such that the
26 fabric material acts as a gas barrier.
27
28

1 When an almost 100% block to diffusion is required, a
2 tightly woven cloth (taffeta has been used successfully) is
3 impregnated with a layer of high temperature melt-point
4 urethane which is laminated to a second layer of lower
5 temperature urethane. This cloth composite is used as the
6 material of the barrier envelope 12 (instead of urethane
7 film). Lamination, using RF energy, successfully bonds the
8 low temperature layer to the coupling agent 48 on distal
9 surfaces of the fabric. In this case, crystalline elements
10 are provided not only by the backing fibers in the surfaces of
11 the core fabric, but also by the crystalline fibers of the
12 taffeta cloth outer barrier layer. In this arrangement, the
13 entire surface of the device, out to and including the
14 perimeter weld, is comprised of this special barrier product,
15 which is selectively permeable to the oxygen gas of the
16 ambient air environment, and which acts as a barrier to the
17 nitrogen gas of the ambient environment.

19 A good way to visualize some of the above concepts o
20 fusing a composite material comprising a combination of both
21 elastomeric and crystalline components is to think of the
22 elastomeric material as the matrix which binds together the
23 crystalline elements. The elastomeric material provides good
24 flexural fatigue resistance and the desired physical
25 properties of modulus of elasticity, elongation, manufacturing
26 processability and heat-sealability. The crystalline
27 components provide the proportional diffusion barrier. In
28

1 this way, the elastomeric properties of the composite
2 structure exist up to the boundaries between elastomeric and
3 crystalline elements of the structure. Thus, the crystalline
4 materials are protected from damaging fatigue stresses. Heat-
5 sealability is accomplished within the inner elastomeric
6 surface portion of the composite barrier product. A weld bead
7 at the inside perimeter juncture of the barrier product
8 assures that there are no cloth fibers exposed to the internal
9 pressurizing gas so as to create a leaking path.

10
11 Another of the advantages of the present invention is the
12 variety of shapes which may be formed. For example, Figure 15
13 illustrates a heel ped 90 in which the upper and lower
14 surfaces are planar and essentially in a parallel spaced
15 relation. This heel ped is unlike prior art heel peds due to
16 the planar configuration of the surfaces thereof as contrasted
17 to the tubular or bulbous articles of the prior art. Since
18 the heel ped of this invention is relatively thin, it can be
19 highly pressurized and is light weight, it offers significant
20 advantages over the prior heel peds since the heel profile of
21 the footwear can be much thinner permitting use in many types
22 of shoes including men's and women's street or dress shoes.
23 The structure of the heel ped 90 is as already described.

24
25 Figure 16 illustrates an inflated ped 95 in accordance
26 with the present invention and which is sometimes referred to
27 as a cobra pad because of its shape. The interior structure
28

1 of the device is as already previously described. The unit
2 may include a medial leg 97 and a somewhat shorter lateral leg
3 99 with an open area 100 between the opposed portions of the
4 legs and forward of the rear section 101. The unit 99 is
5 inserted in footwear such that the medial leg 97 is on the
6 medial side of the foot with the open area 100 generally under
7 the calcaneus. The medial leg is located under the arch of
8 the foot and provides arch support while the rear section 101
9 is curved, as shown, to fit the general contour of the heel.
10 The top and bottom surfaces are flat and planar and in spaced
11 generally parallel relation. The device tends to stabilize
12 the foot as well as to provide cushioning and arch support.

13
14 Referring to Figures 17 and 17a, a modified form of
15 inflated stabilizer 110 is illustrated again in the form of a
16 cobra pad with medial and lateral legs 112 and 113,
17 respectively. The internal structure is as already described.
18 The medial and lateral legs are spaced from each other and
19 joined to a rear section which is curved 114 to fit the heel
20 contour. In this form, there is a separate inflated chamber
21 115 forward of the rear section and between the legs. This
22 inflated section is bulbous in configuration, as seen in
23 Figure 17a to provide a special cushion element located under
24 the calcaneus. The surface of the bulbous section is above
25 the surface of the adjacent legs. In the form illustrated, a
26 heat seal weld extends all the way around the periphery of the
27 inflated chamber and is a separate chamber from the outer
28

1 portions of the ped. Thus, the outer portions may be
2 pressurized at one level and the chamber 115 at another level,
3 usually a lower pressure for comfort and cushioning. The
4 center portion may also be connected to the outer portion and
5 thus function as an accumulator to provide different load
6 deflection properties in the air-cushion.

7
8 It is understood that the separate chamber 115 may be
9 fabricated with a three dimensional fabric material rather
10 than being merely an inflated bulbous chamber. In this
11 variant, the fabric material may be thicker than the material
12 in the medial and lateral legs for added cushioning and the
13 inflatant pressure may be lower for softness under the
14 calcaneus.

15
16 Figures 18 and 34a-b illustrate an inflated structure 120
17 in which there are multiple chambers 122 and 124 formed by
18 three barrier sheets 125, 126, and 127. The barrier sheets
19 are composed of an elastomeric material as already described
20 and a fabric material, 128 and 129, as already described is
21 received between adjacent sheets. This particular form of the
22 invention may be a product in which one chamber is a full
23 length insole and the upper part is in the form of a heel ped
24 or moderator. Further, the upper part may be pressurized to
25 a lower pressure than the lower part in order to provide a
26 relatively soft upper cushion in contact with the bottom of
27 the foot and a more pressurized under section to prevent
28

1 bottoming out.

2
3 In the form of Figure 18, the upper chamber may be of a
4 smaller surface area than the lower chamber, i.e., the upper
5 part need not be coextensive with the lower part. For some
6 products, it may be desirable to use a heel pad at higher
7 pressure than the lower part since it may be placed in a
8 cavity in the heel while the upper section may function as a
9 full length sock liner. It is apparent, that the present
10 invention offers a wide variety of possible structures and
11 variations thereof.

12
13 By way of example, the pressurized article may be used
14 either as a full-length slip-in or partial length sockliner.
15 It may be configured to provide arch support as a slip-in item
16 or built into footwear. It may be installed in footwear
17 during manufacture by placement in a recessed cavity in the
18 midsole or elsewhere in the footwear. It may be fully or
19 partly encapsulated in foam in a midsole or elsewhere in
20 footwear.

21
22 It is also to be understood that the sheets of the
23 product may have different gas diffusion characteristics.
24 Thus, only one surface layer need be semi-permeable to gas and
25 the other may be impermeable. In effect, all that is required
26 is that there be at least one semi-permeable region in the
27 structure. While it is preferred to have the surfaces of the
28

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1 fabric uniformly bound to the facing surface of the barrier
2 material, there may be a situation in which defined regions of
3 one surface are not bonded or in which no fabric component is
4 present. A typical such structure is illustrated in Figures
5 17 and 17a and Figure 33a hereof. Further, it is apparent
6 that the envelope may be formed from starting materials other
7 than sheet materials. Other techniques such as blow molding
8 or injection molding may be used to form the envelope,
9 followed by joining the envelope to the fabric components and
10 then pressurizing. Figures 19-19d illustrate such an
11 approach. There, the heel ped 130 includes a thicker rear
12 wall section 132 and thicker side walls 133 and 134, as shown.
13 The fabric material 14 is also present. Additional approaches
14 would include vacuum forming, slush casting, roto molding,
15 blow molding, vulcanizing, open pour casting and the like.

17 At this point in discussion, it is important to emphasize
18 again the unique properties of compliance that the new
19 inflated device provides. As mentioned earlier, an optimum
20 cushioning product should absorb the maximum possible shock
21 input energy, and return the largest possible percentage of
22 that energy; while at the same time attenuating the shock
23 forces to the lowest possible level. Such an optimum
24 cushioning device is defined as having superior compliance.

26 The manner in which the present product functions to
27 provide good compliance is seen in examination of Figures 20,
28

1 21, 22, 23, 24. The air cushion of this invention can absorb
2 maximum shock input energy, with maximum cushioning (good
3 shock attenuation within a maximum allowable deflection)
4 because of the unique shape of the load-deflection curve 150
5 of Figure 20. The configuration of this curve 150 approaches
6 a rectangular shape, which is the ideal shape as compared to
7 curve 152 which represents the load-deflection curve for a
8 prior art multiple chamber inflated device. Figure 21
9 illustrates the energy absorption of the prior art product as
10 represented by curve 155 as compared to the energy adsorption
11 of a product of the present invention, 156, the latter about
12 1/2 the thickness of the prior art product.

13
14 Figures 22 and 23a and 23b show how this is achieved.
15 The foot is shown initially impacting the air cushion 160 in
16 Figure 23a. As is seen, the pressure within the device can
17 act over the entire load bearing surface area of the bottom of
18 the foot, instantaneously producing a large supporting force
19 before significant deflection occurs. As the foot sinks
20 farther into the air cushion, as illustrated in Figure 23b,
21 the upper distal element, which is a composite structure of
22 fabric outer layer imbedded within the polyurethane coupling
23 agent and the barrier film, acts in tension as a drum head and
24 adds a second supporting force by virtue of the vertical
25 components of the tension in the upper distal element,
26 indicated by the vector diagram 162. This additional
27 supporting force is shown in Figure 22 as the cross-hatched
28

1 area 165.

2
3 Because of the efficient energy return characteristic of
4 1) the drum head effect and 2) the very efficient,
5 essentially perfect-gas thermodynamic properties of the
6 inflatant fluid; as well as 3) the fact that cushions of this
7 invention can be built into footwear or other cushioning
8 devices without foam encapsulation (which greatly interferes
9 with the energy-return capabilities) the products of this
10 invention return a large percentage of the cushioned impact
11 energy as compared to foam encapsulated conventional gas
12 pressurized products, foam midsoles, Sorbathane*, gels, etc.,
13 which waste and dissipate most of the energy, in the form of
14 heat. In Figure 24, 170 represents the curve for the energy
15 absorbed by a conventional foam encapsulated prior art
16 product, curve 172 represents the energy return (about 40%
17 efficient) for that product; curve 175 represents the energy
18 absorbed by the product of this invention, curve 176
19 represents the energy return (50% to 90 % efficient) for such
20 product; curve 177 is for a foam product (30% efficient), and
21 curve 179 is for Sorbathane and gel type products (2%
22 efficient).

23
24 As compared to my conventional tubular prior art
25 pressurized product, it is possible to absorb a given amount
26 of impact energy in much less displacement space using the
27 product of this invention. For example, Figure 21 shows the
28

*trade-mark

1 product of this invention absorbing the same impact energy in
2 one-half the displacement distance of the conventional
3 pressurized product, still with overall excellent cushioning
4 (i.e., acceptably low-shock loads).

6 Inflation pressure is the primary factor (but not the
7 only factor) which can be utilized to alter the shape of the
8 force-deflection properties of the product of this invention.
9 Plots for three different cushions at three different
10 pressures are shown in Figure 25, i.e., medium pressure curve
11 180, high pressure curve 182 and low pressure curve 184. As
12 is seen, the high pressure unit can absorb much more energy in
13 a much restricted space (or deflection). Curve 182 of Figure
14 25 is identical to curve 156 of Figure 21. The low-pressure
15 unit has a softer feel, but can bottom-out in some instances.

17 In some cases, the sharp initial rise of the load-
18 deflection curve is objectionable. This occurs in shoes where
19 perceived comfort is of primary importance and impact loading
20 is low, as in street shoes, workmen's duty shoes and also some
21 types of walking shoes. There are various ways to produce an
22 initial softer feel (other than reducing inflation pressure).
23 Some of these are illustrated in Figure 26 and related Figures
24 26a and 26b. For example, tits, or lugs 190, bars 191 or egg
25 crate pattern 192 on the bottom of the moderator can achieve
26 this effect by altering the load/deflection characteristics of
27 the drum head (see the various dotted portions of the load-
28

1 deflection curve). The moderator is used with the air cushion
2 of this invention with the studded face in contact with the
3 cushion of opposite the cushion. In addition, the type of
4 yarn, fabric construction, modulus of elasticity of the
5 barrier film, etc., can change the perceived comfort and
6 load/deflection of the device.

7
8 It is now valuable to discuss the solution to one of the
9 more troublesome problems encountered during the six-year
10 development program which brought the new air-cushions to the
11 status of a reliable market-ready product.

12
13 The problem involves fatigue failure of the tensile
14 filaments (drop-threads) after prolonged exposure to many
15 cycles of bending, flexing, twisting and abrasion. These
16 failures (as well as delamination failures) were encountered
17 during testing of the inflated elements in many hundreds of
18 athletic shoes for many thousands of miles of testing by
19 numerous world class athletes. Although the failure rate was
20 not out-of-line with failure rates of other components of the
21 shoe, for a high pressure inflatable device of this type, the
22 reliability must be greater than for other components because
23 failure results in the overall product becoming essentially
24 useless.

25
26 Air-cushions used in athletic shoes are subjected to many
27 different types of loading in addition to that related to
28

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1 simple up-and-down motion. For example, shear forces due to
2 turning and stopping, longitudinal flexing as the foot moves
3 from heel-strike to toe-off rotation movements, lateral
4 flexing and torsional twisting during pronation and
5 supination. Very special testing machines which simulate the
6 in-shoe duty cycle are also used to accelerate the quality
7 control testing of the air-cushions. These machines run at
8 relatively high speed and subject the air-cushion to as many
9 cycles of loading in two days that an athlete would accumulate
10 in two to three years of testing. Furthermore, these tests
11 are much more severe in the type of loading so that two days
12 of testing with what we call the Kim flex tester machines is,
13 in fact, approximately equal to 3,500 miles of marathon
14 running. The typical well made running shoe will not last
15 beyond about 800 to 1,400 miles. Therefore, parts that pass
16 two days of this test will generally out last the footwear by
17 a factor of two or more times. Figures 27a and 27b show a
18 typical air-cushion 210 mounted under the movable test head
19 212 and supported by fixed guides in the form of rollers 213
20 on each side of the test head of one of these special "Kim"
21 flex-test machines. As is seen, the cushion 210 is exposed
22 to severe up-and-down compression loading as well as
23 bending/flexing as well as some shear action by up and down
24 movement of test head 212 while the rollers remain fixed.
25 Compression is provided by the head 212 forcing the cushion
26 against a contoured cylindrical seat 215, as seen in Figure
27 27b. Many of these tests were run to isolate failure modes.
28

1 The test is able to accurately and quickly duplicate the
2 failure modes experienced in the actual wear tests.
3

4 The exclusive purpose and function of the drop-thread
5 yarns is to act as tensile members to contain the pressurizing
6 medium and maintain the desired geometrical configuration and
7 structural integrity of the device. Therefore, the subject
8 failure problem was somewhat unexpected in that it occurs
9 during the portion of the duty cycle when the drop-yarns are
10 not in tension and are not performing any useful function.
11 The drop-yarns have no purpose when not in tension and do not
12 support compression loads, so as not to interfere with the
13 primary function of the pressurizing medium which is to
14 support compression loads.
15

16 A good design deflects as much as possible within space
17 constraints, so as to allow the pressurizing medium to fully
18 support and attenuate shock loads and absorb and return as
19 much otherwise wasted energy as possible. As soon as the drop
20 yarns go out of tension (Figure 28b) they start to bend, coil
21 and fold. As the downward motion continues, they bend and
22 fold further in random fashion and thus also rub against one
23 another. During this portion of the duty cycle, there is
24 considerable motion among and between the yarn strands. This
25 motion is aggravated by shearing loads (associated with
26 stopping and turning) applied to the air-cushion as well as by
27 the longitudinal and lateral twisting and flexing of the
28

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1 cushion as the athlete goes through the sometimes very severe
2 motions while performing various athletic endeavors. Such
3 bending and flexing of the drop yarns generates fatigue
4 stresses in the outer portions of individual fibers. Abrasion
5 damage can occur as the fibers squirm and move against one
6 another. Under extremely heavy load conditions (i.e.,
7 generally less than 2% of the normal time/life duty history of
8 the part) the product bottoms-out trapping and crushing the
9 tensile fibers against one another and against the inner
10 surfaces of the composite facing layers (Figure 28c). After
11 many cycles of such contorting, it is possible for tensile
12 yarn filament fatigue and fibrillation failures to occur as a
13 result of the repeated crushing of the tensile elements when
14 bottoming-out occurs, (Figures 29c and 30). Some of the
15 fibers are weakened and then subsequently fail in tension.
16 Tension stress in remaining fibers increases, and a ripple
17 effect occurs as successive fibers fail in tension. Eventually
18 an aneurysm occurs. The air-bulk, heat set texturizing of the
19 fibers is effective in controlling and preventing this type of
20 failure and is explained next.

21
22 Because most cushioning devices of this type are designed
23 to operate close to their limits for bottoming-out, in order
24 to provide maximum cushioning in minimum space, instances of
25 bottoming-out do occur, which aggravates this failure problem.

26
27 In order to solve this problem, considerable failure
28

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1 analysis and laboratory testing were conducted. The mechanism
2 of failure and the solutions which were devised to solve the
3 problems are best described in referring in more detail to the
4 series illustrated in Figures 28 and 29. The series of Figure
5 28 illustrates the manner in which three types of fibers, i.e.,
6 1) straight or flat fibers 200, 2) conventionally texturized
7 fibers 201 and 3) air-bulked, heat-set fibers 202 function
8 differently during the downward flexing mode, especially as
9 regards the bottomed-out condition. As is indicated in Figure
10 28a, when in the tension mode, all three types of fibers are
11 stretched-out in a taut, straight line, and all three
12 function in much the same way under tensile loads. However,
13 as soon as an external compression load is applied, the air-
14 cushion deflects downwardly and the fibers of the drop yarns
15 immediately go out of tension and enter the relaxed mode
16 (Figure 28b). The straight (untexturized) fiber 200 functions
17 much like an Euler column and starts to bend. The
18 conventionally texturized fiber 201 (which, as seen, is
19 bulkier than the straight fiber) shortens in length like a
20 coil spring. The air-bulked, heat-set fiber 202 (bulkier than
21 the conventionally texturized fiber) also shrinks in length in
22 a similar manner as a spring. The bottomed-out condition,
23 after several million cycles of up and down flexing is shown
24 in Figure 28c. As is seen, the straight fiber 200 has bent
25 over onto itself. The air-bulked fiber 202 is compressed into
26 a bulky, compliant bundle of looped and intermixed fibers
27 coiled amongst themselves in various directions in random
28

1 fashion. The conventionally texturized fiber 201 because of
2 many cycles of tension and flexing is seen as having resorted
3 back to its original pre-texturized condition, i.e., it is now
4 a straight fiber, and, as such, has bent back upon itself in
5 the same way as the other straight fiber in this illustration.
6 After many cycles of exposure to such action the fiber will
7 tend to fail, as next explained.

8
9 A portion of a yarn containing the straight fibers is
10 shown in the bottomed-out configuration (at 40 times actual
11 size) in Figure 29a. As is seen, the fibers are tightly
12 packed together in essentially a parallel, aligned, side-by-
13 side arrangement. The compression load is shown applied to
14 the sides of the yarn bundle as seen in Figure 29a and the
15 cross-section Figure 29b. The fibers are applying transverse
16 loading one to another. Each fiber is made from a polymer
17 with a long-chain molecule oriented generally along the
18 longitudinal axis of the fiber. After prolonged bending and
19 flexing during the up and down portions of the cycle,
20 coupled with the squirming, rubbing and transverse loading of
21 the bottomed-out portion of the cycle, transverse decohesion
22 (delamination) between individual bundles of molecular chains
23 within the interior of a single straight fiber can occur.
24 This failure mode is illustrated in Figure 29c which is a
25 magnified cross section view (1000 times actual size) of a
26 single fiber from the bundle of fibers (Figure 29B). As is
27 seen, when the transverse compression load is applied to the
28

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1 straight fiber, the fiber tends to burst outwardly on the
2 horizontal centerline plane, and tensile separation stresses
3 occur at the sides of the fiber tending to delaminate and
4 unravel the various bundles of molecular chains one from
5 another. The fiber breaks apart into individual bundles or
6 strands of molecular chains. Eventually, these small strands
7 are weakened by fatigue and soon snap and fail either in
8 tension or bending. This condition is seen in Figure 30 which
9 is a scanning electron microscope photograph of a typical
10 failure of this type (enlarged approximately 1,000 times).
11 The separation of a single fiber into various strands (of
12 molecular bundles) is seen.

13
14 On the other hand, the heat-set, air-bulked fibers
15 (Figure 29d and 29e) behave differently from the straight
16 fiber. The air-bulked fibers in the bottomed-out condition
17 have been compressed into an intertwined mass of looped and
18 undulating filaments. Such a conglomeration of fibrous
19 material functions as a cushioning element (much like a felt
20 mat), thereby mitigating compression stresses on any single
21 filament and distributing forces throughout the fibrous
22 volume.

23
24 As a result of testing and analysis of the type just
25 described, it was determined that several factors are
26 important to take into consideration in order to control or
27 eliminate this type of failure. First, it is important to
28

1 have a fiber with the longest possible molecular chain
2 oriented as much as possible along the longitudinal axis of
3 the filament. Secondly, it is important to use a polymer with
4 superior abrasion resistance, such as DuPont's industrial
5 polyester 68L. Better yet, are fibers made from the NYLON 66
6 family, especially CORDURA* nylon, (having especially long
7 chains).

8
9 Thirdly, texturizing of the drop-thread filaments is
10 anecessity to improve abrasion flexural fatigue, and
11 fibrillation resistance by helping to cushion the loading on
12 any individual fiber and preventing the filaments from being
13 subjected to sharp folds, as yarns move against one another.
14 In this regard Cordura, is greatly superior because of its
15 air-bulked type of heat-set texturizing which not only
16 provides a yarn with increased bulk but also with fibers which
17 retains their texturized spring-like condition after prolonged
18 cycles of going from the tension mode to the relaxed, folded
19 mode and back again to the tension mode because of being heat-
20 set in the texturized condition. Other types of texturized
21 filaments, lose their texturized shape after exposure to
22 repeated cycles of loading and unloading (as we as due to
23 heating during fabrication) of the product and return to their
24 original untexturized, flat yarn configuration. It is for
25 this reason that air cushions of this new type made from
26 Cordura nylon exhibit a service life which is about one order
27 of magnitude better than the standard texturized nylon 66
28

*trade-mark

1 yarn. Further, the standard texturized yarn is approximately
2 one full order of magnitude superior in service life than the
3 flat untexturized tensile yarn.

4
5 There is also a fourth important consideration to
6 minimize these failures. It has been found necessary to
7 provide a sufficient number of fibers per unit area of the
8 drop threads to further cushion the abrasion and transverse
9 loading forces, especially those associated with side-load
10 shear crushing and bending of the planar surfaces of the air-
11 cushion. In this regard, the approximate minimum number of
12 drop yarn fibers per square inch is 5,000 and the maximum is
13 approximately 80,000.

14
15 Several other embodiments of the invention are shown in
16 Figure 31 and related Figures 31a-31d in order to highlight
17 the different cushioning properties possible with different
18 types of designs all at the same inflation pressure. The
19 Figure 31a ped 220 exhibits a steep rise 220a in support force
20 as deflection increases because of the small volume of gas
21 contained within the ped (i.e., most of the load supporting
22 volume of the device is trapped beneath the loaded area). The
23 various compartments 221, 222 and 223 of the Figure 31b full-
24 length design behave in the same way (220a), and provide a
25 stiffer feel as compared to the full-length cushioned product
26 225 of Figure 31d (see 225a). The form 227 of Figure 31c, in
27 a dog-bone configuration, provides support primarily under the
28

1 load-bearing portions of the foot (for cost saving purposes),
2 and has an intermediate force-deflection curve 227a.

3
4 Referring to Figures 32 and 32a-32e, another way to
5 influence and control the cushioning characteristics is to
6 provide an accumulator volume into which the inflation gas can
7 be mass transported from one portion of the device to another
8 upon application of load. One such accumulator transport
9 volume can be around the perimeter 230 as is shown in Figures
10 32, 32a and 32b. The larger volume 233 of Figures 32c-32e, of
11 course, provides the softer feel. The softness of feel is
12 achieved in two ways: 1) the extra volume outside the loaded
13 area (Figure 32e) provides a space for the inflatant gas to
14 move into upon application of load and 3) the elastomeric
15 film enclosing the accumulator can elastically expand and
16 contract in response to changes in the gas pressure when the
17 load is applied, thereby further increasing the volume of the
18 accumulator and the soft responsive cushioning properties of
19 the device. This larger tubular section serves a secondary
20 dynamic, load proportional function of cupping and holding the
21 foot centrally positioned within the shoe.

22
23 Figure 33 illustrates an alternate and beneficial unique
24 means for providing an accumulator volume. This is
25 accomplished by having a hybrid product 250 in accordance with
26 this invention, including a standard air-cushion system
27 incorporating a tubular portion 251 in the arch area, as shown
28

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1 in Figures 33b and 33c and a portion 252 in accordance with
2 this invention. Figure 33b shows a section view through the
3 arch area with zero load. Figure 33c is the same section view
4 in the loaded condition. Figure 33d is the load-deflection
5 graph illustrating the conventional product 253 in accordance
6 with this invention (without the standard air cushion) while
7 plot 255 is that for the hybrid product in accordance with
8 this invention. As is indicated, the tubes can elastically
9 grow and shrink in size (diameter) when the load is applied
10 and removed in direct proportion to the applied load and the
11 resultant instantaneous pressure changes within the device. A
12 softer feel is provided to portions of the air-cushion where
13 the load is applied (heel area or forefoot). Also an
14 automatic dynamic arch support proportional to the wearer's
15 need occurs under the longitudinal arch portion of the foot to
16 assist as an orthotic device for pronation control. At toe-
17 off the arch support automatically recedes away from
18 supportive contact with the foot so as not to irritate the
19 plantar tendons as they extend during the toe-off phase.

21 Another interesting configuration involves a multi-layer
22 pressurized product. This is shown in Figures 34a, 34b and 18
23 where the reference numerals are the same. The two (or more)
24 pressurized layers can be achieved with two separate tensile
25 air-cushion devices, one on top of the other, with separate
26 perimeter seals, all as already described. Another method is
27 to laminate the stack in a single operation, and to seal the
28

1 three sheets of barrier film around the perimeter in a single
2 operation. For maximum comfort, the top portion can be
3 inflated to a lower pressure than the bottom chamber. The
4 top, at lower pressure, thus deflects more easily than the
5 bottom portion, and conforms more readily to the bottom planar
6 surface of the foot; thus a high degree of initial contact
7 softness is perceived. The higher pressure bottom chamber
8 prevents the device from bottoming-out under high loads and
9 returns a greater percentage of the otherwise damaging and
10 wasted impact energy.

11
12 In some shoe applications, a high degree of toe flex is
13 desired, as in a walking shoe. This can be achieved by
14 incorporating two or more separate ped elements into the shoe,
15 one for the heel and one for the forefoot, and possibly one
16 for the arch/mid-foot region. Another method involves sewn
17 flexlines 260 extending laterally across the die-cut fabric
18 blanks prior to the final step of laminating the barrier film
19 into place as shown in Figures 35a and 35b. Such sewn lines
20 draw the fabric down a prescribed distance ($1/2$ to $3/4$ of the
21 thickness of the fabric) using care not to seal the fabric
22 completely closed, thereby precluding movement of air across
23 the sewn line, or a line of discomfort under the foot.
24 Another method is by having lugs, or bars positioned on the
25 bottom of a moderator element in the region(s) where flexure
26 is desired, as shown in Figure 26a.
27
28

1 To better understand the leakage problem which was
2 discovered to be a significant problem and which is solved by
3 this invention, reference is made to Figures 36a, 36b and 36c.
4 In Figures 36a and 36b, a weld section 275 composed of layers
5 275a and 275b is shown in which the pressure side is 276. A
6 single filament 277 is shown extending through the weld 275
7 from the pressure side 276 to the outside ambient pressure
8 side 278. The residual stress in the film or layers 275a and
9 275b tends to pull away from the filament 277 resulting in
10 minute leakage paths 279a and 279b typically along the lateral
11 sides where the layers join to the filament. As shown the
12 filament 277 extends all the way through the weld and
13 represents the worst condition. Leakage may occur even if the
14 filament does not extend all the way through the weld since
15 the distance between the end of the filament and the outside
16 of the weld may be sufficiently small to permit more rapid
17 diffusion in that area than is taking place in other regions
18 of the film.

19
20 Figure 36c illustrates another feature of the invention
21 which is the effect of the coupling agent in reducing leakage
22 along the fibers 290. For example, fiber 291 is one of the
23 drop threads and is located on the gas pressure side 295 of
24 the inflated product of this invention. During application of
25 the coupling agent, the latter is melted and flows around the
26 fiber, as indicated at 297, effectively sheathing all or a
27 portion of the outer surface of the fiber with coupling
28

1 material. This effectively prevents or substantially reduces
2 passage of the gas along the fiber or the outer surface
3 thereof and between that surface and the barrier film
4 material.

5
6 What has been described are preferred embodiments and
7 modifications in which changes may be made without department
8 from the spirit and scope of the accompanying claims.
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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An internally pressurized envelope having spaced
inner and outer surfaces characterized by a load deflection
curve having a first and second region,

the first region reflecting the compliance upon
initial application of a load,

the second region reflecting the compliance after
the initial application of the load, and

the compliance of the first region of said curve
being less than the compliance of the second region of said
curve.

1/18

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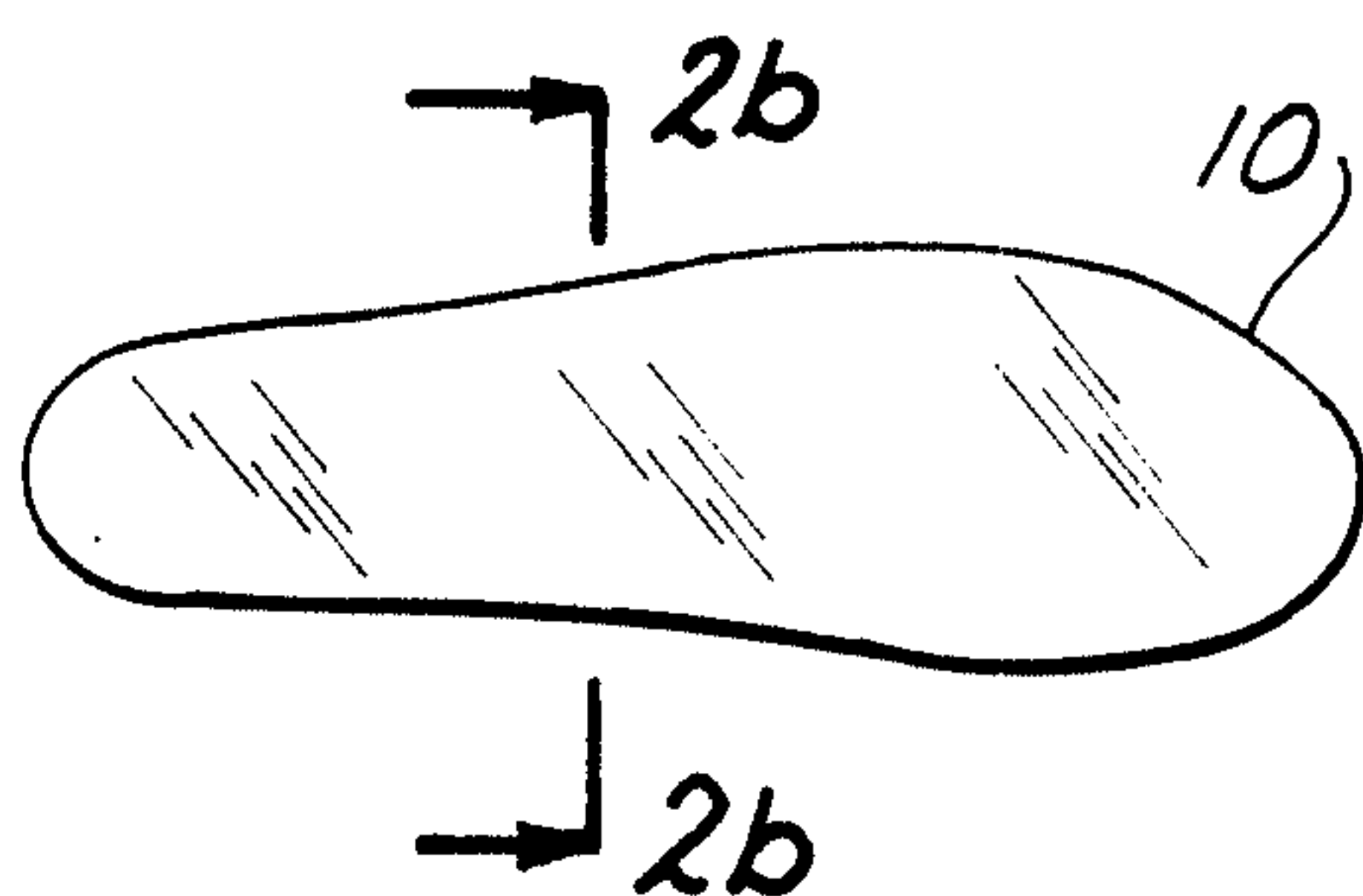


FIG. 1

FIG. 2

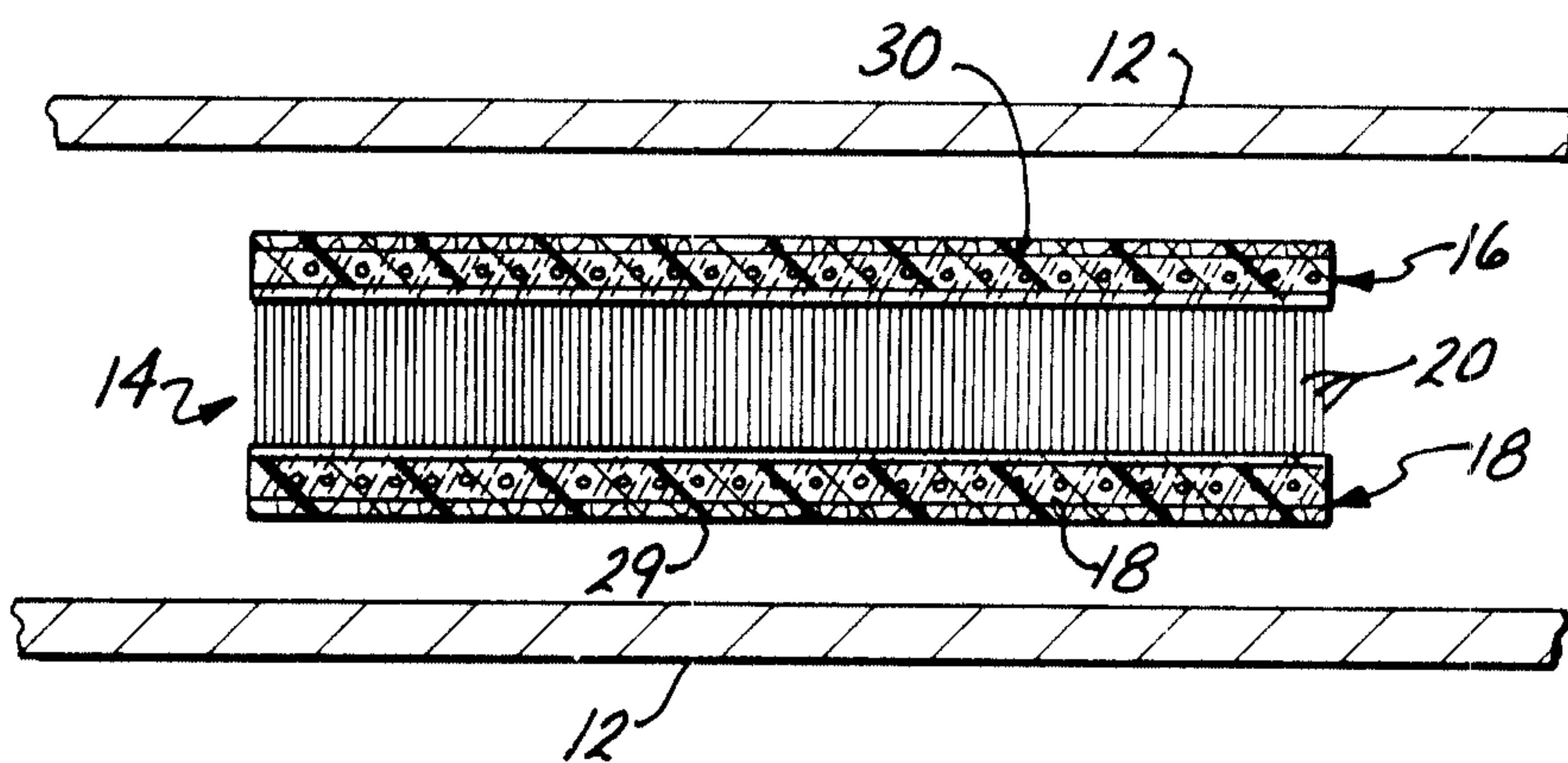
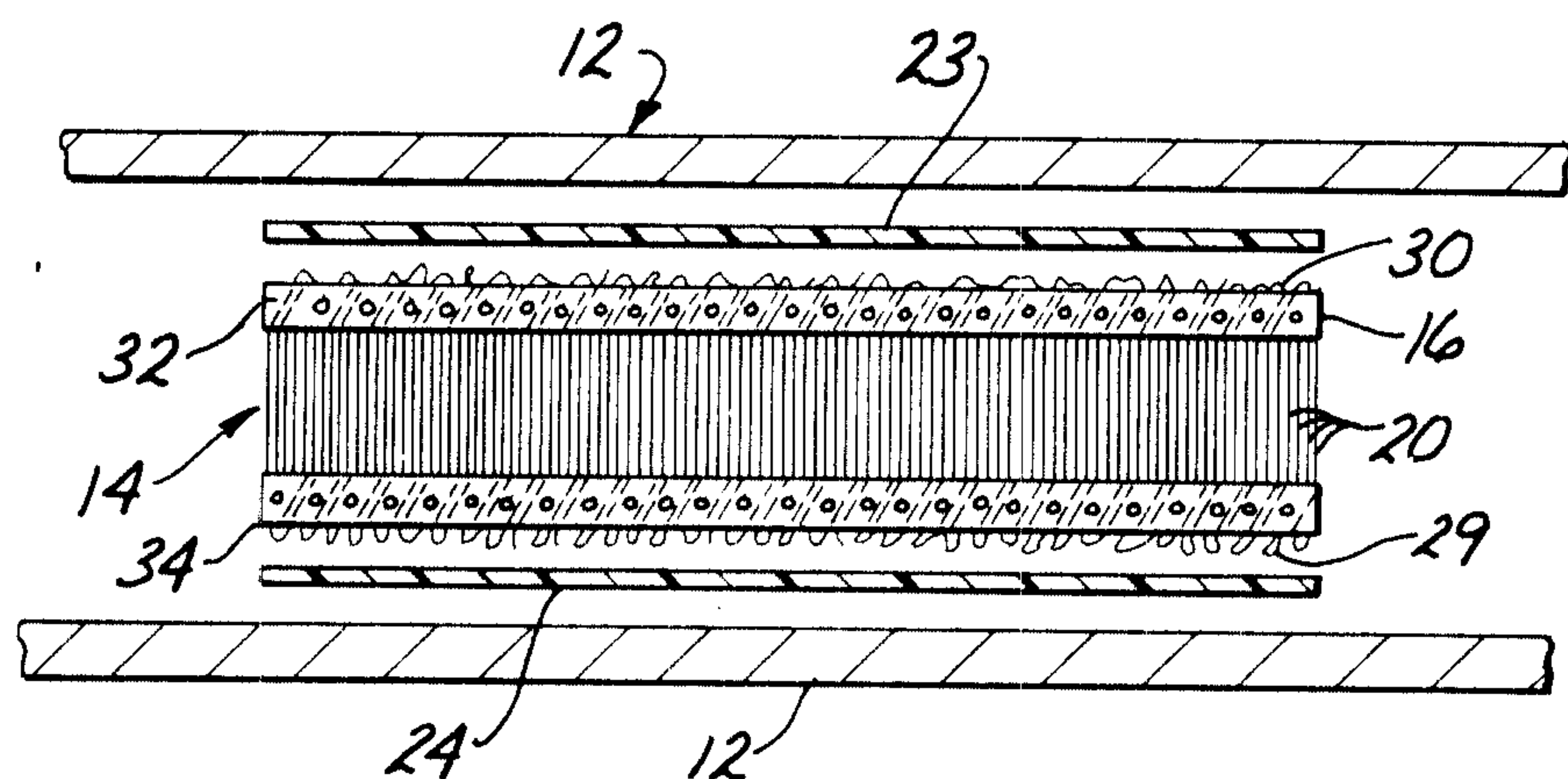


FIG. 2a

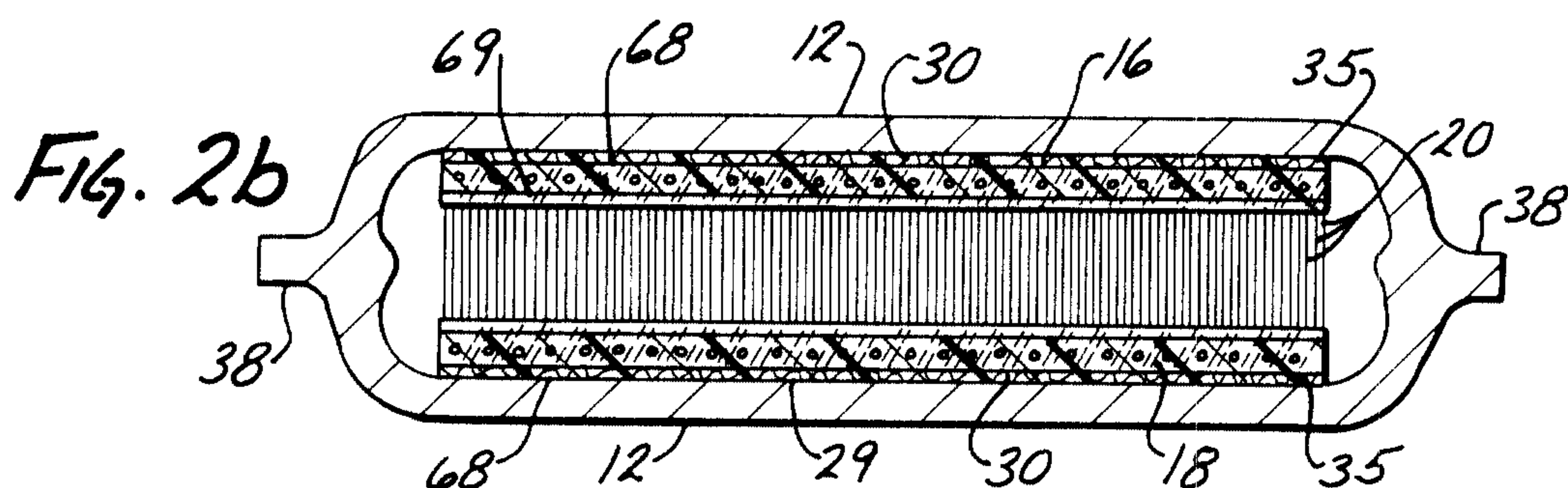


FIG. 2b

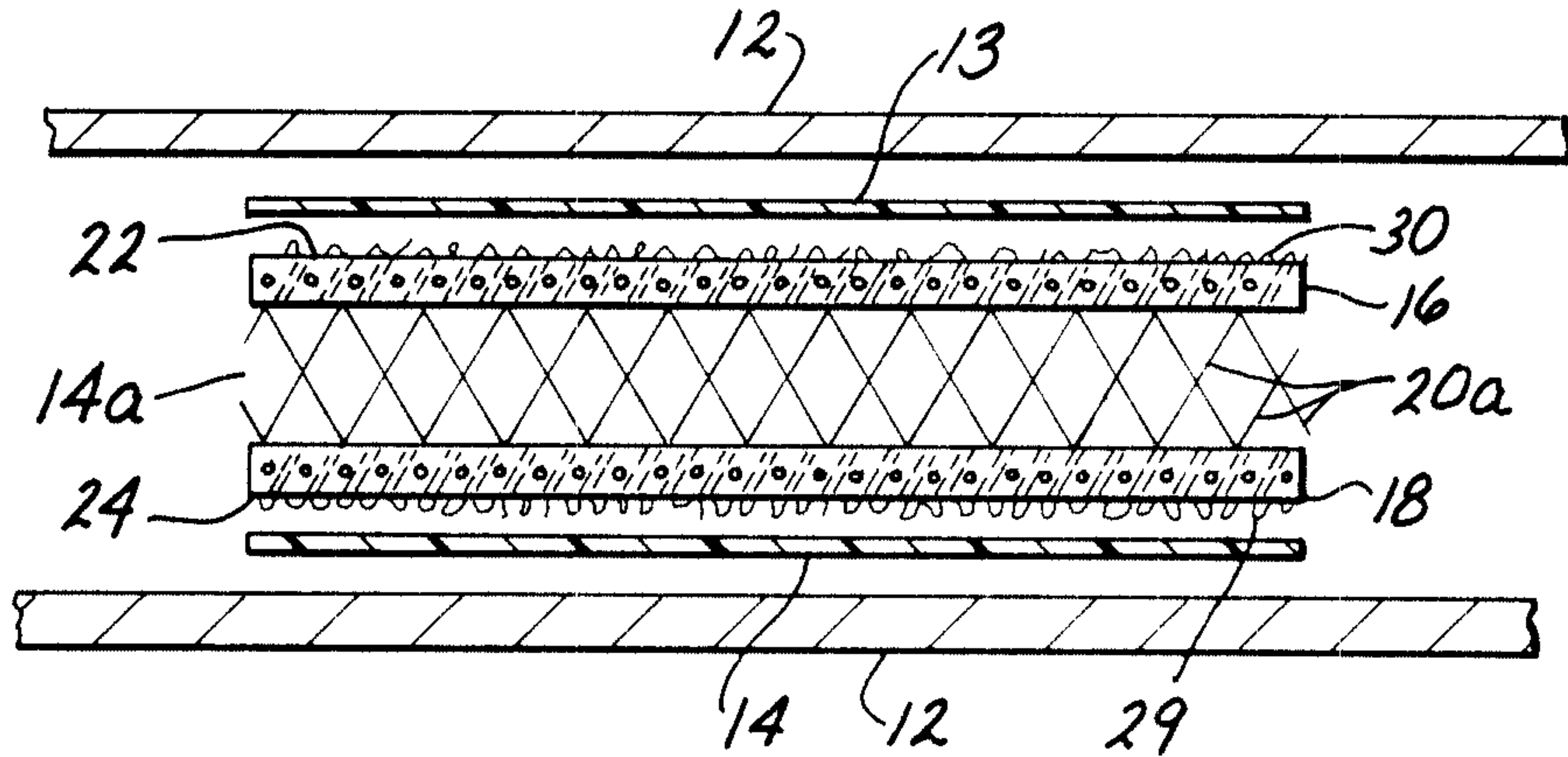


FIG. 3a

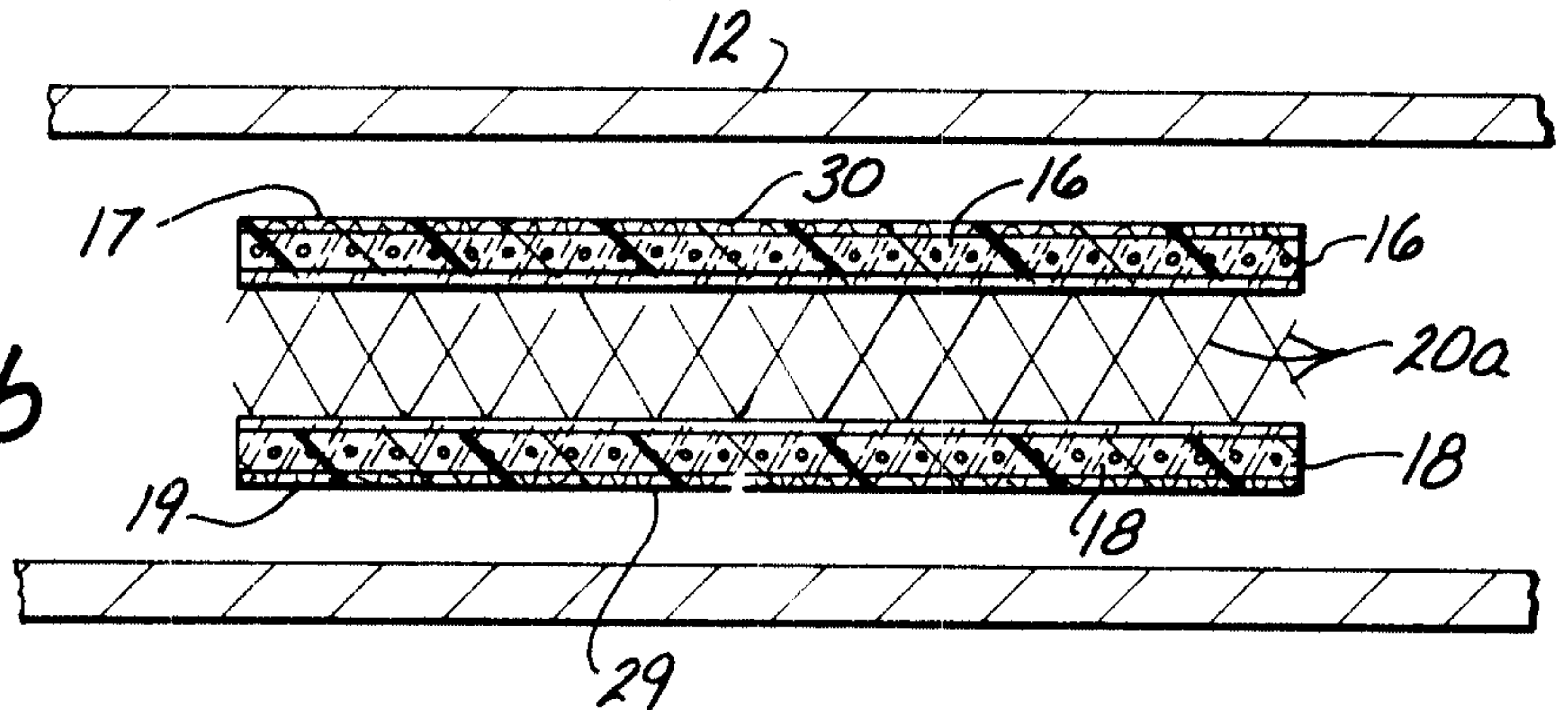


FIG. 3b

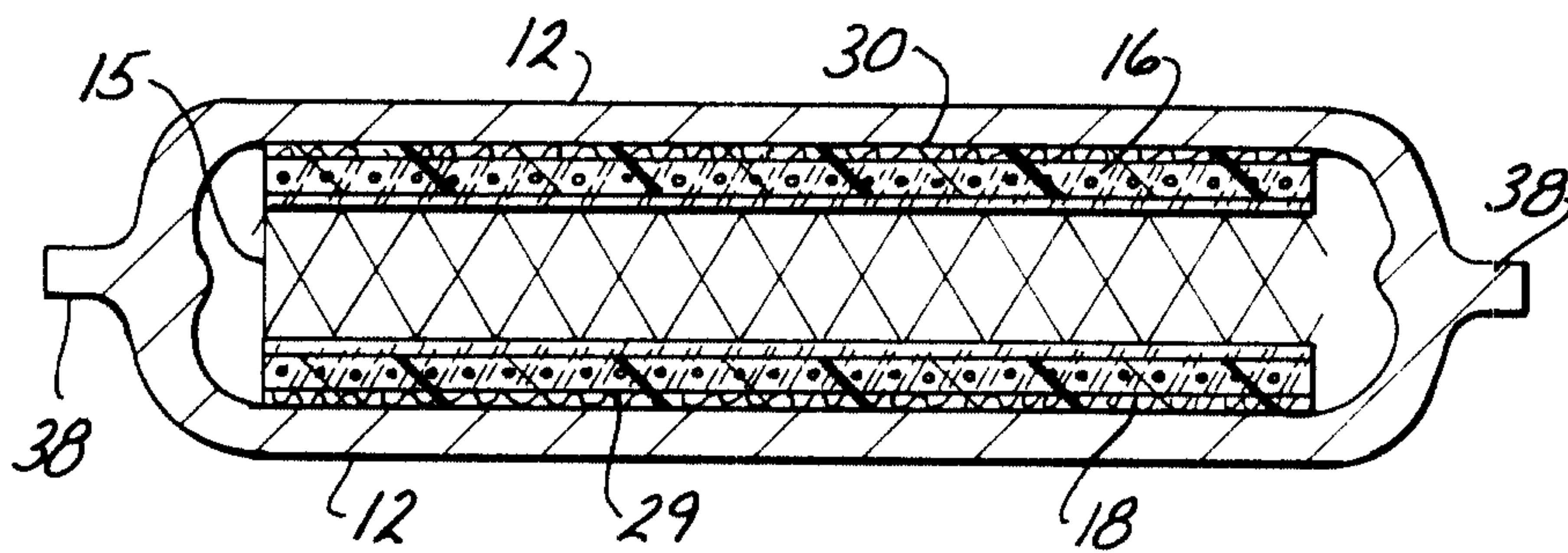


FIG. 3c

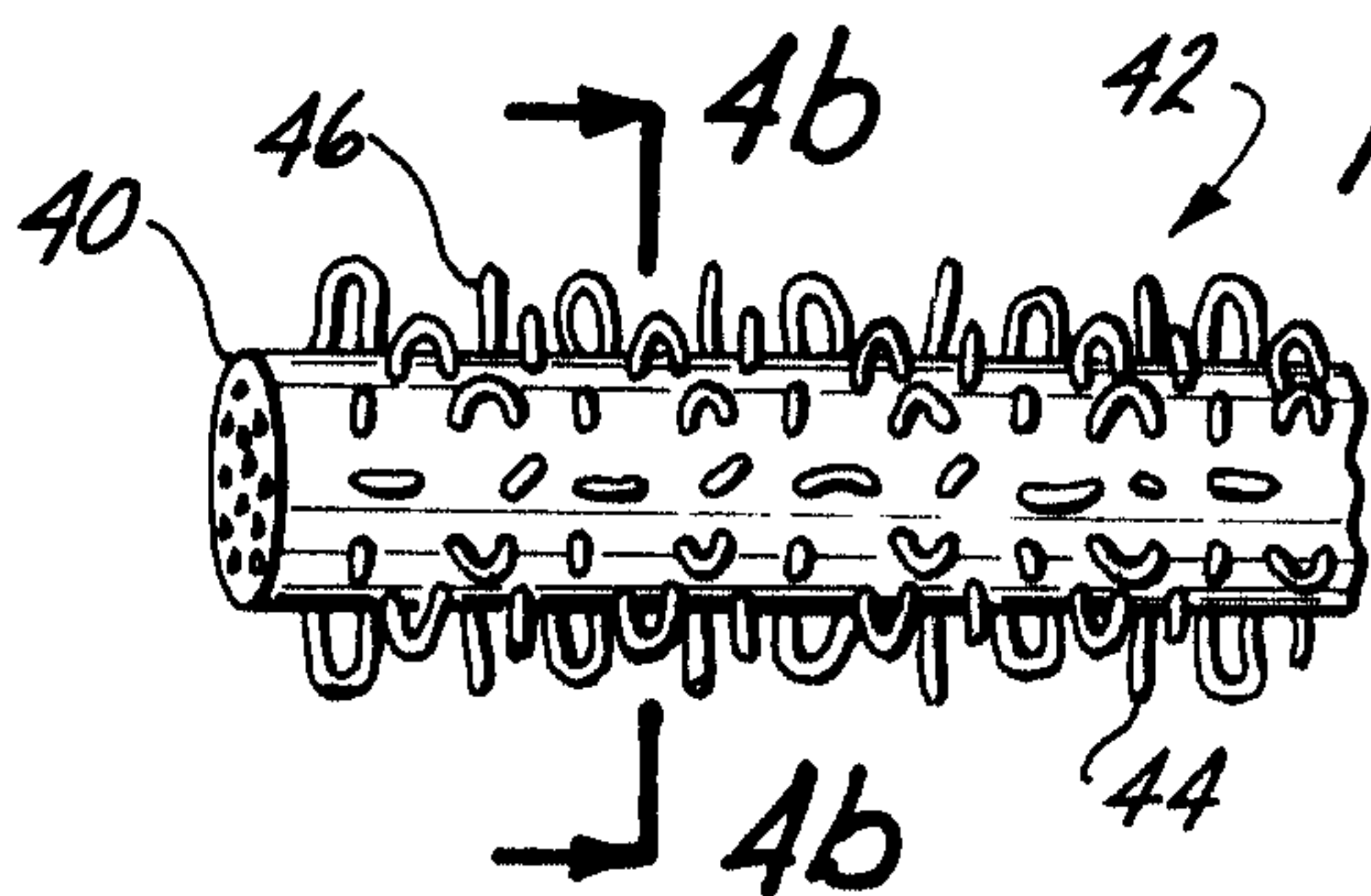


FIG. 4a

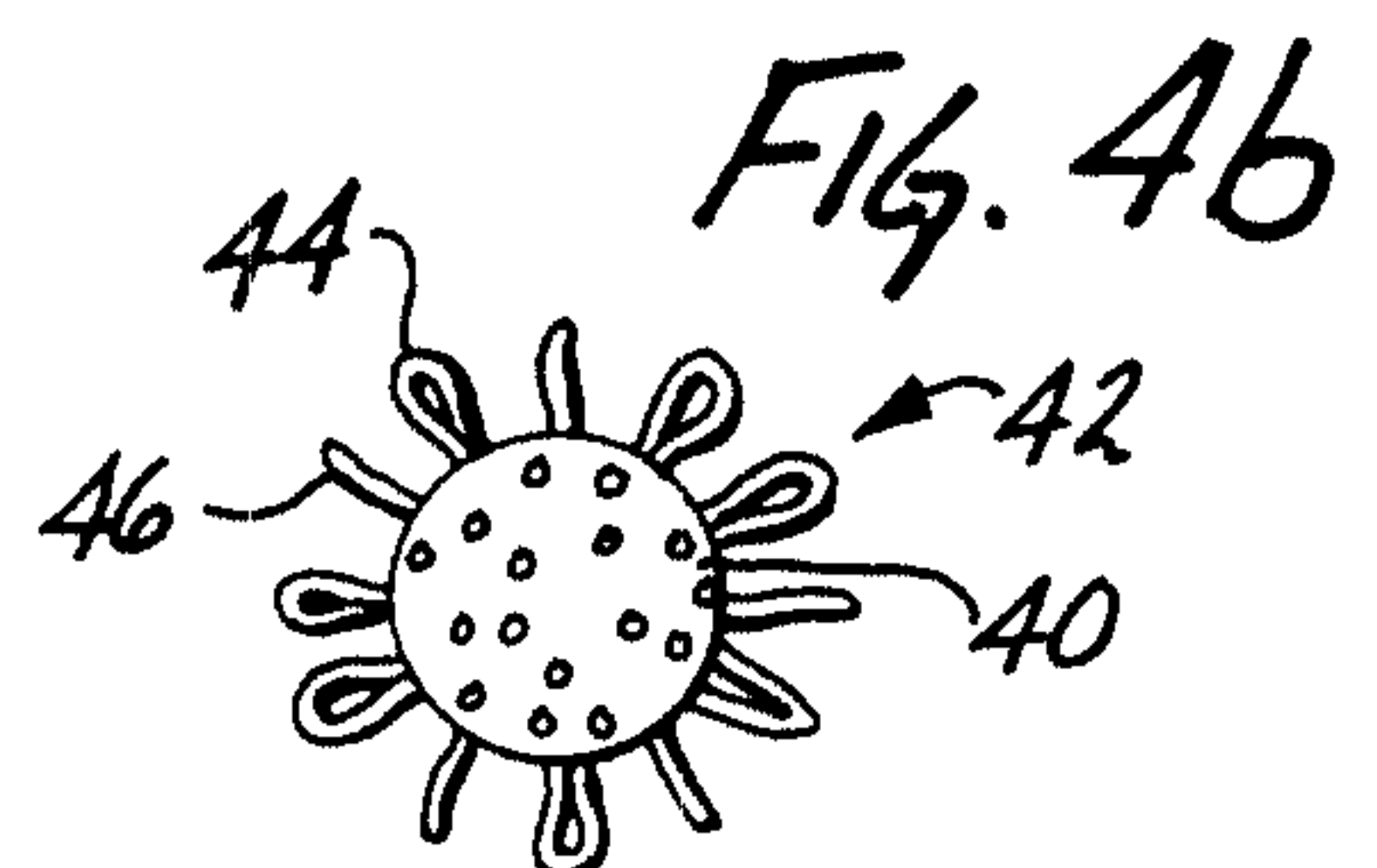


FIG. 4b

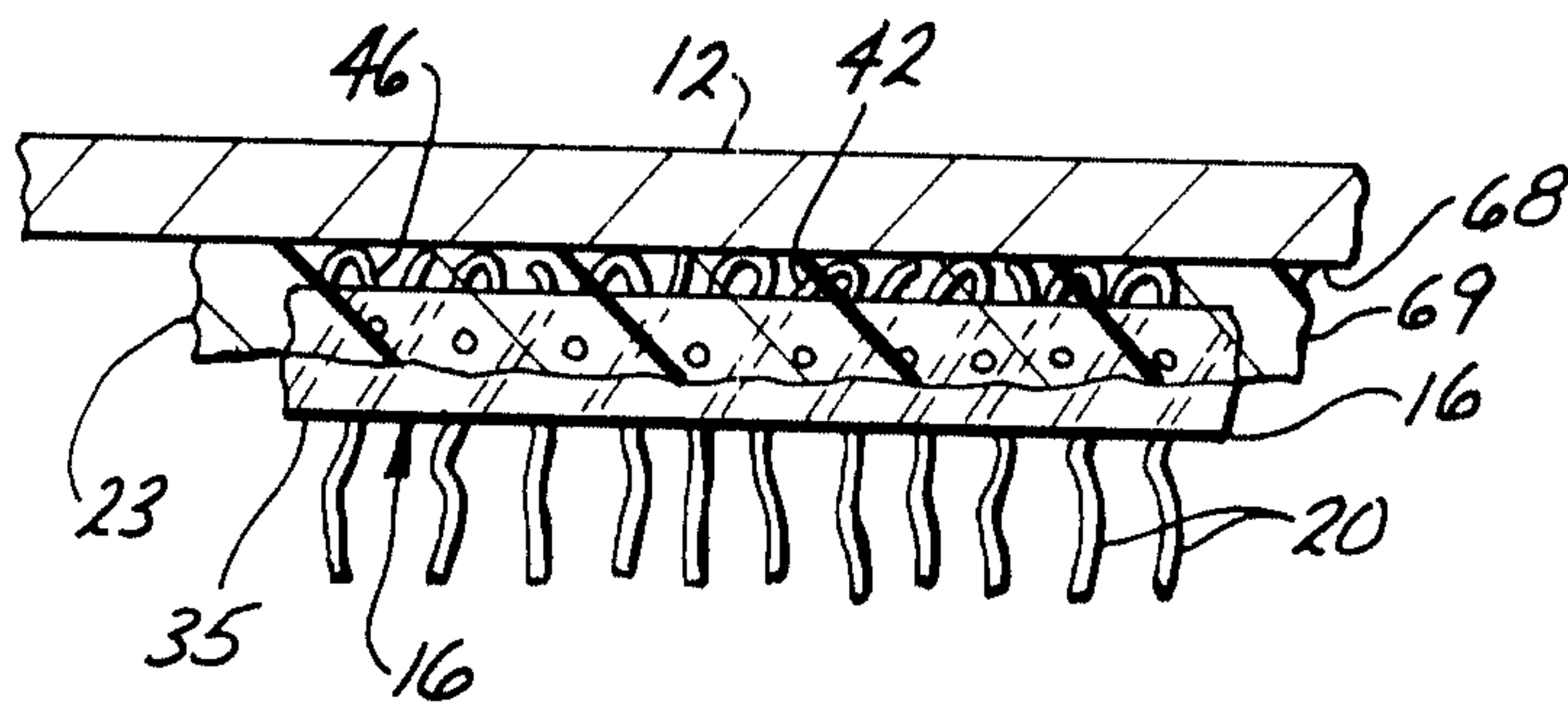


Fig. 4C



50

Fig. 5

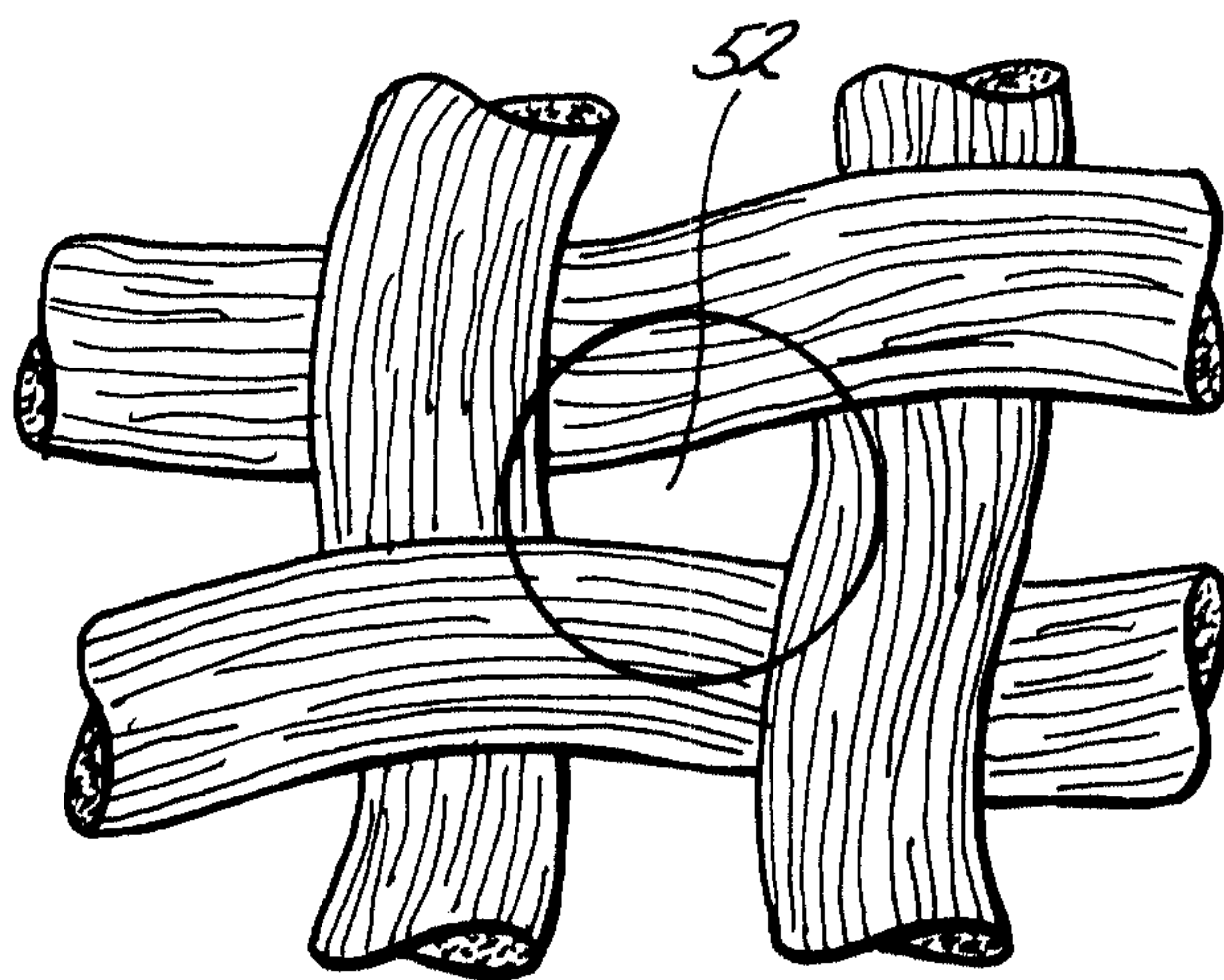
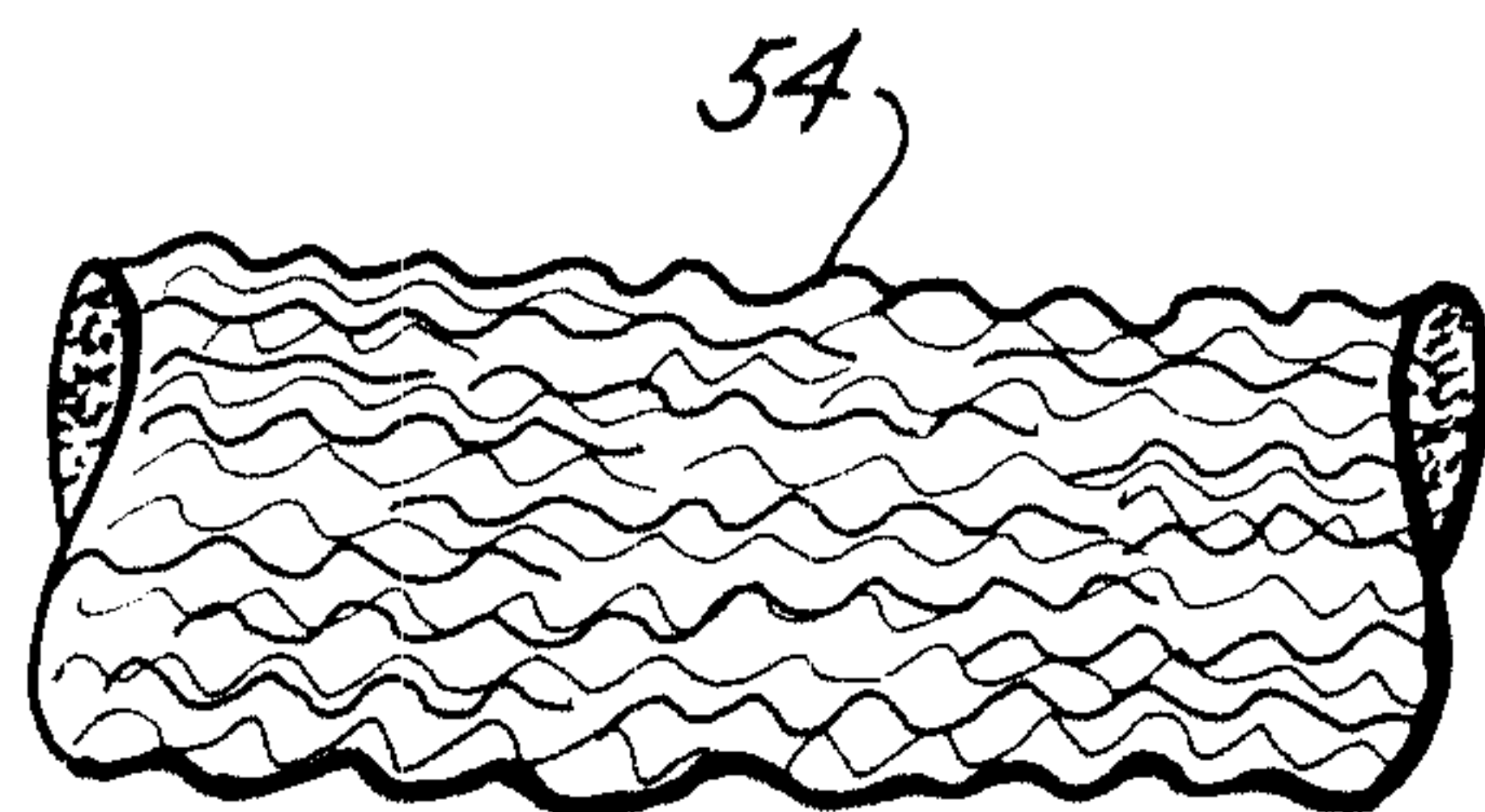


Fig. 6



54

Fig. 7

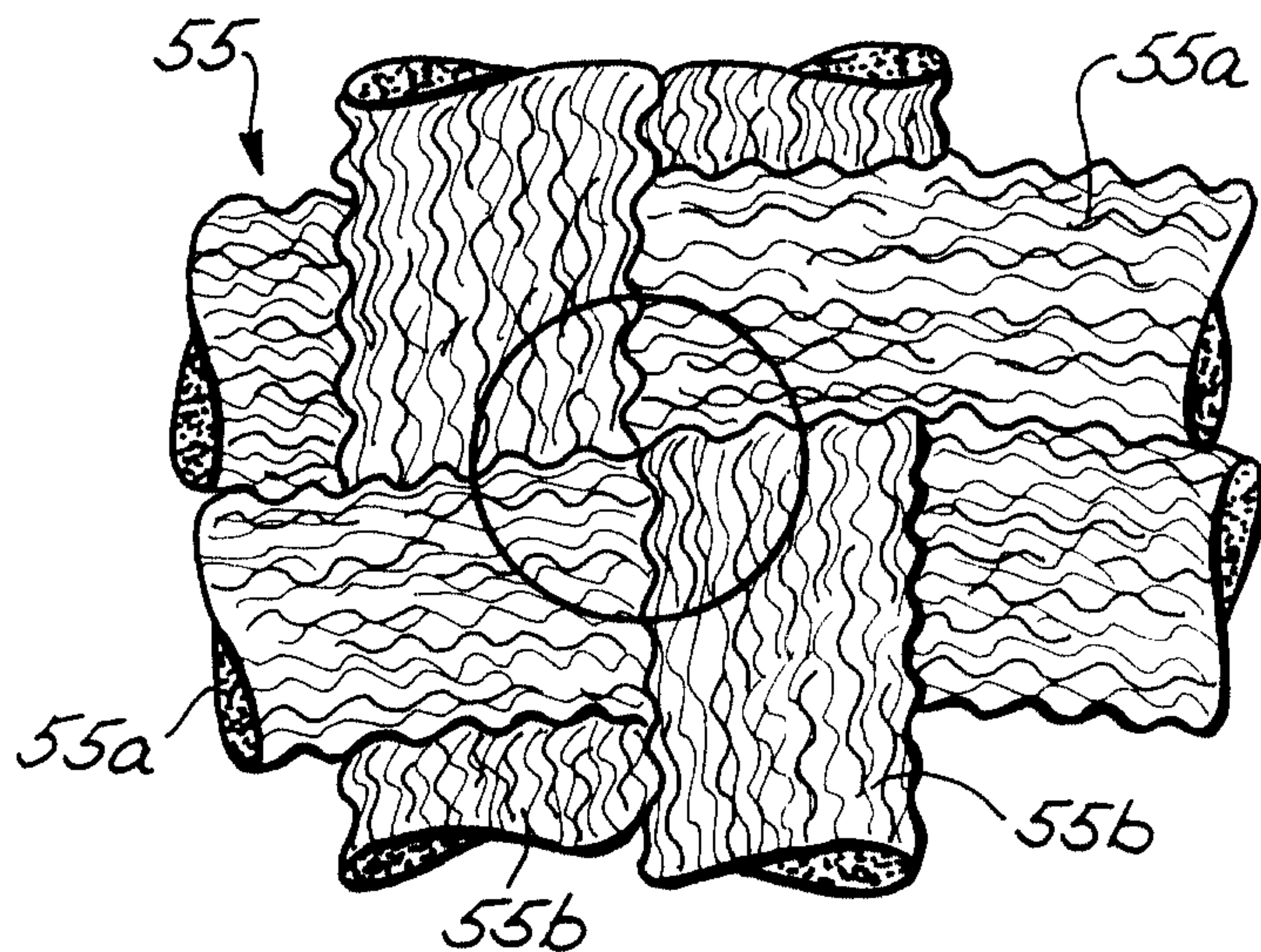


Fig. 8

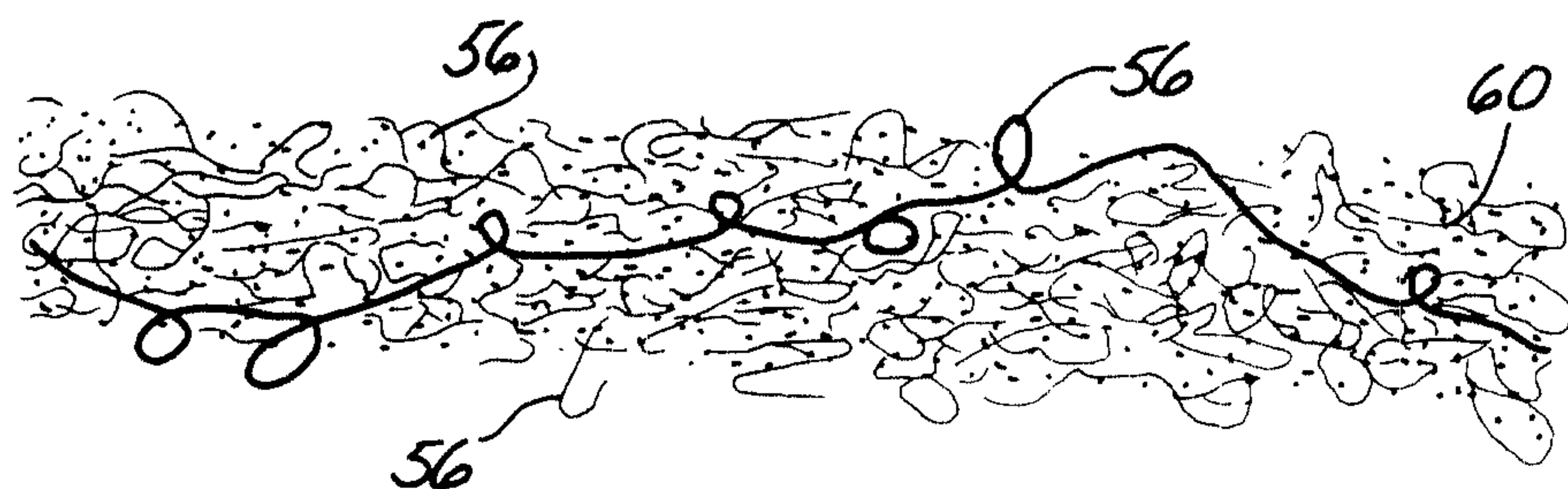


Fig. 9

Fig. 10

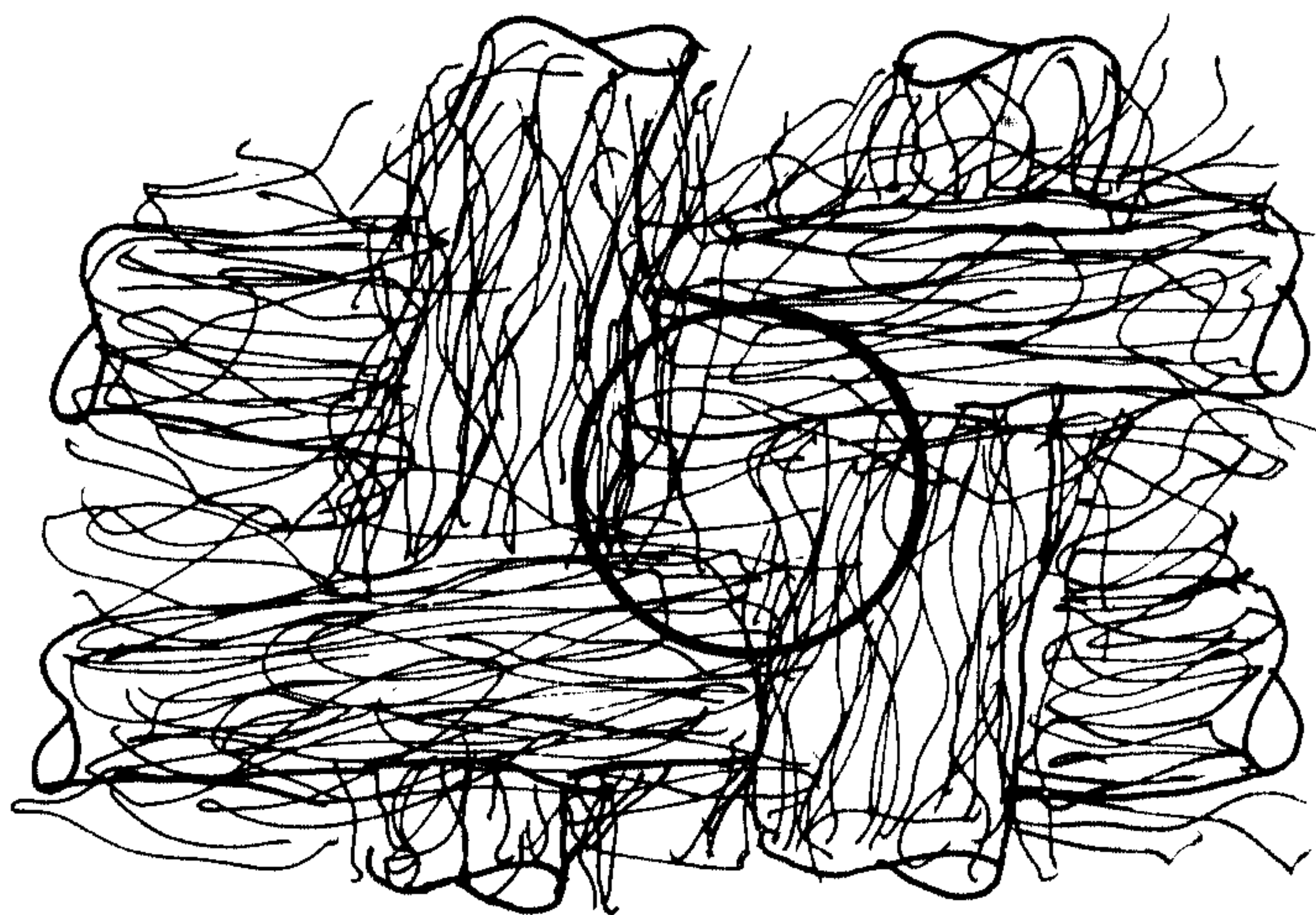
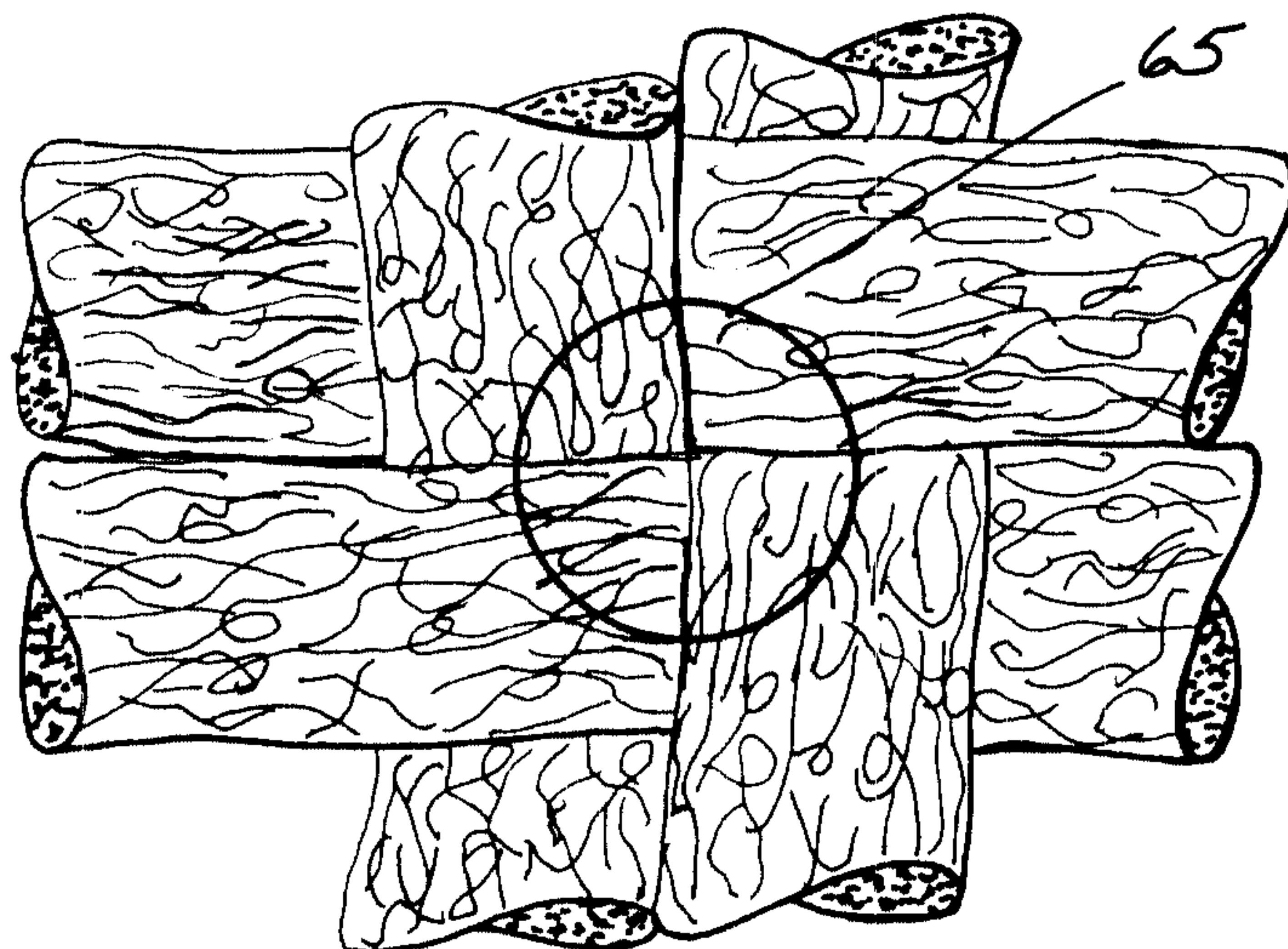


Fig. 11



Fig. 12

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1 3 4 1 3 3 7

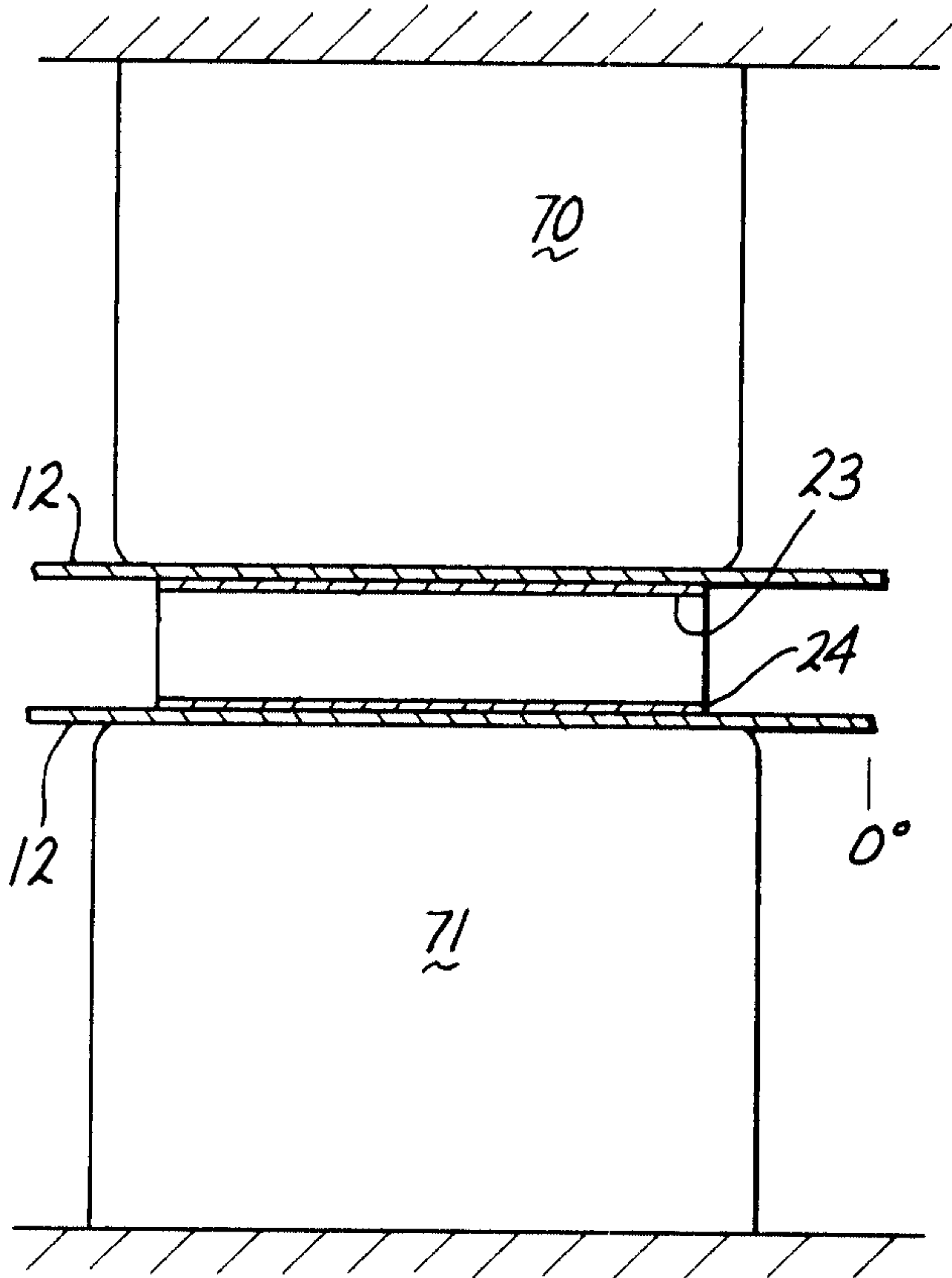


Fig. 13

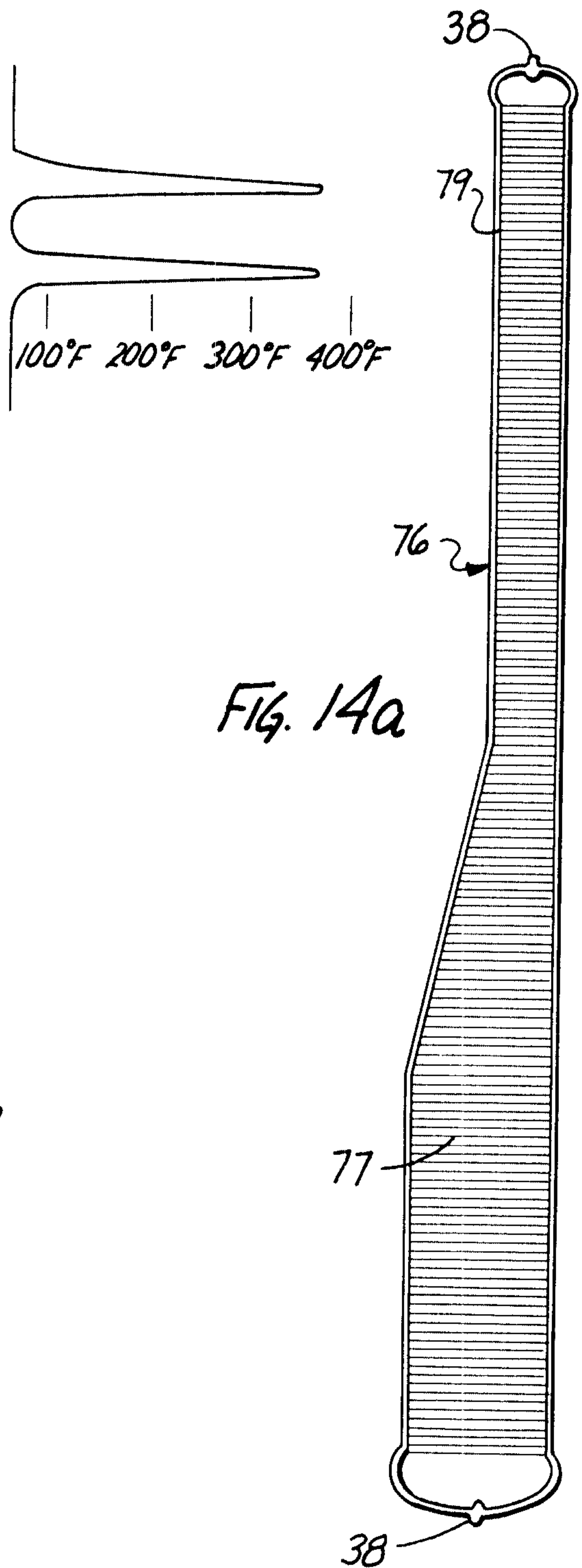


Fig. 14a

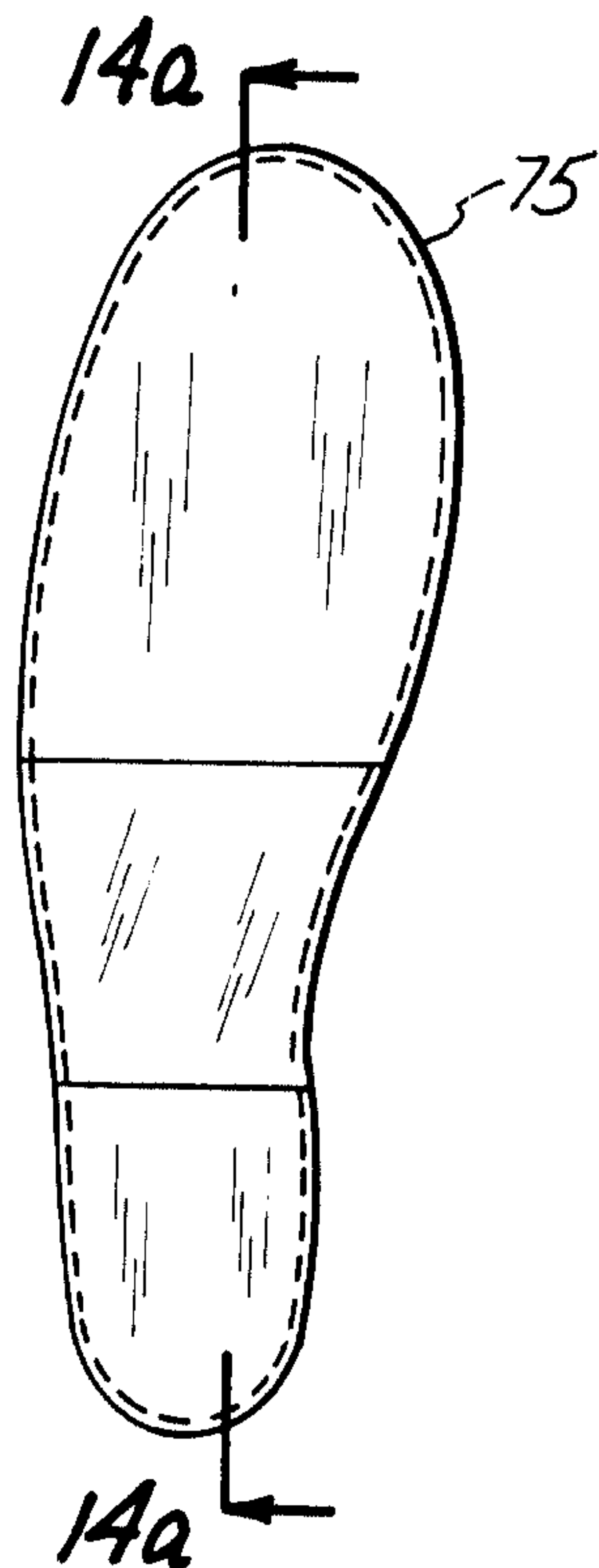


Fig. 14

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1 3 4 1 3 3 7

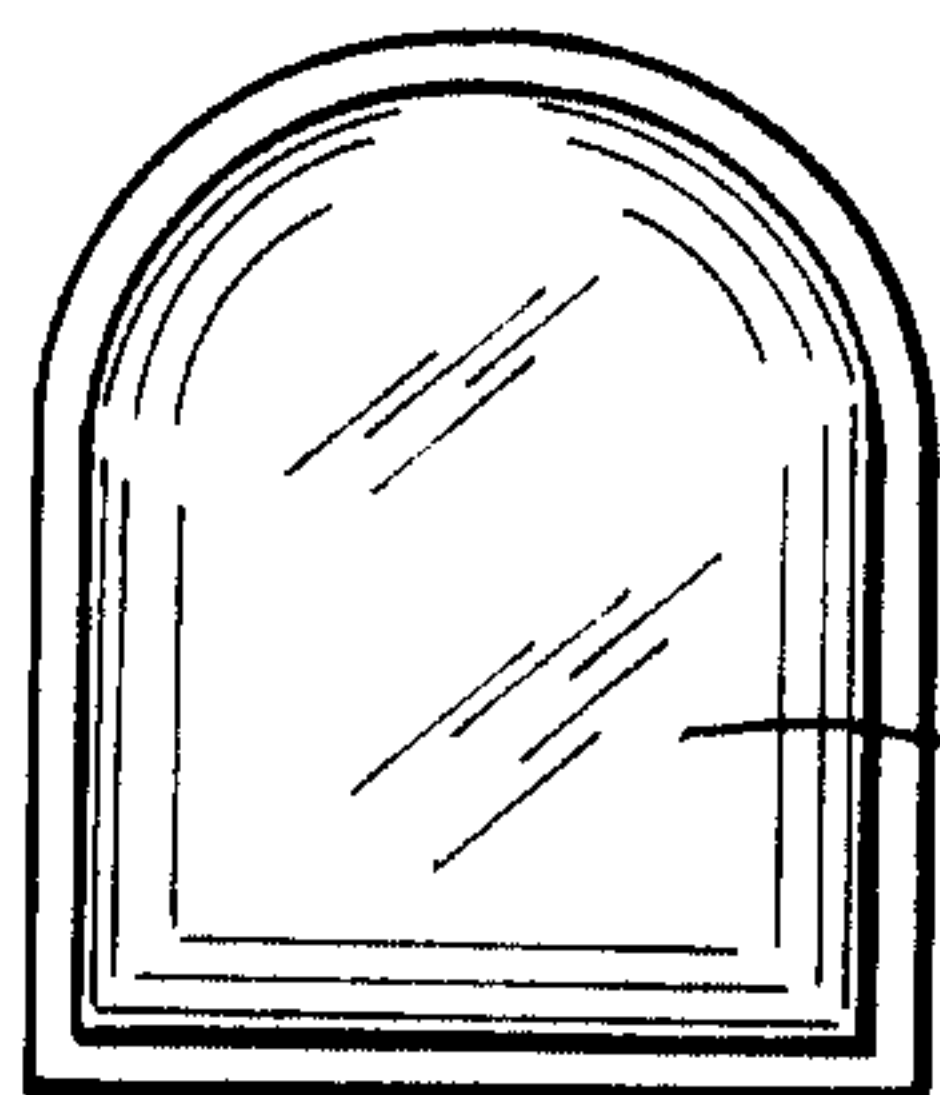


Fig. 15

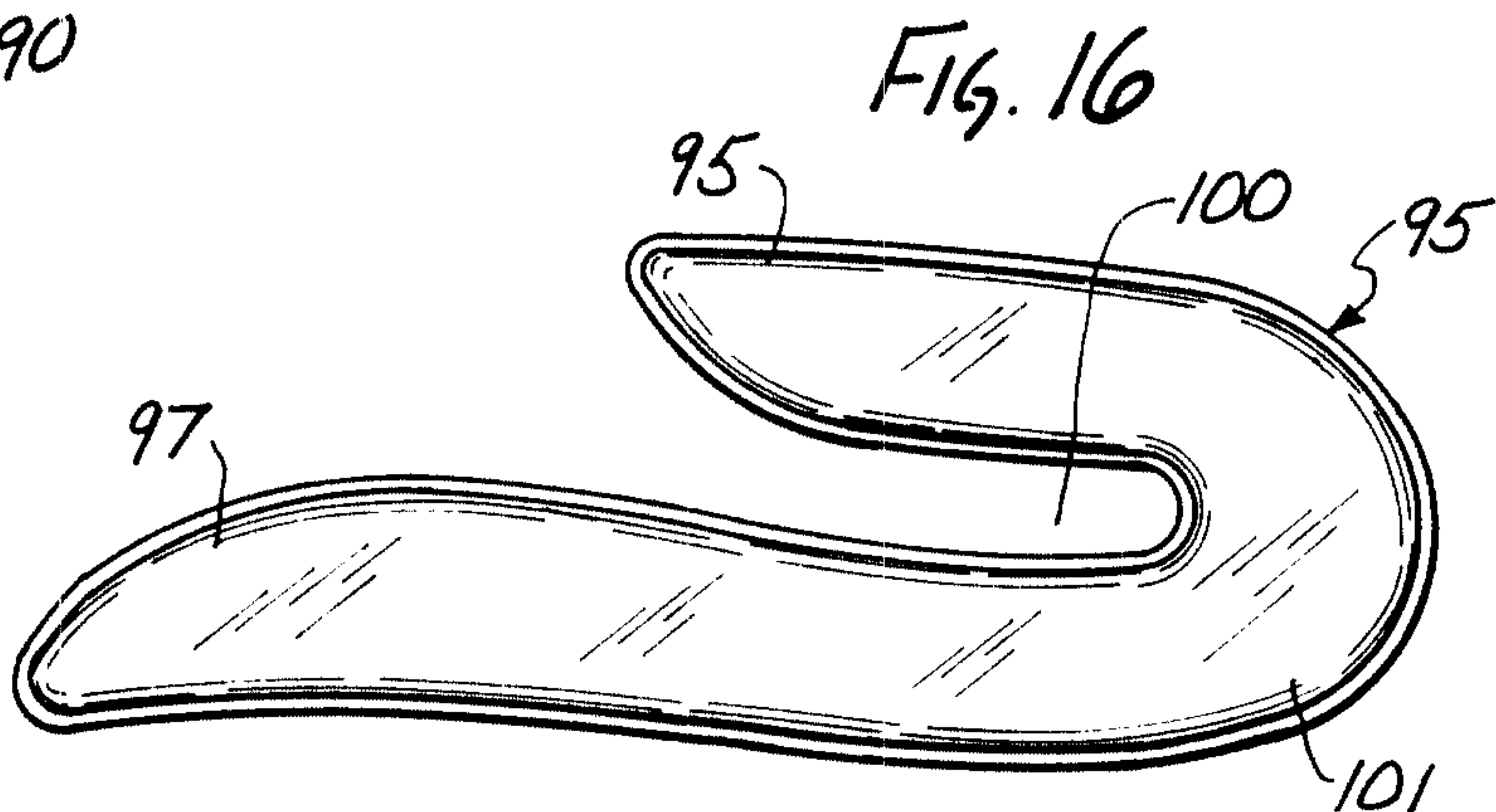


Fig. 16

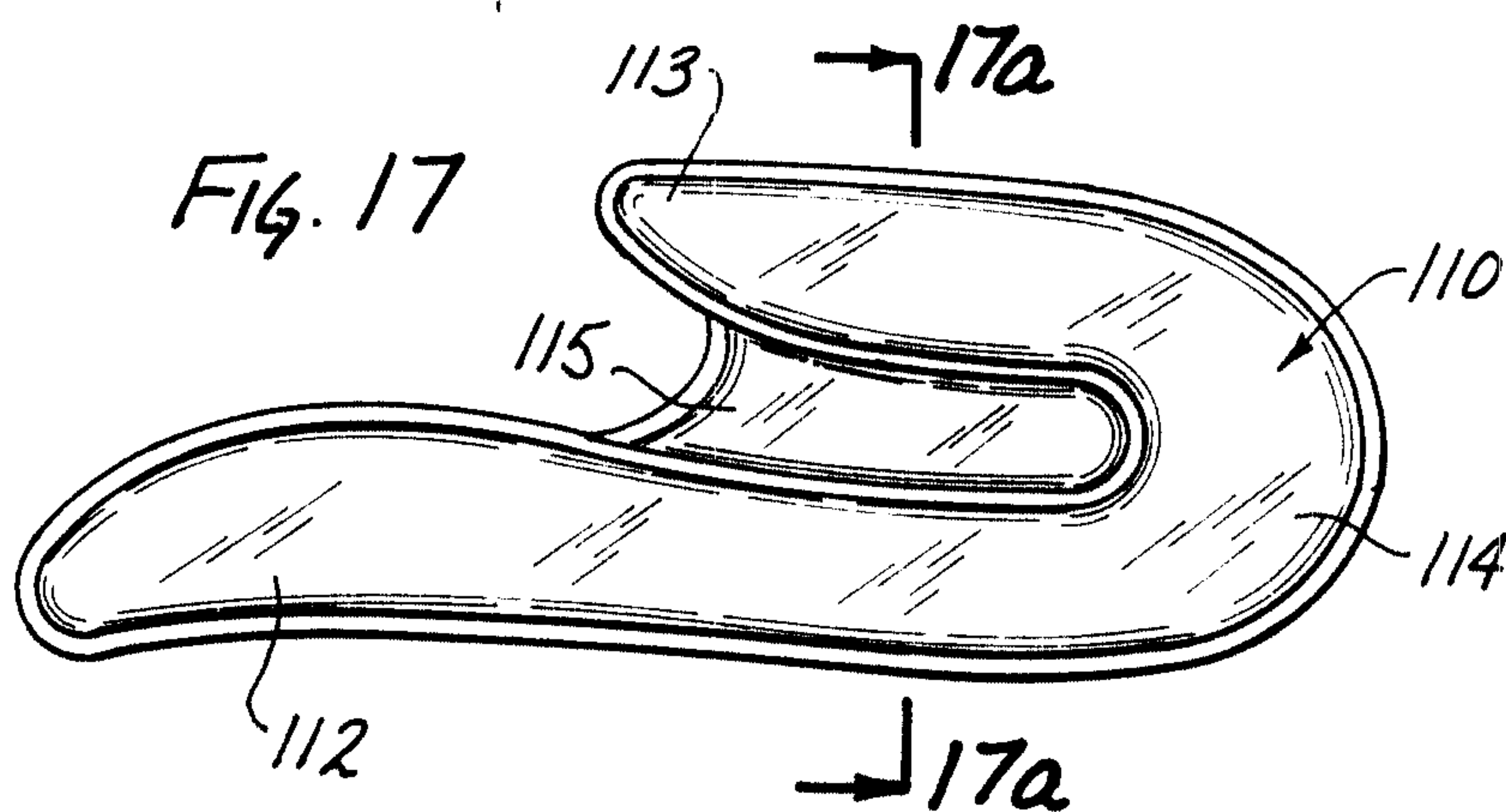


Fig. 17

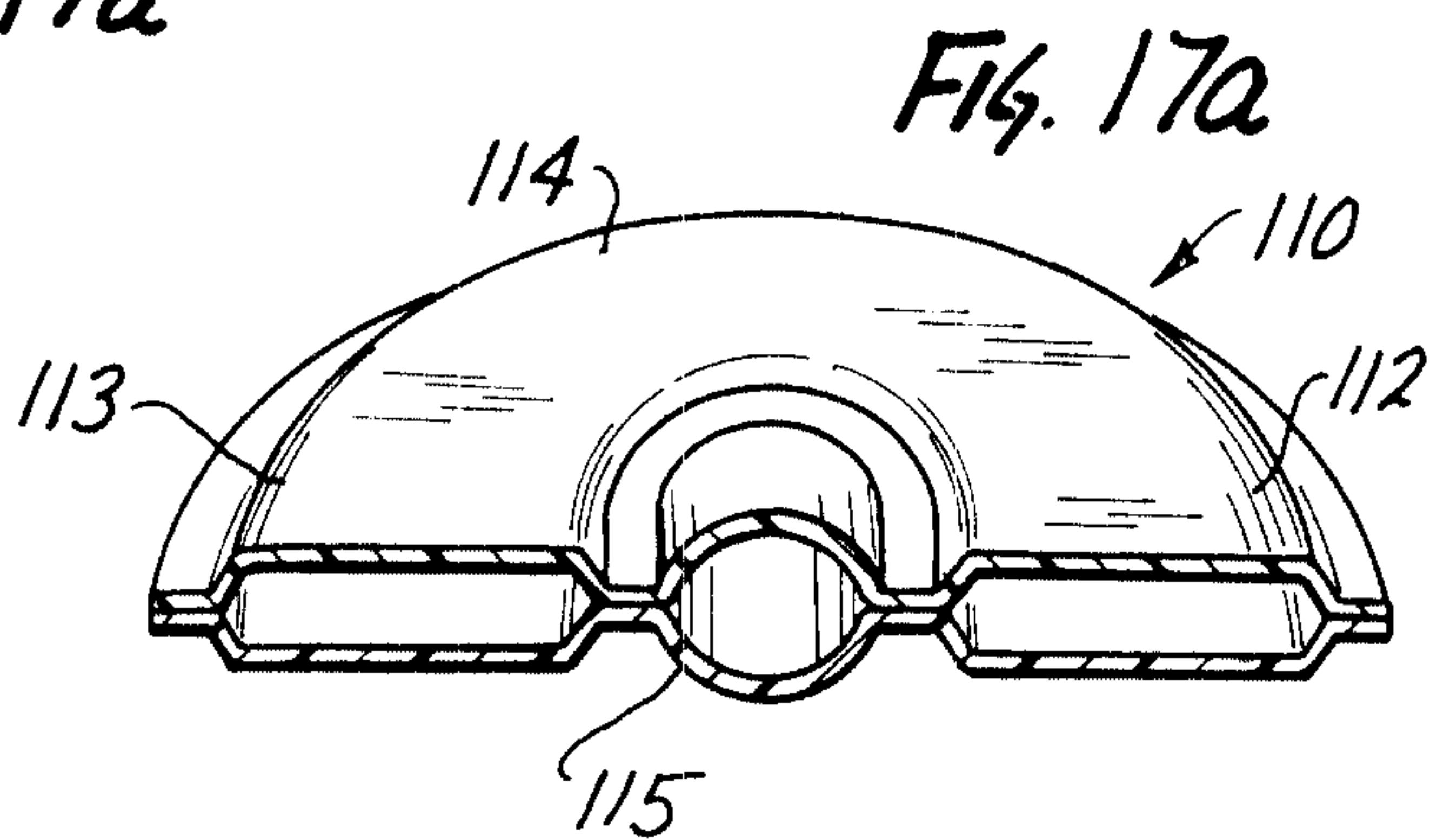


Fig. 17a

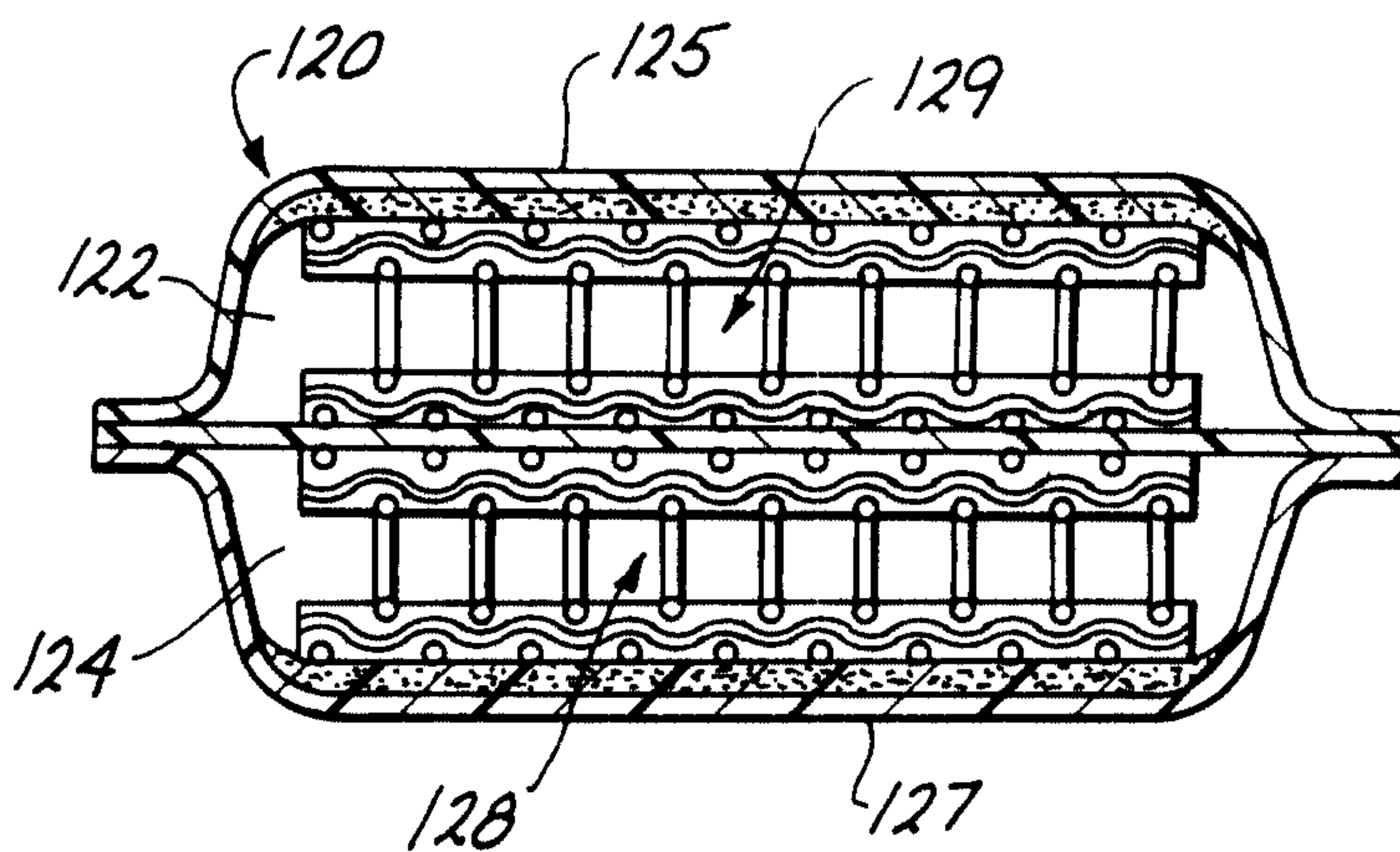


Fig. 18

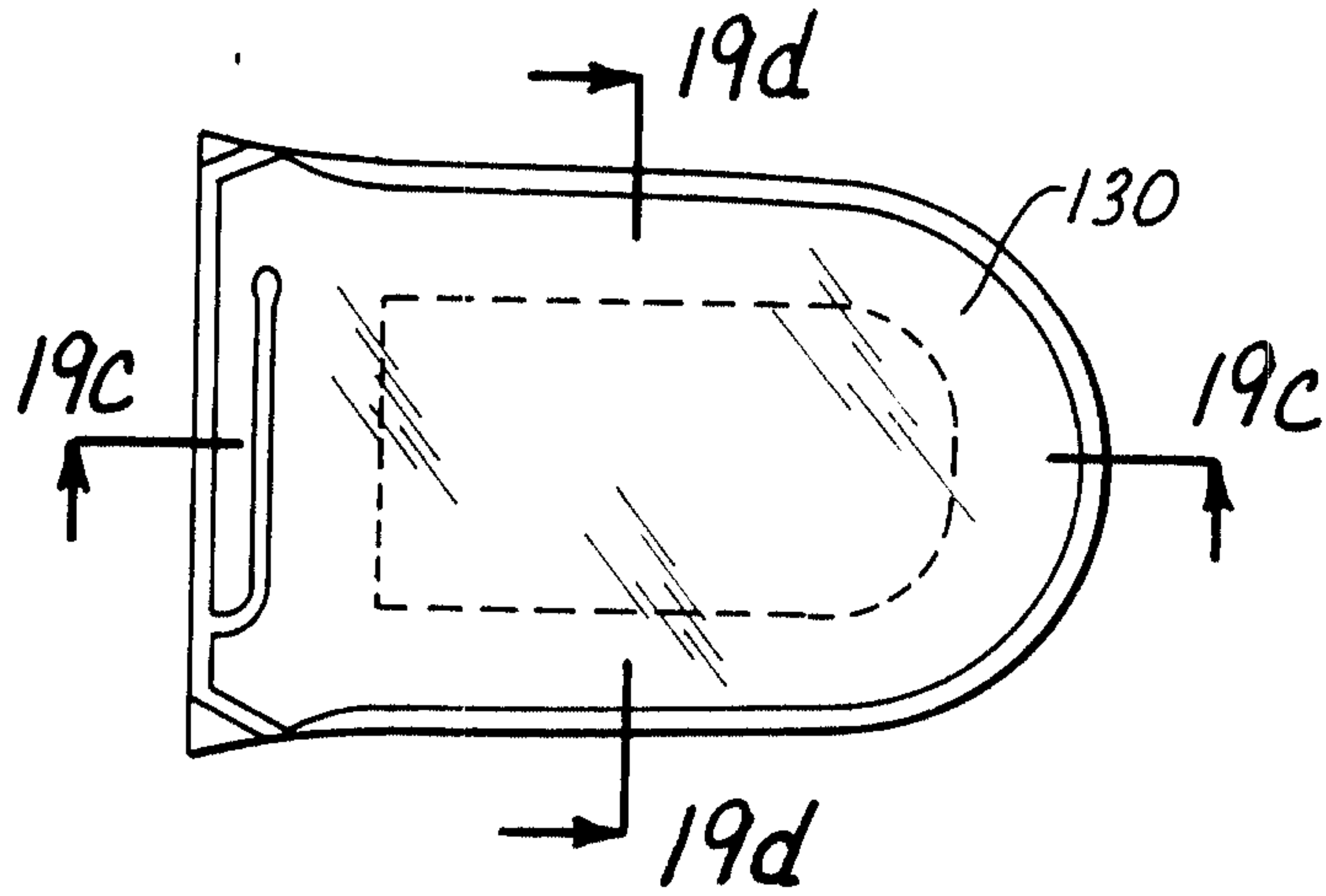


Fig. 19

Fig. 19b

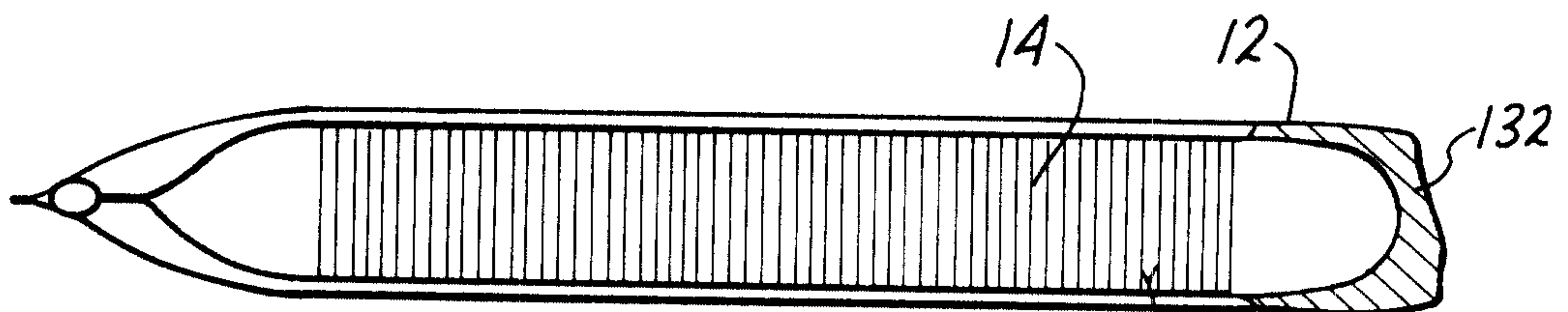


Fig. 19c

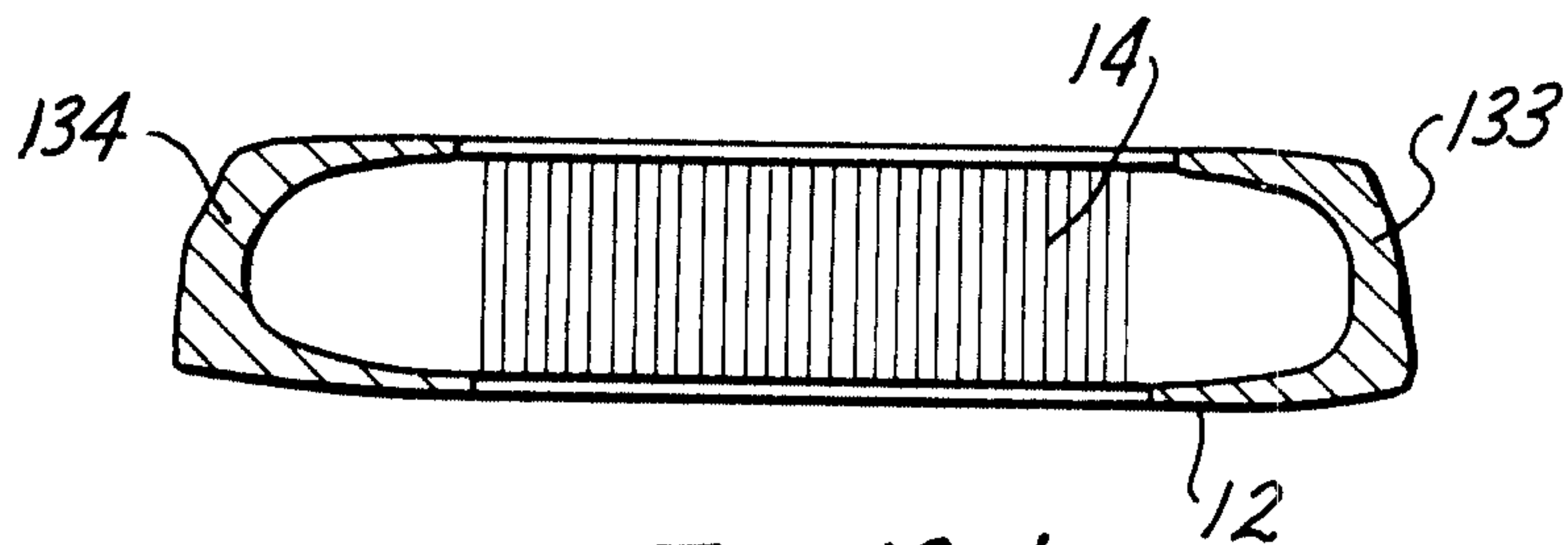


Fig. 19d

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1 3 4 1 3 3 7

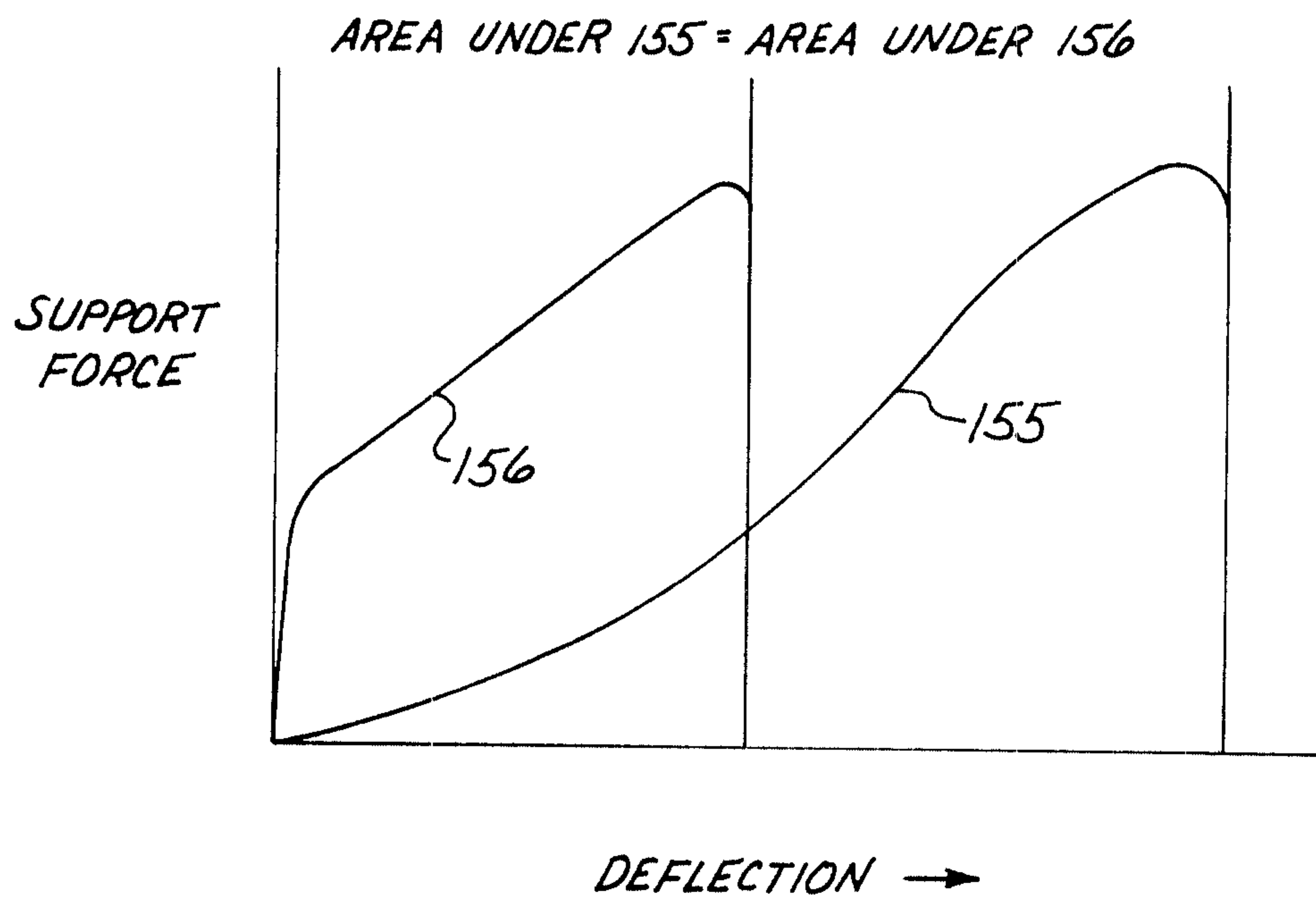
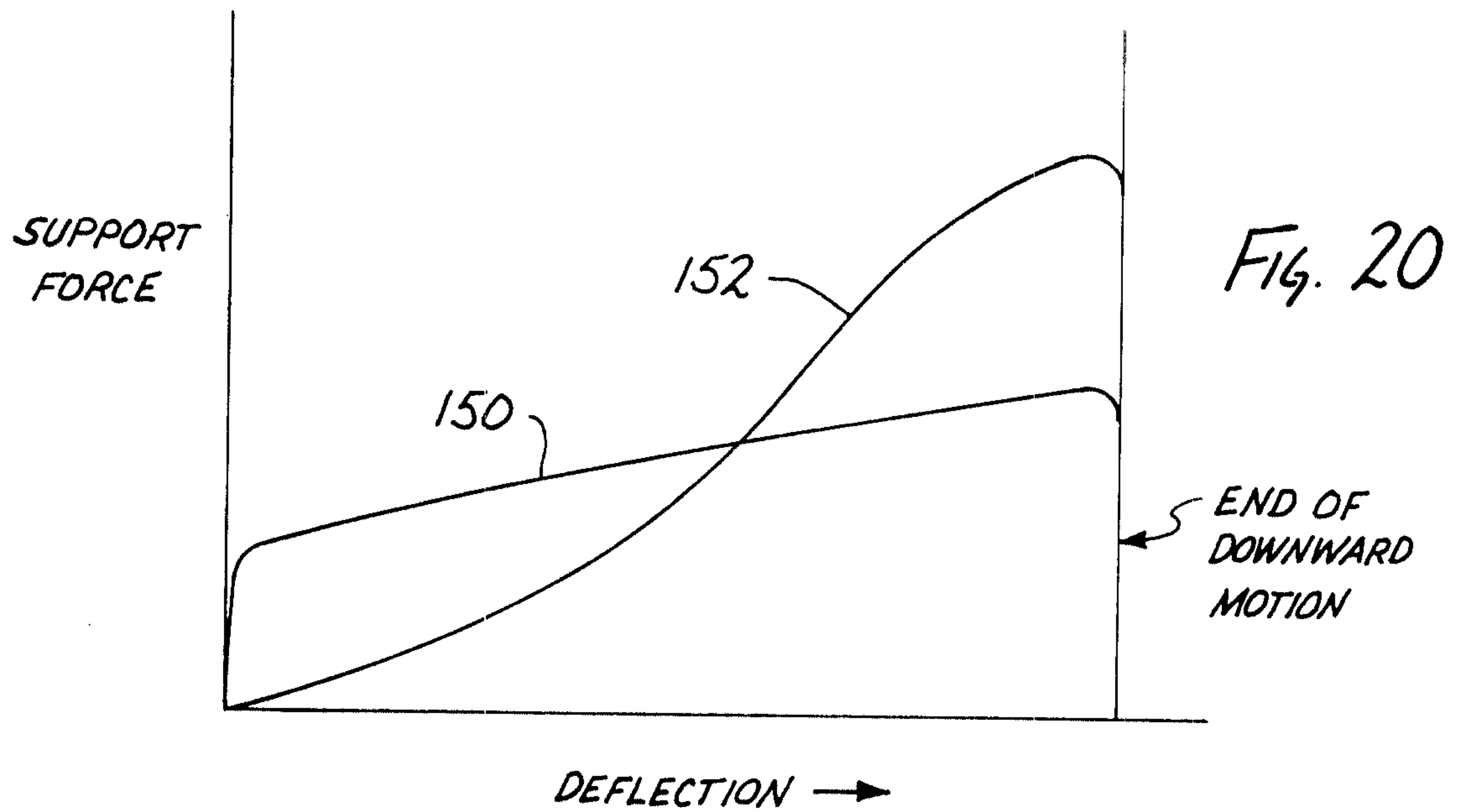
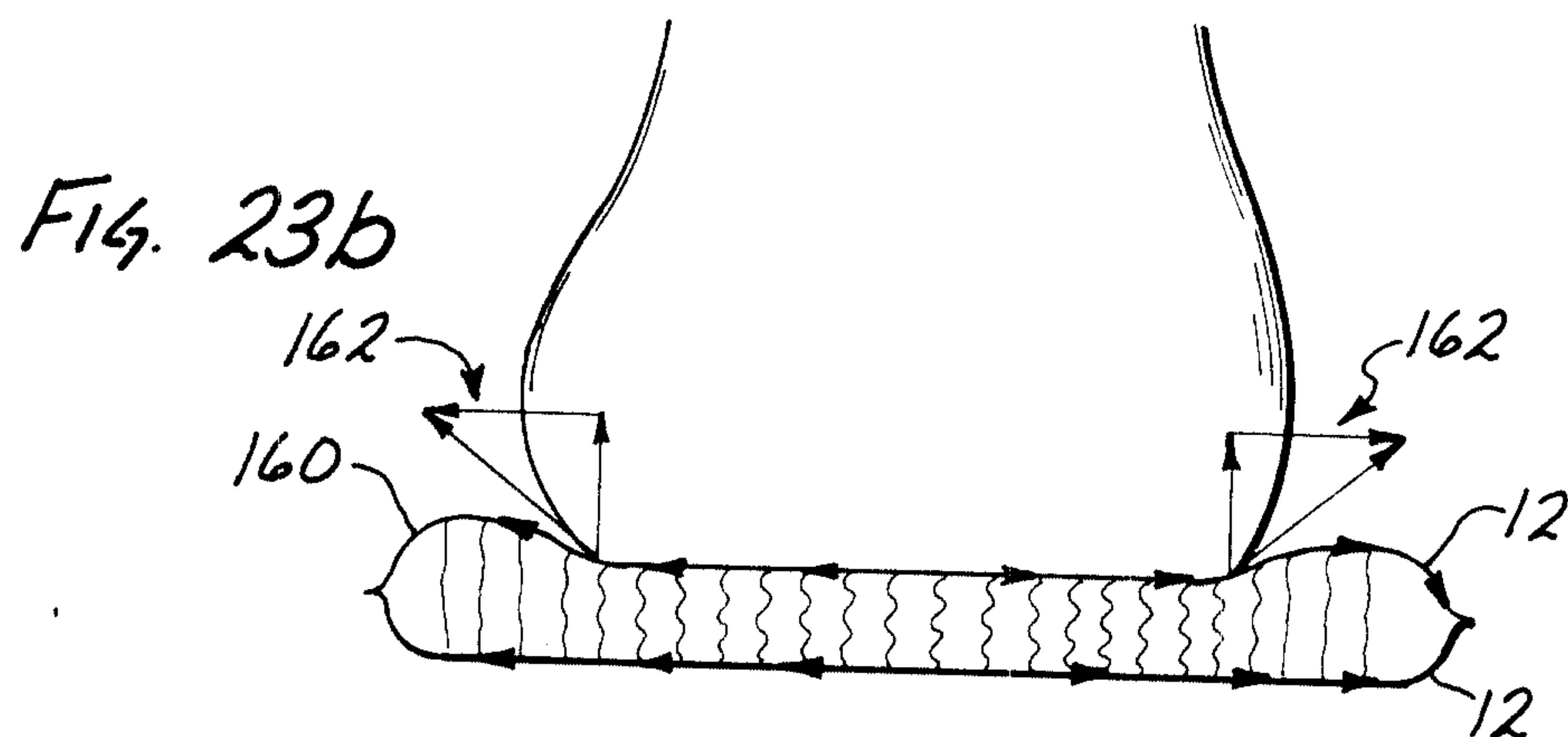
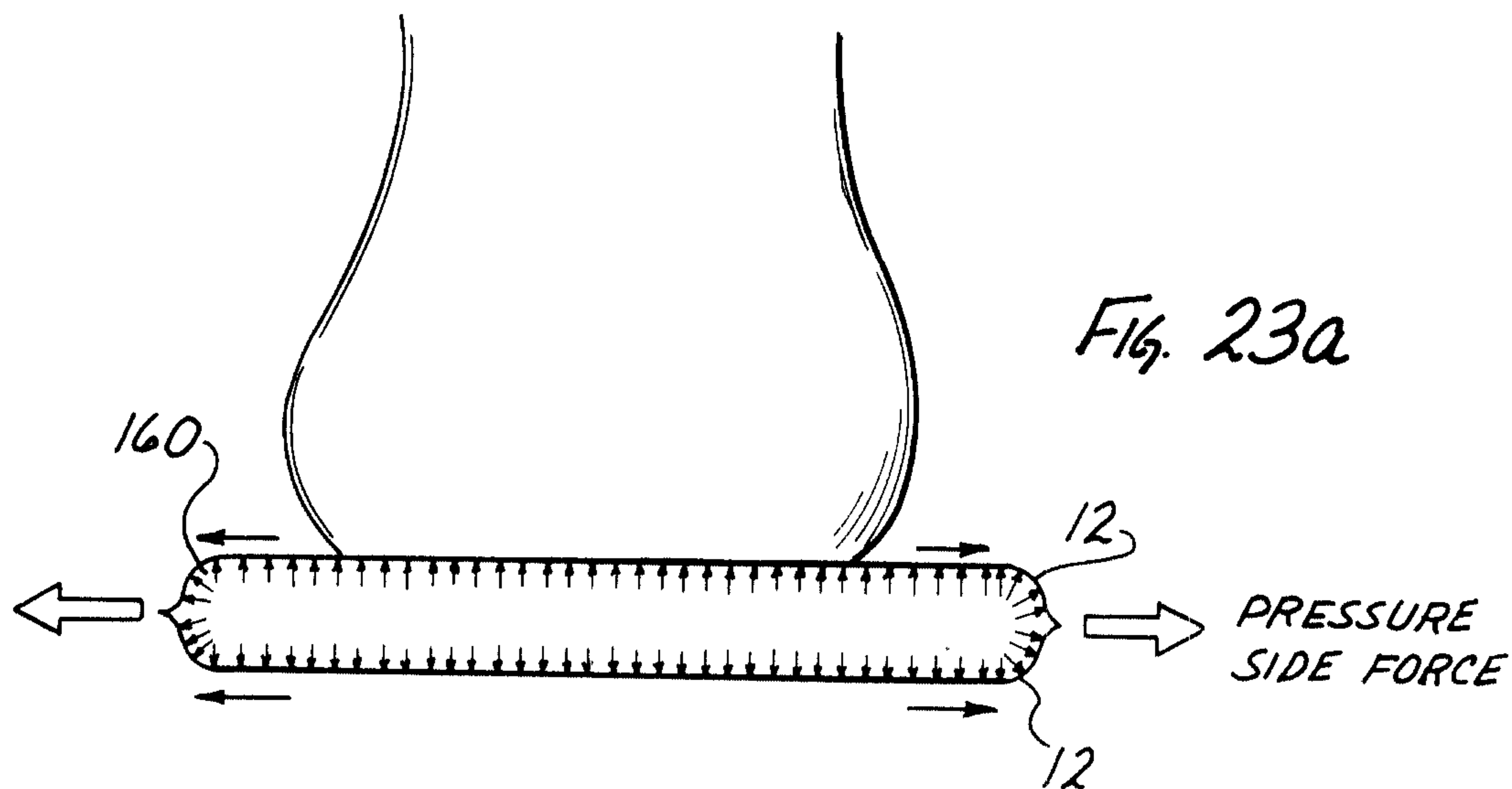
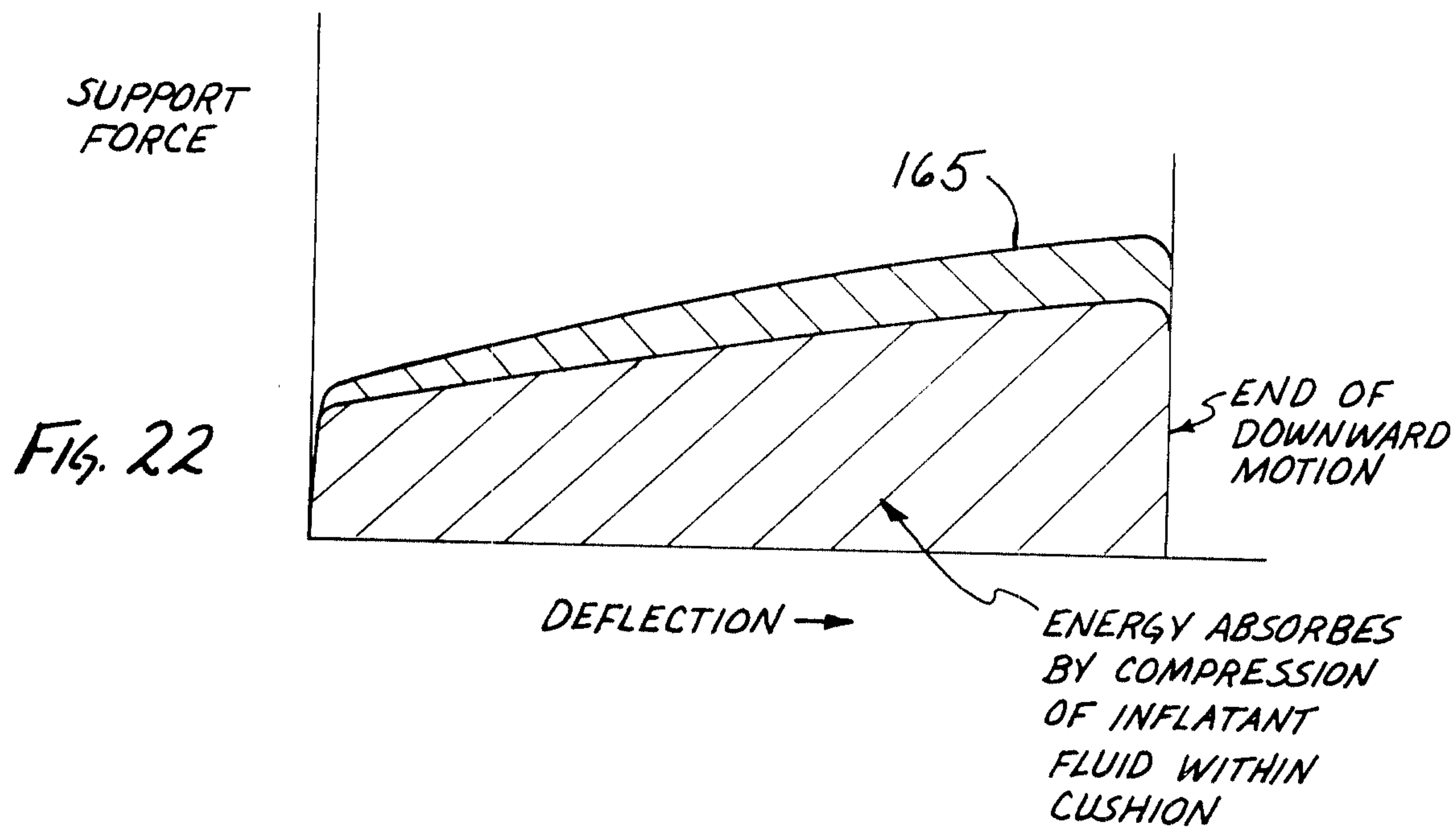
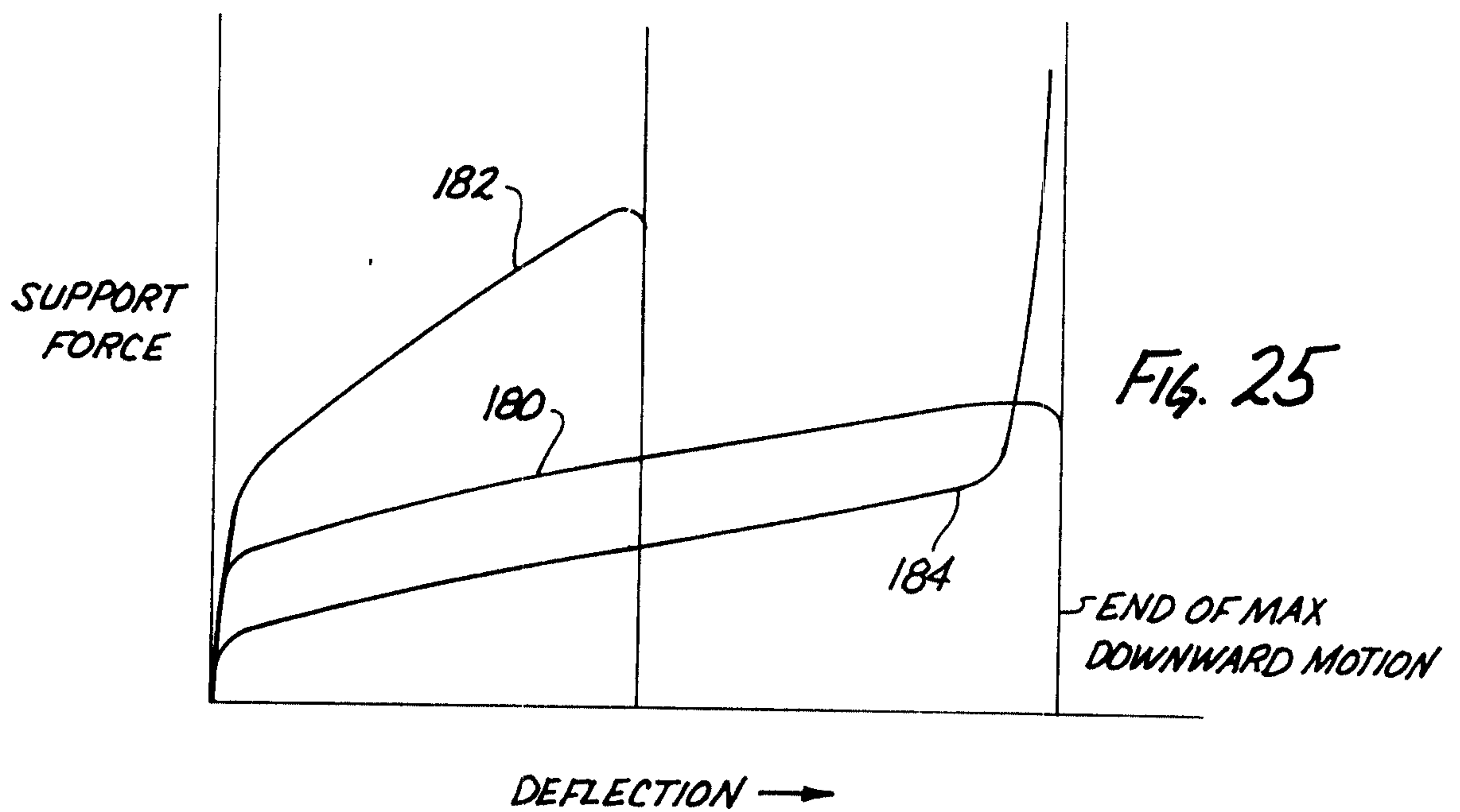
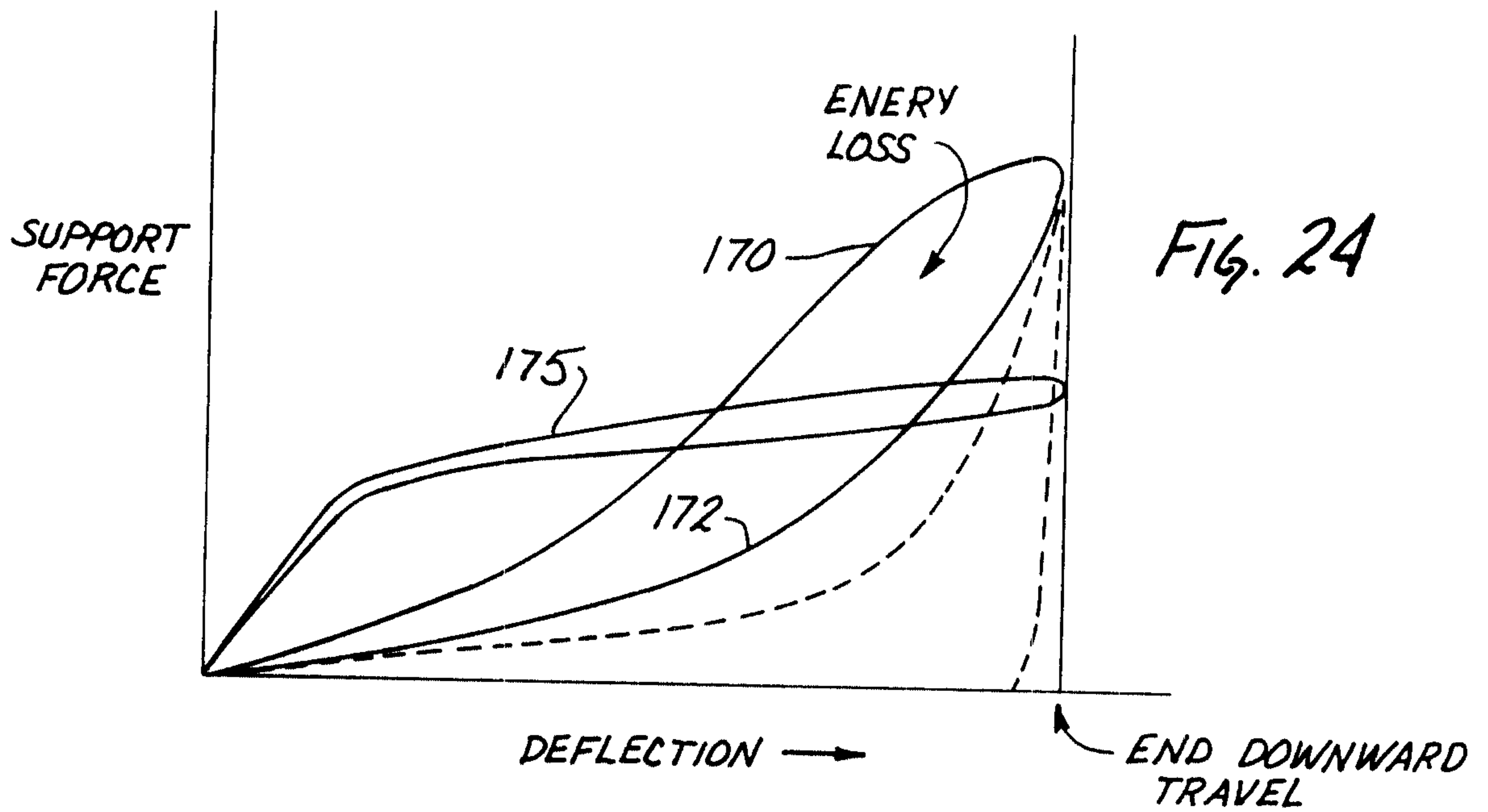


Fig. 21





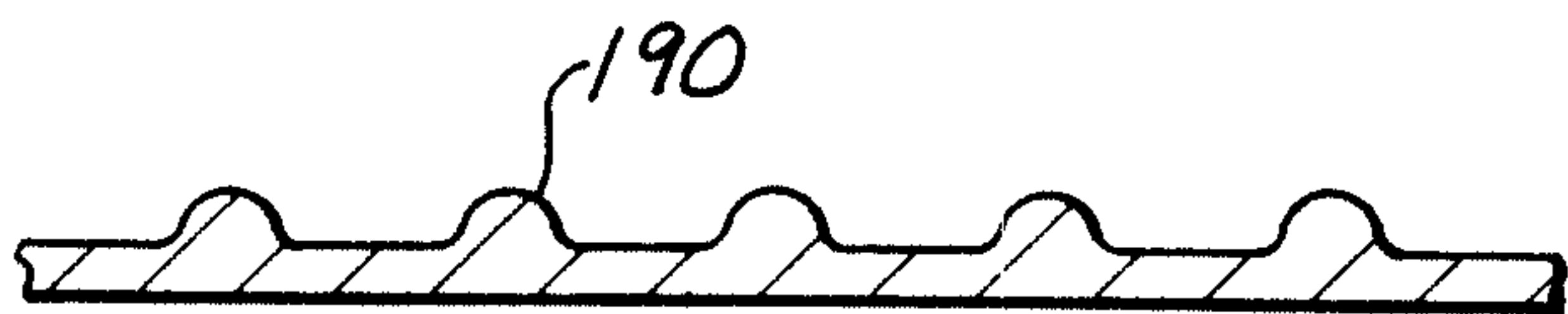
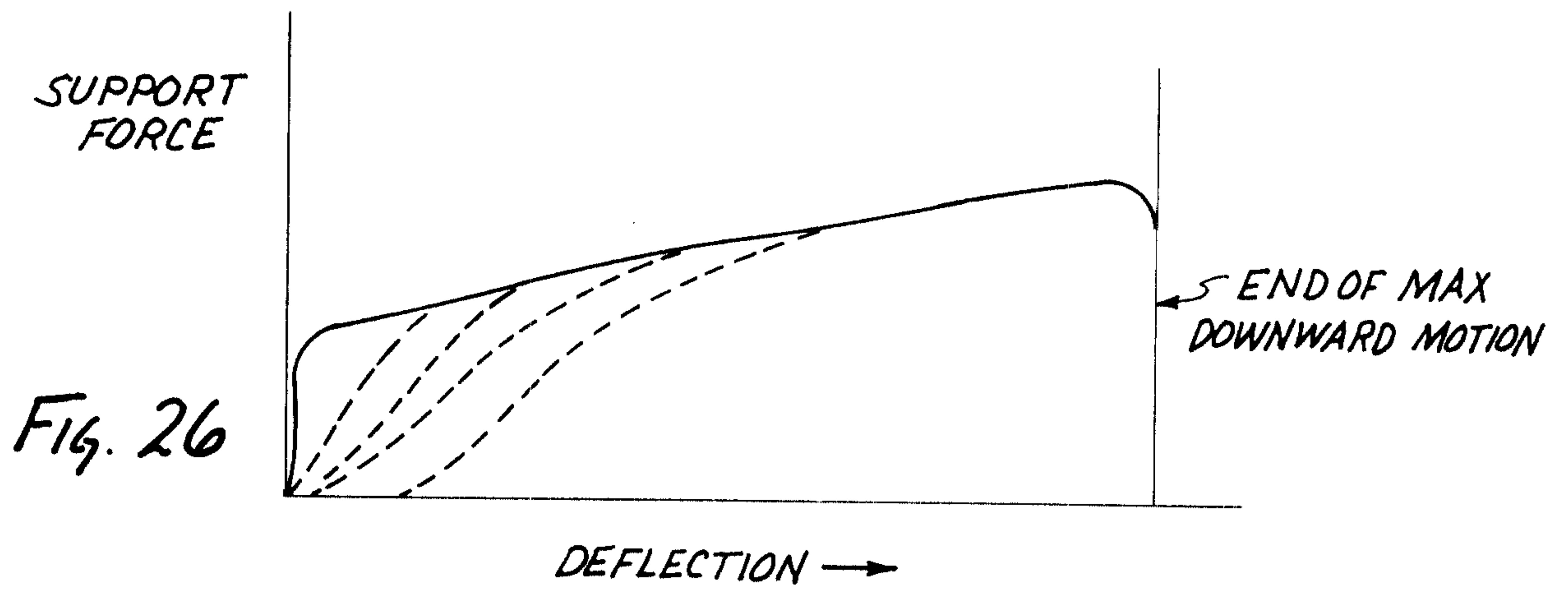


Fig. 26b

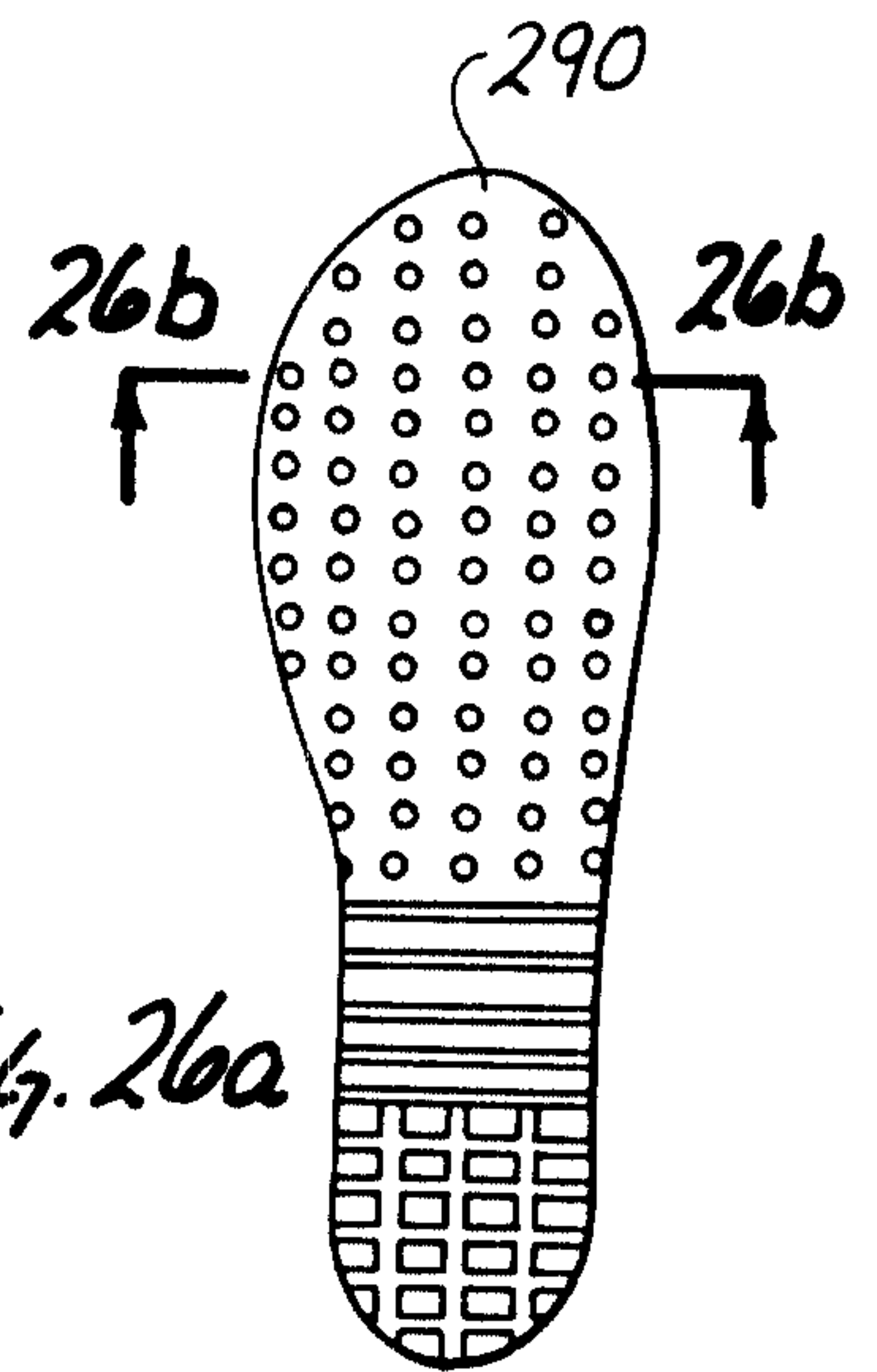


Fig. 26a

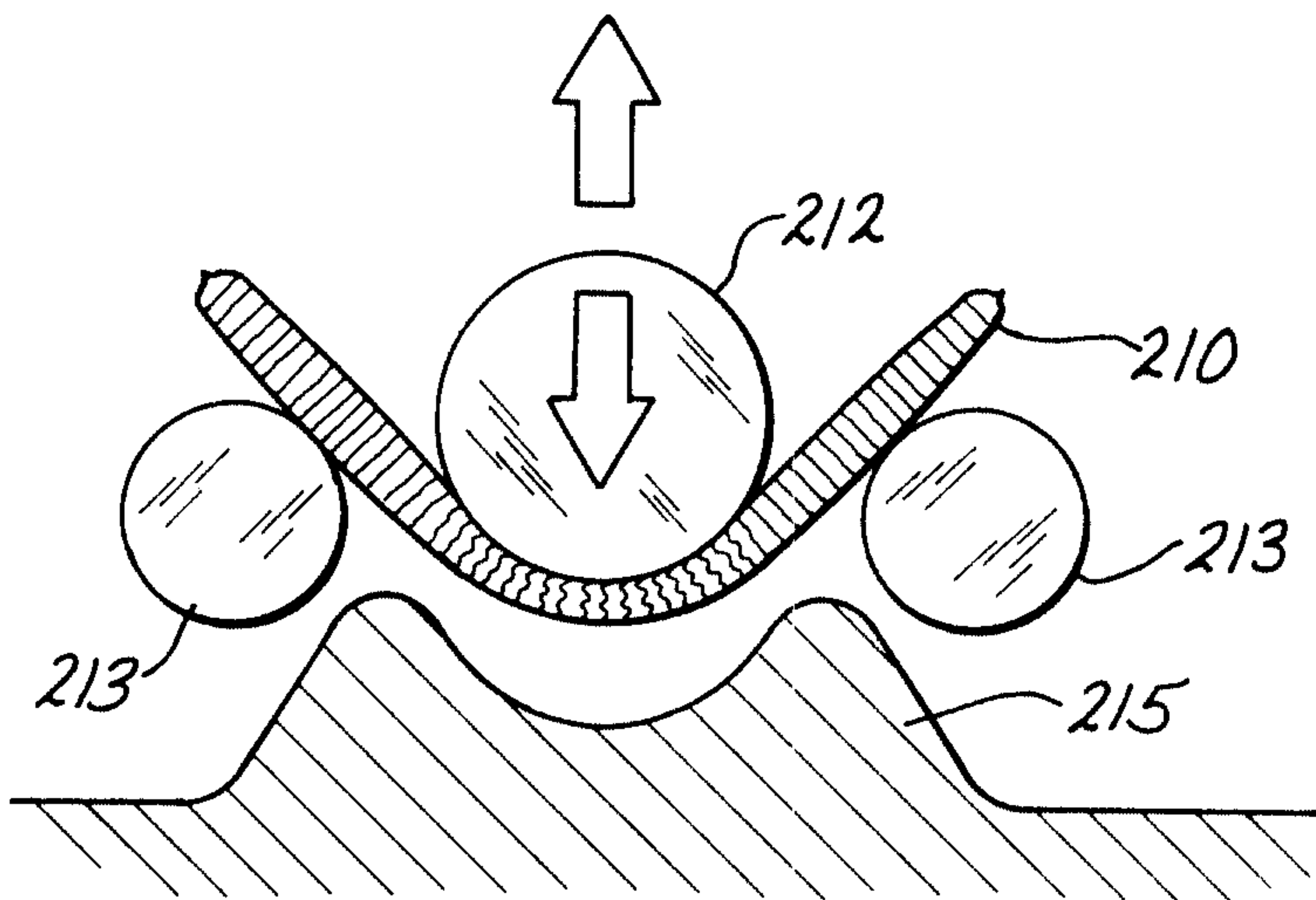
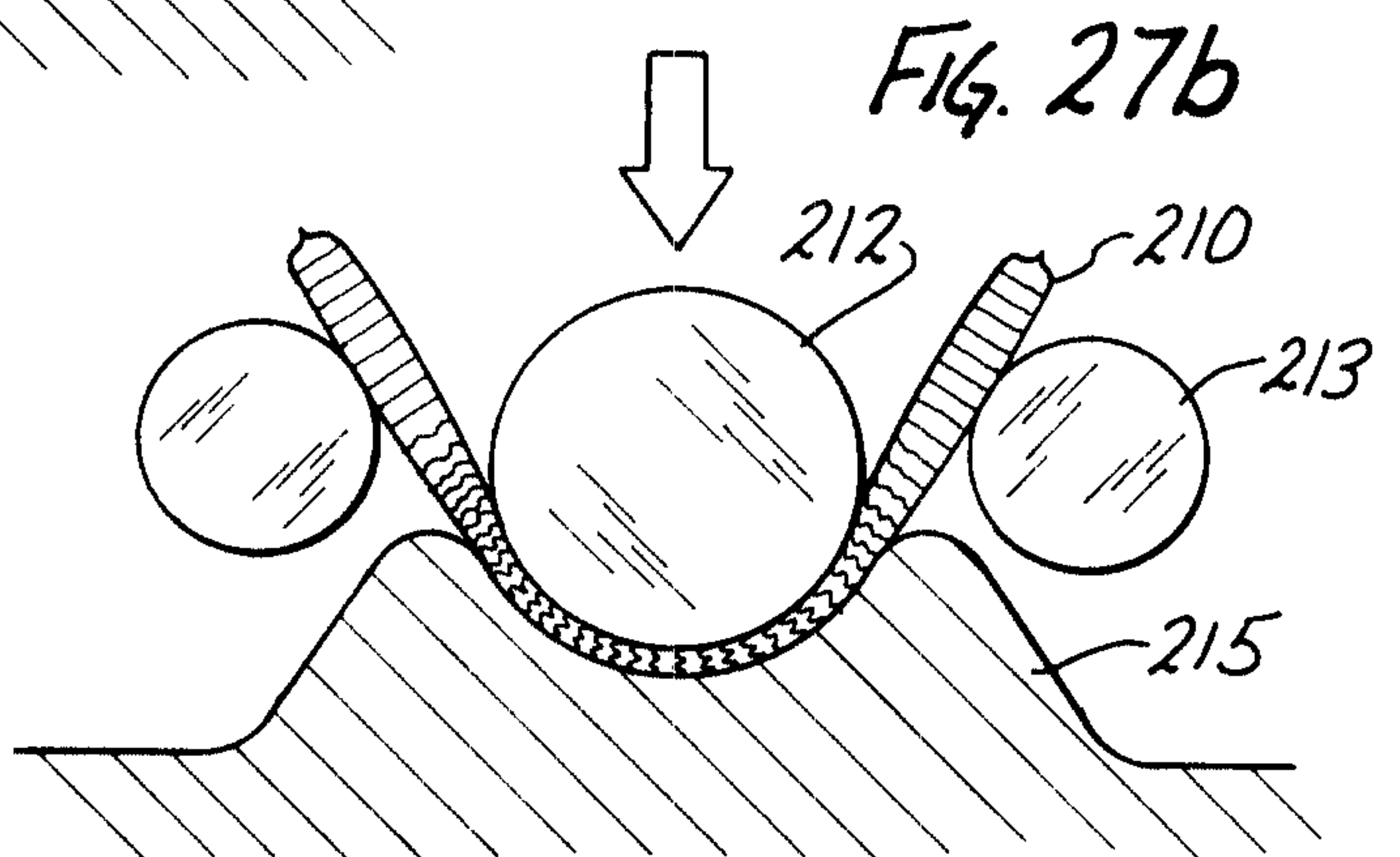


Fig. 27a



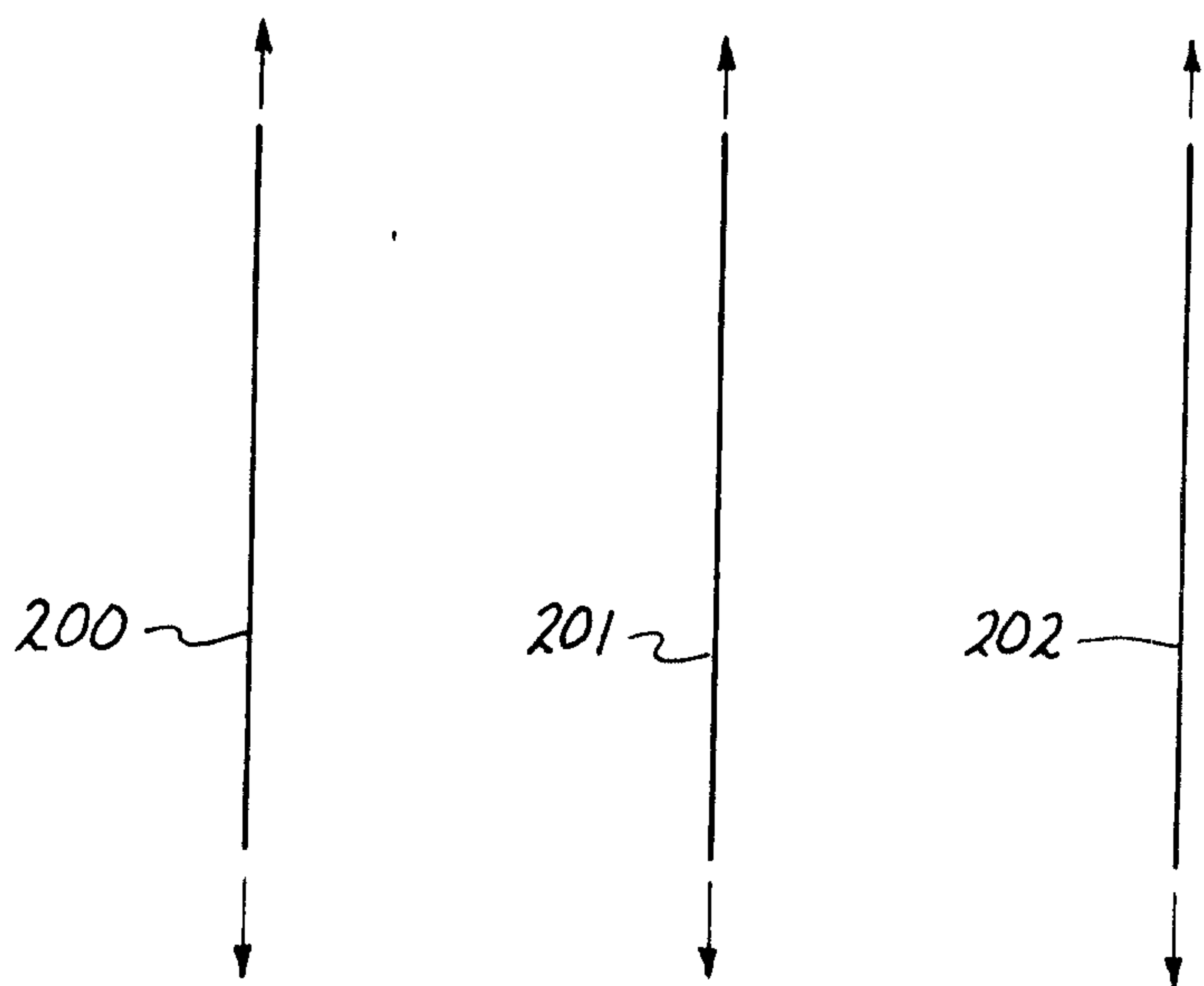


FIG. 28a

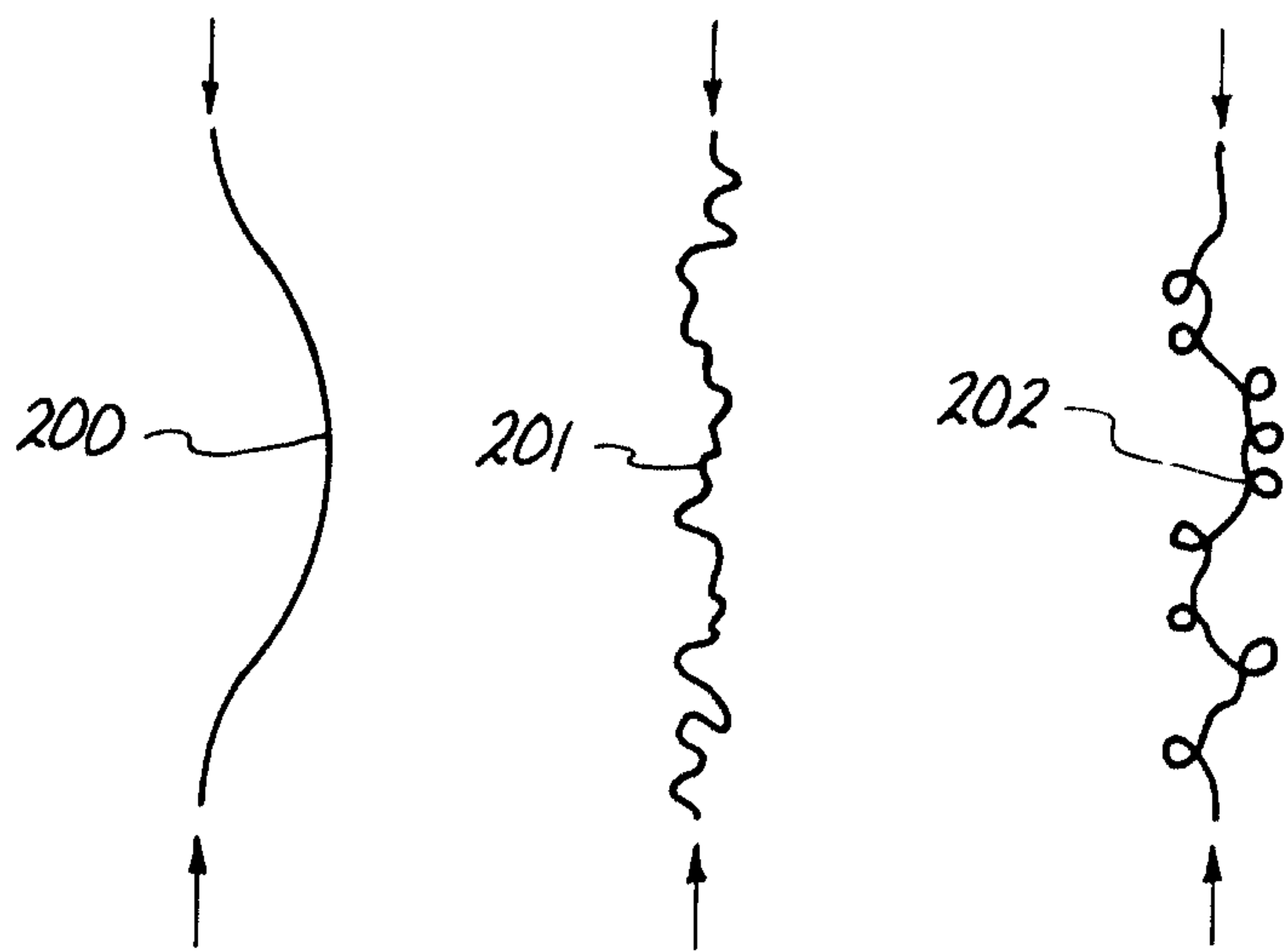


FIG. 28b

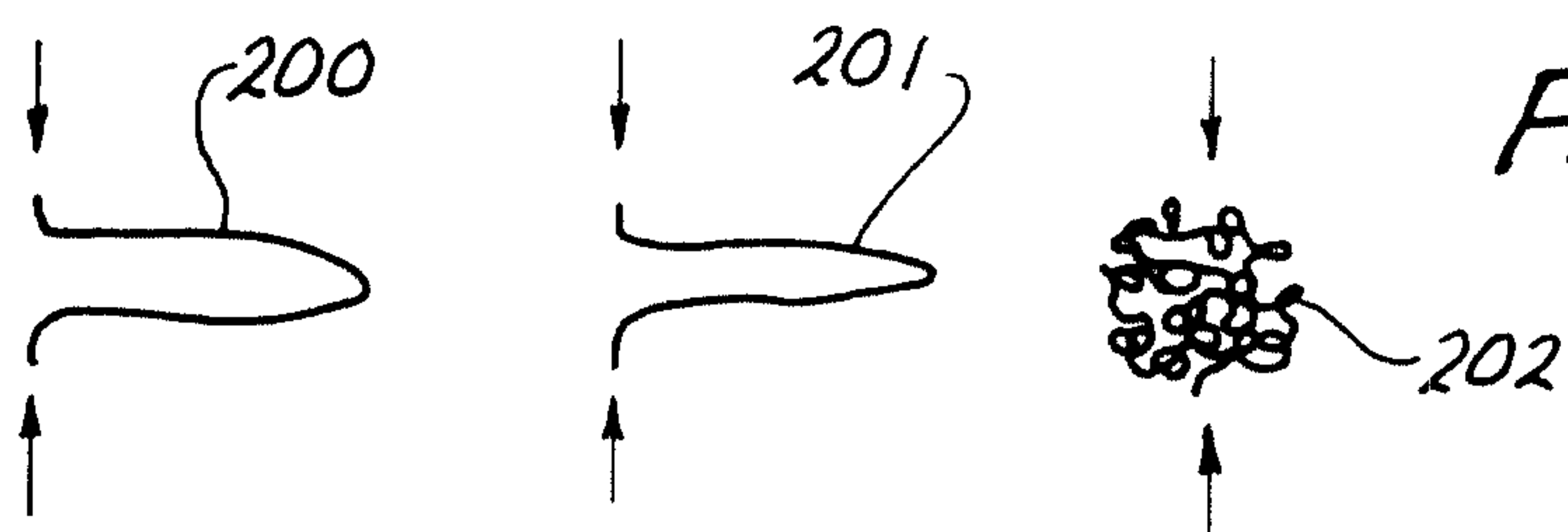


FIG. 28c

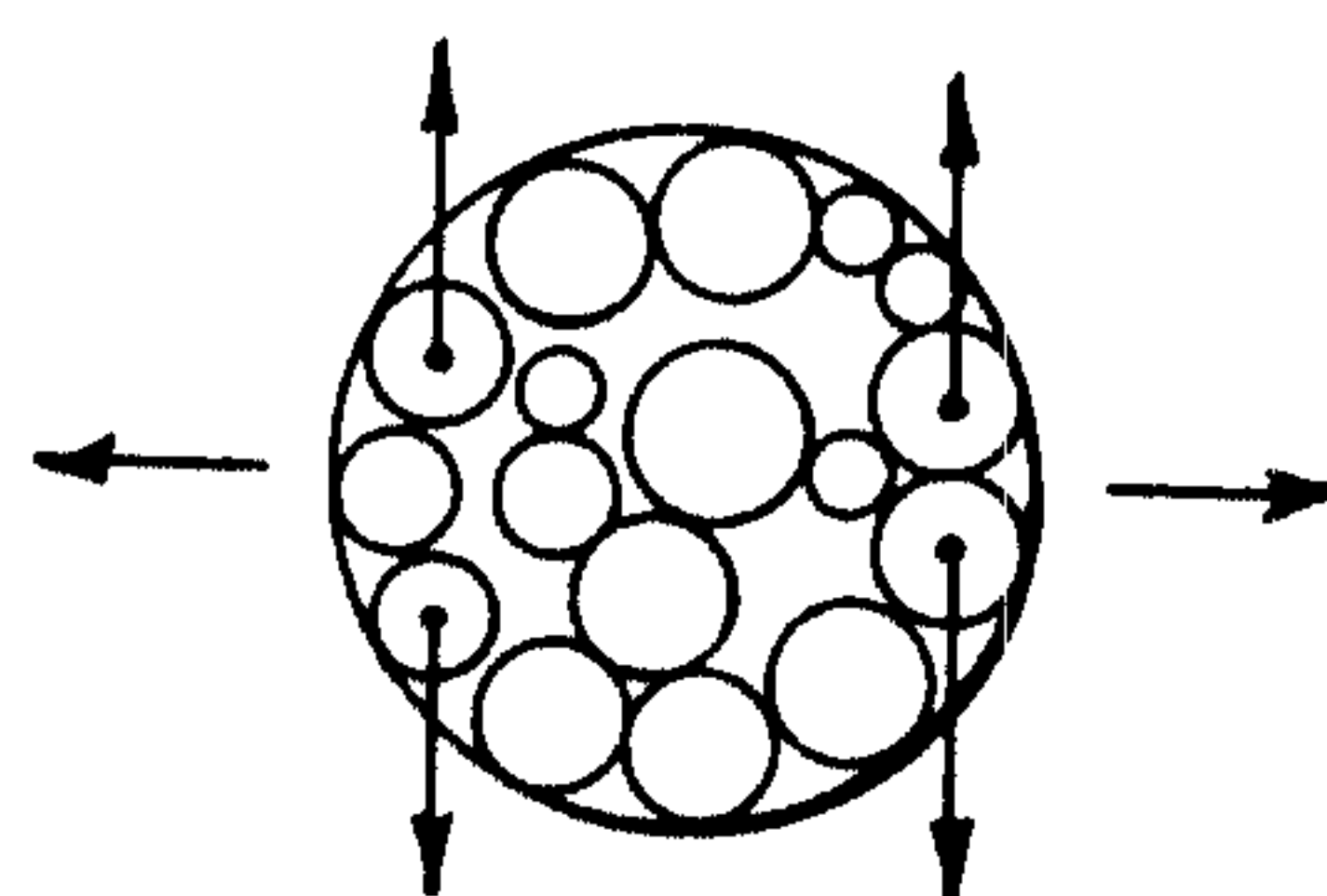
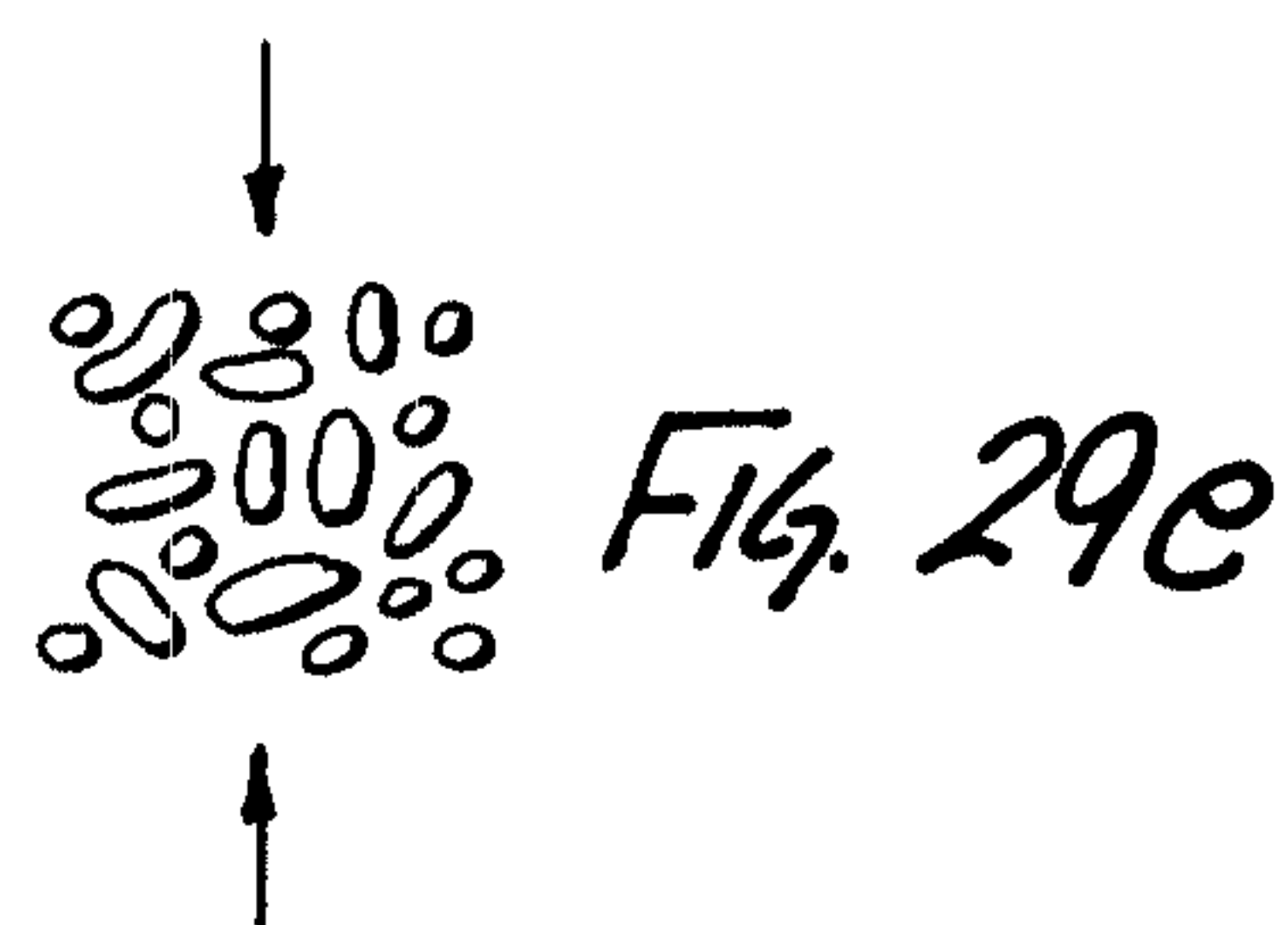
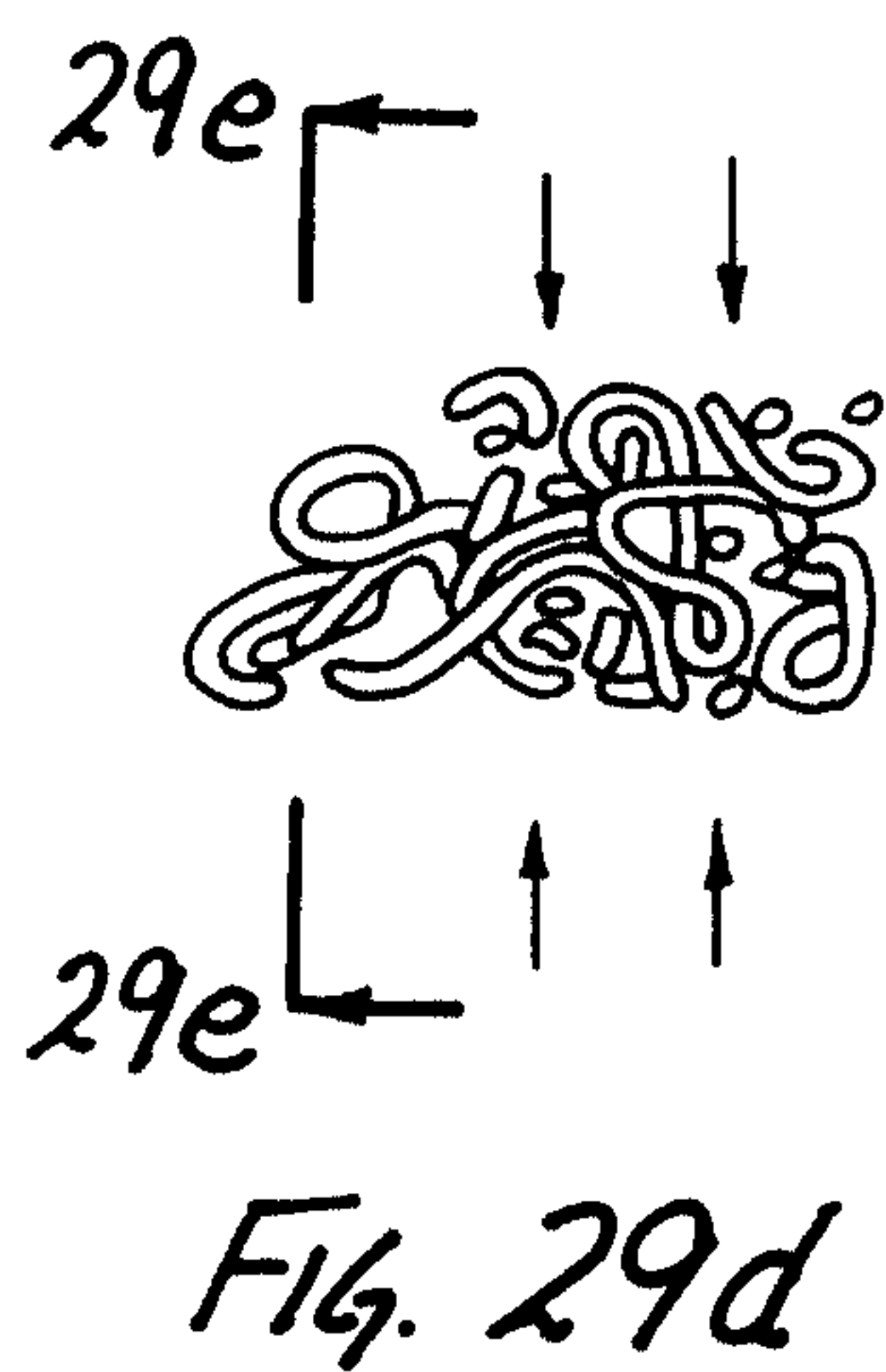
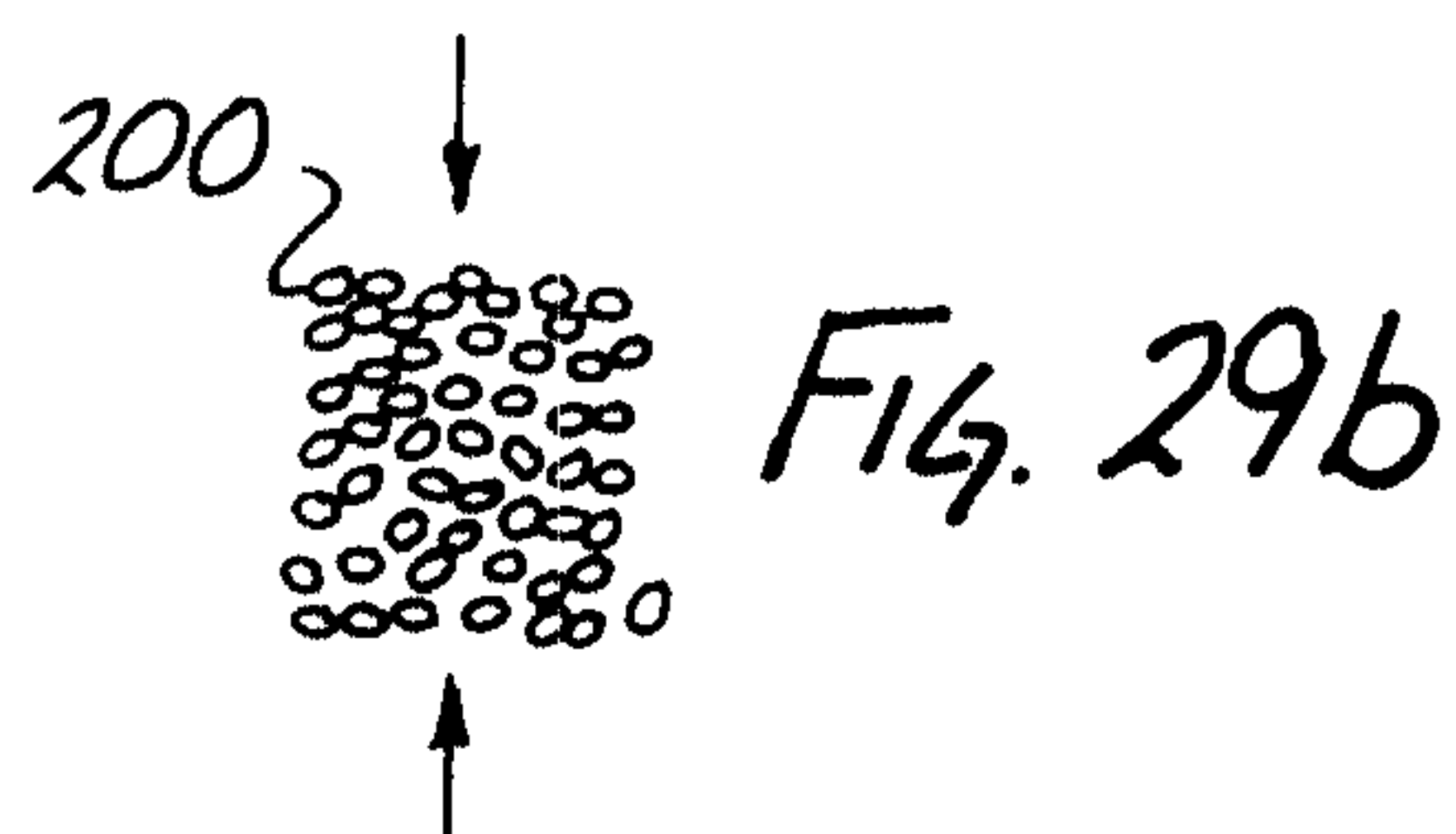
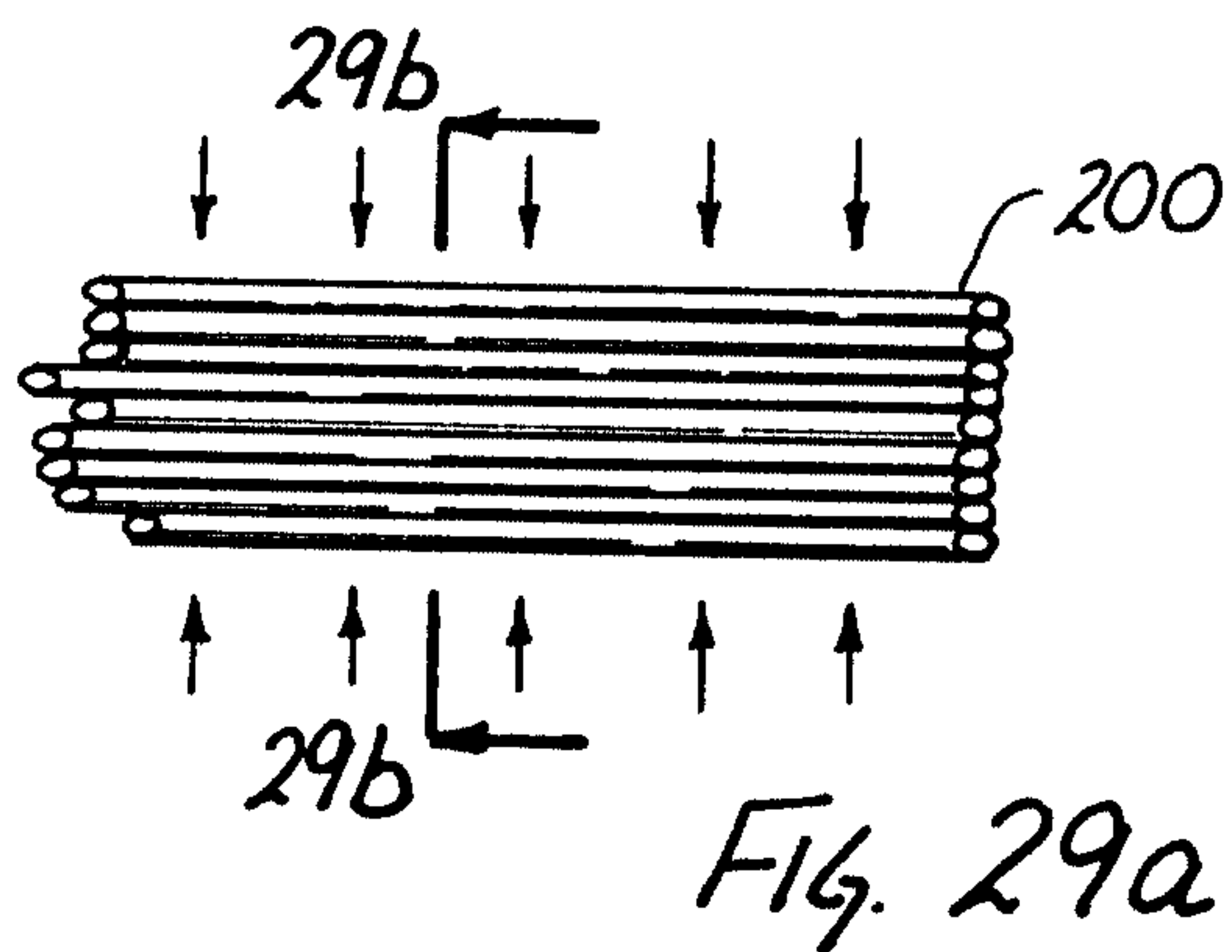


Fig. 29c

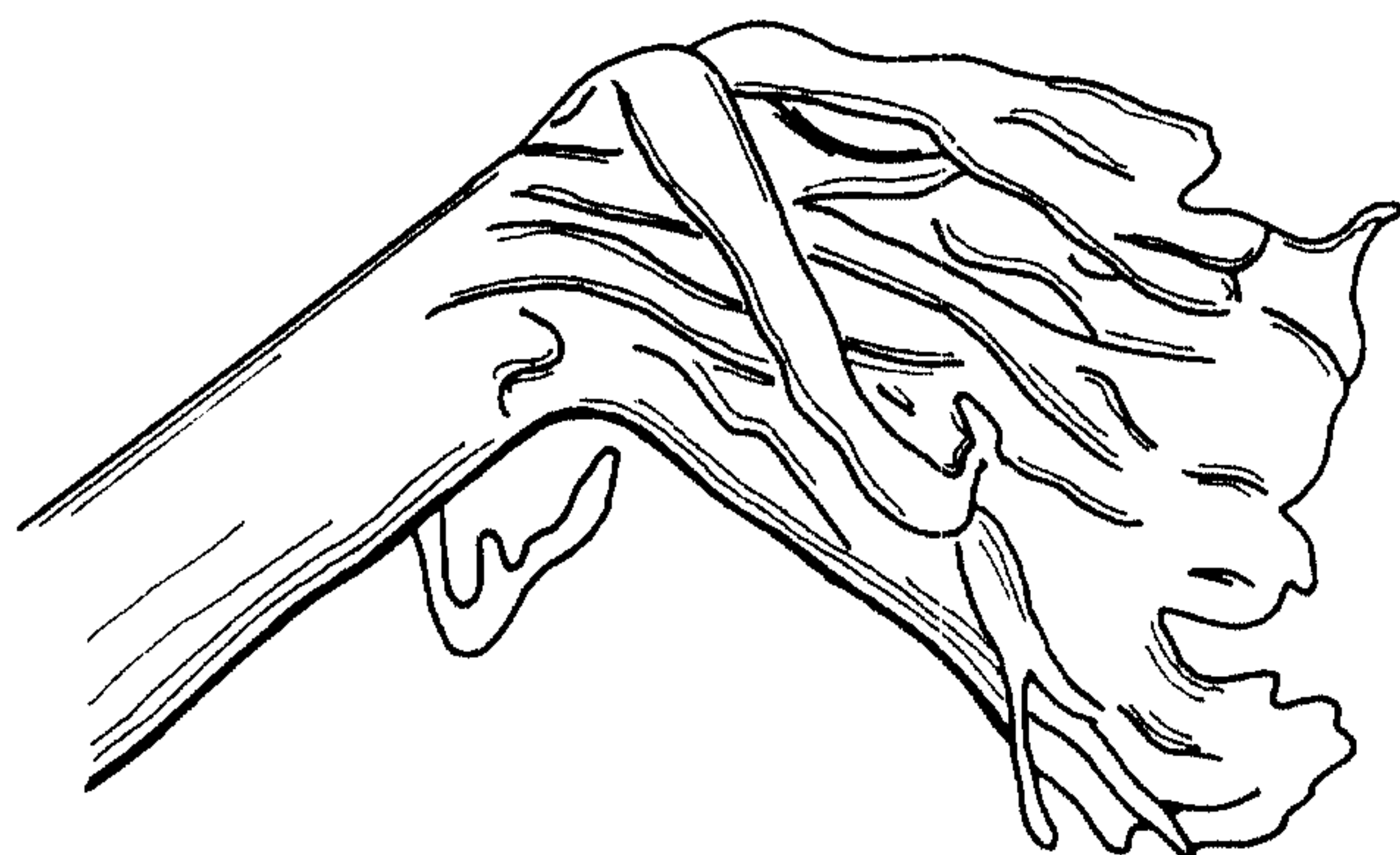


Fig. 30

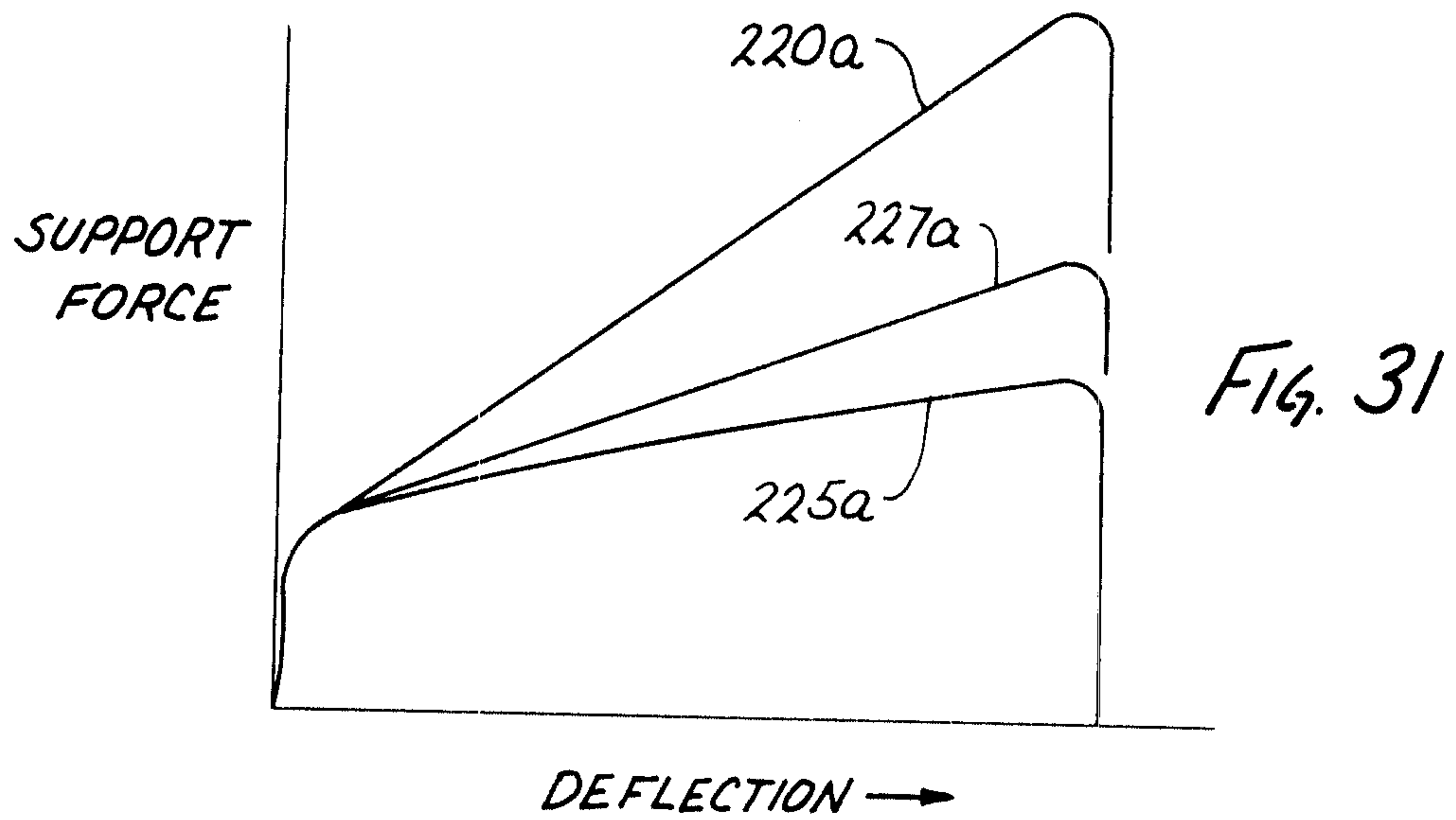


Fig. 31a

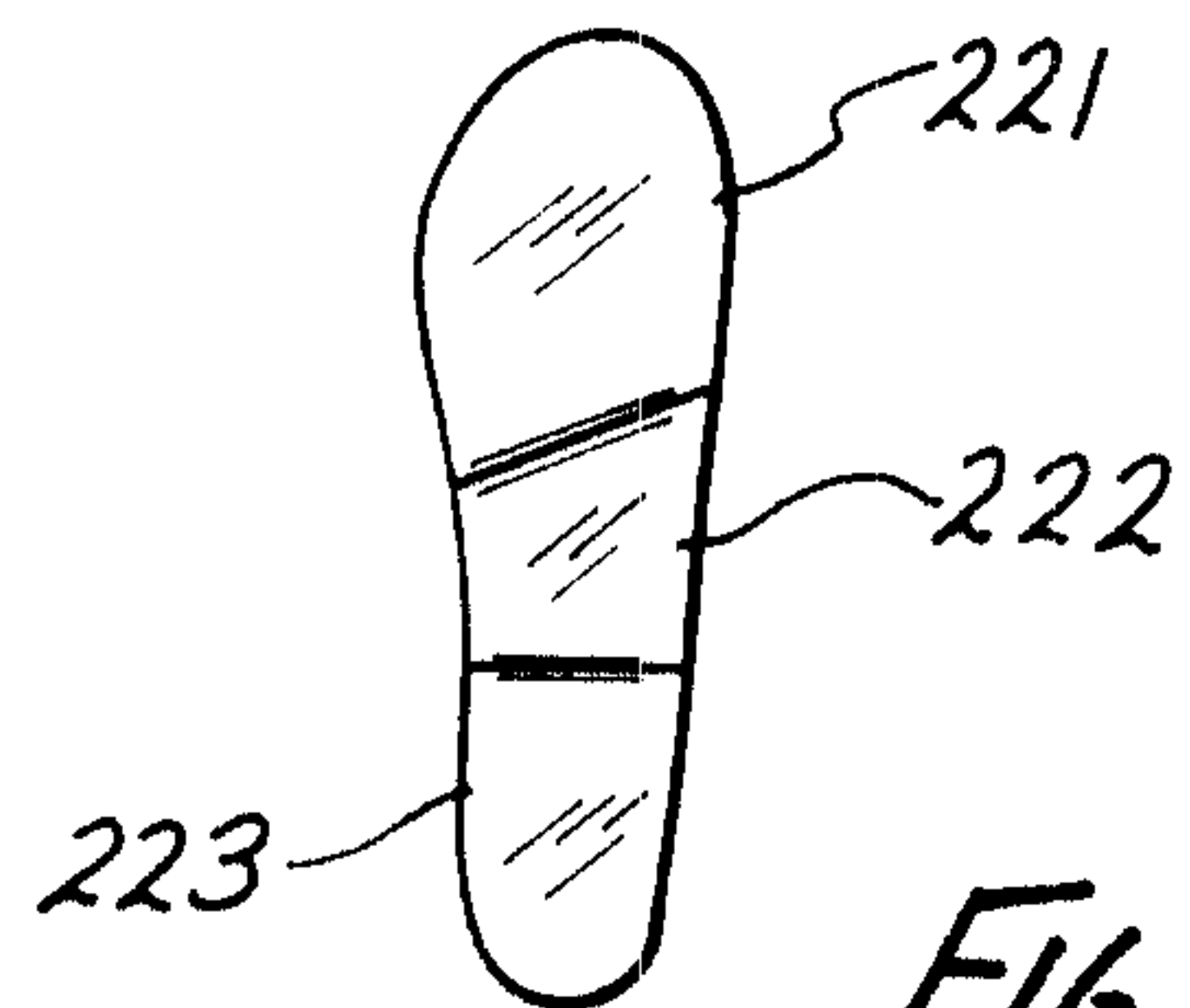


Fig. 31b

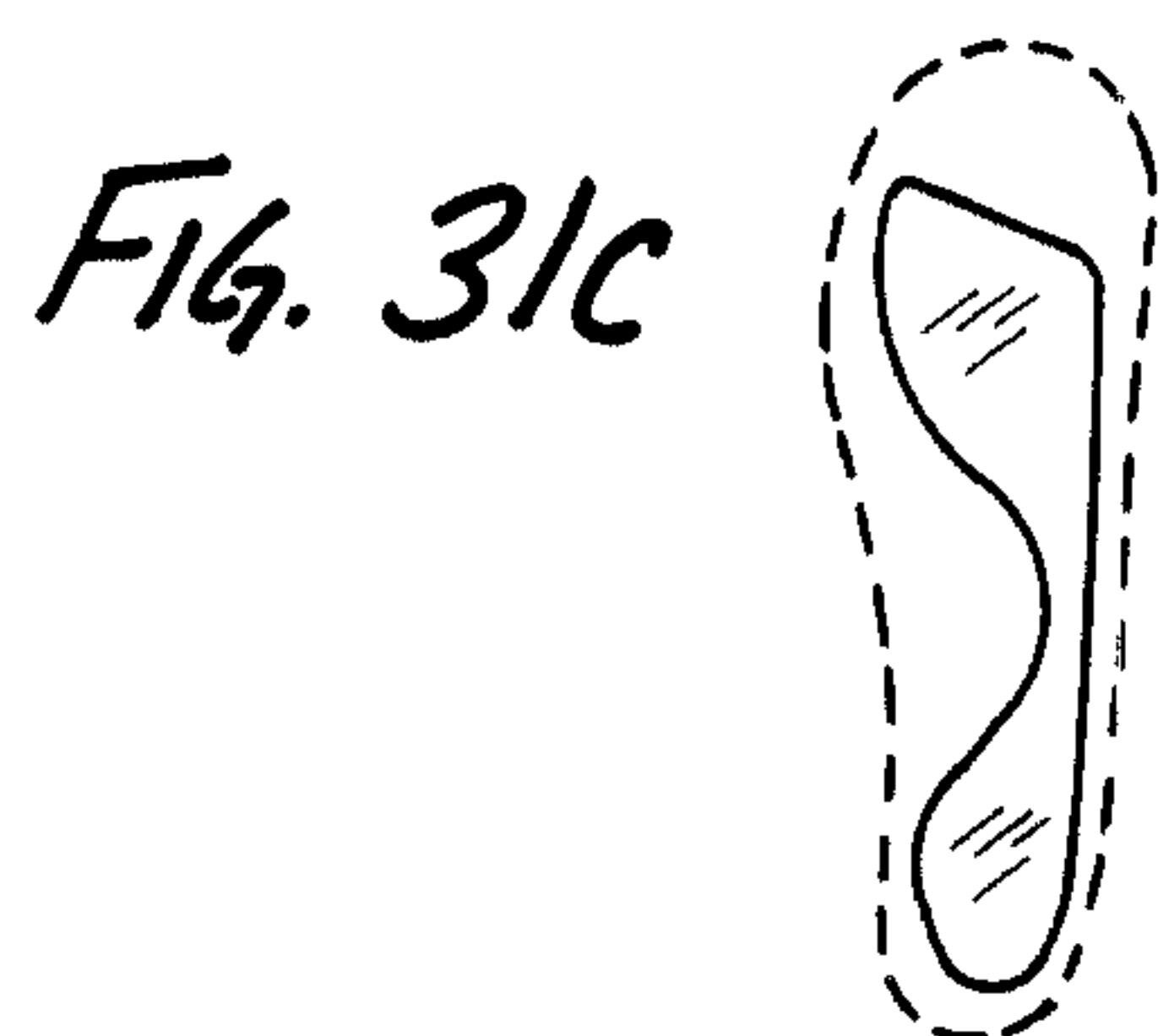


Fig. 31c

Fig. 31d

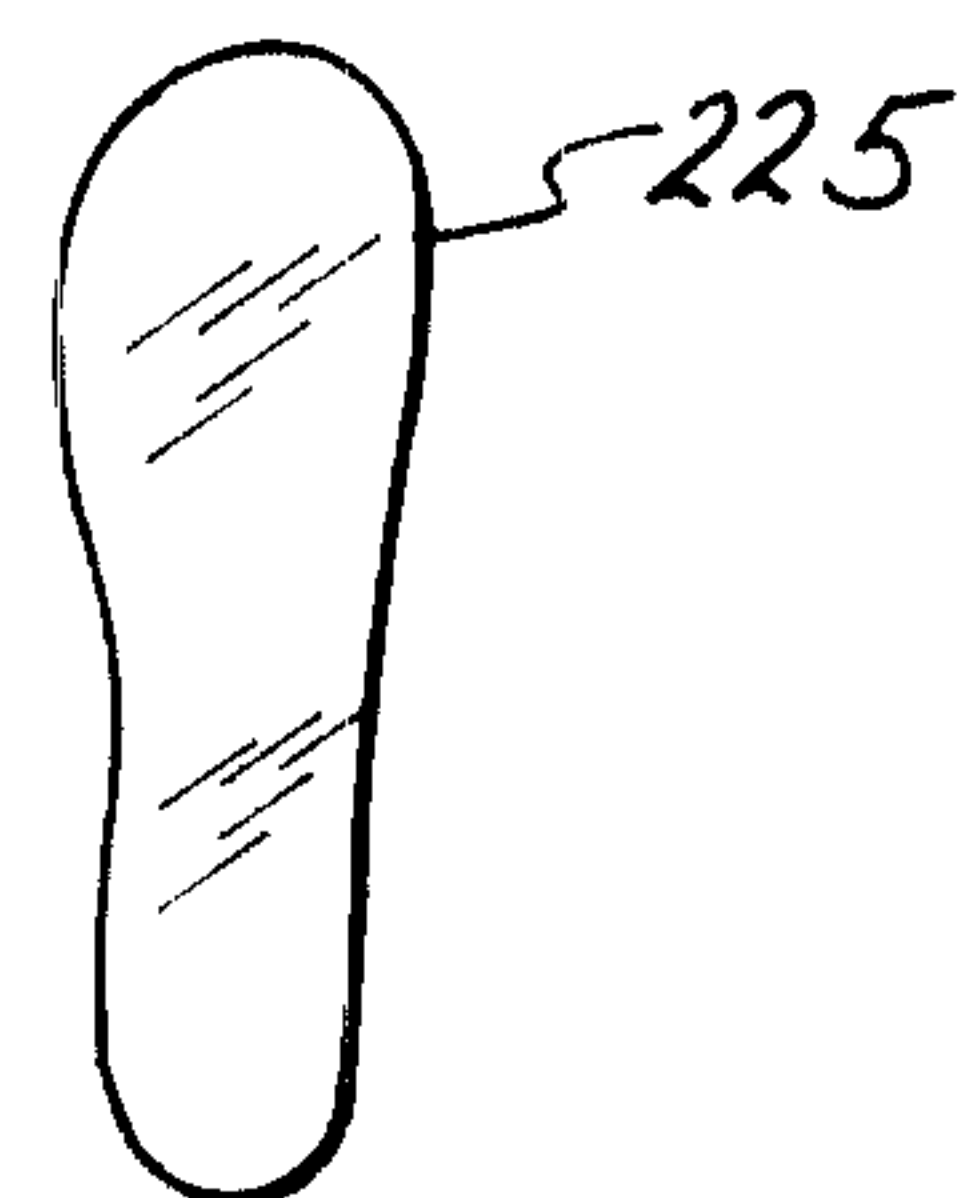
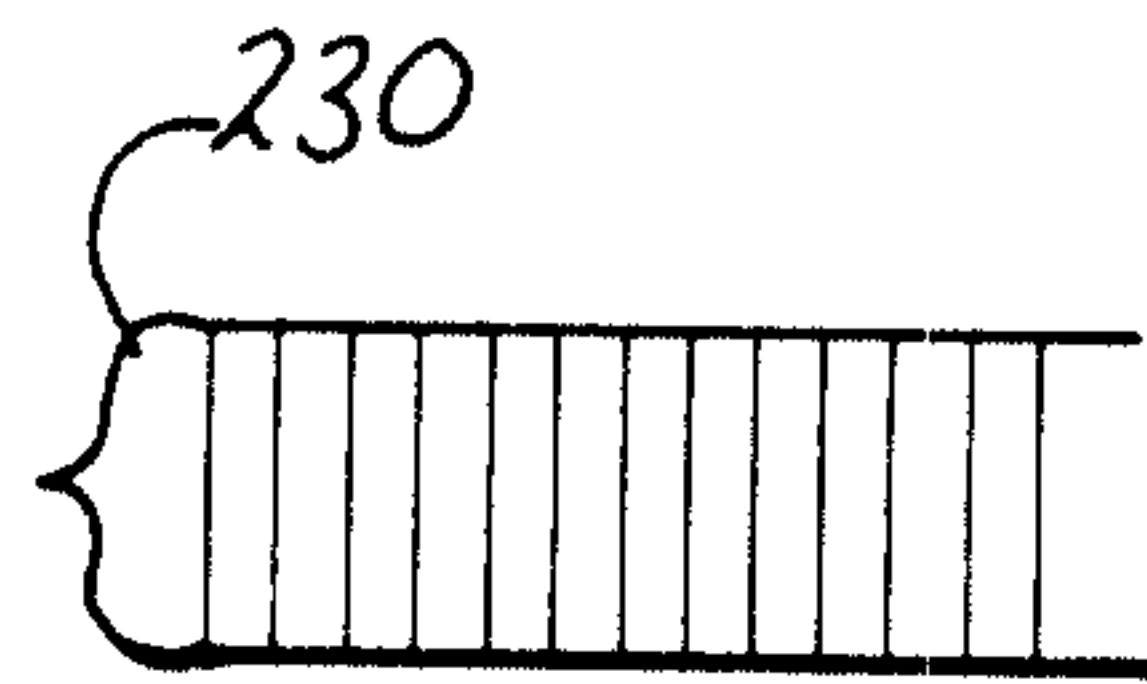




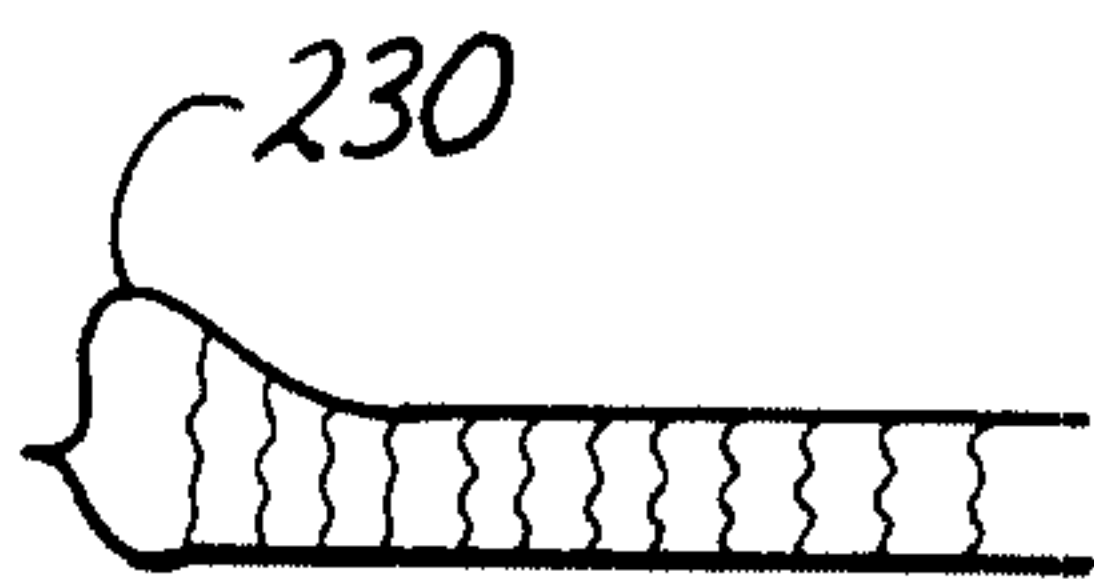
Fig. 32

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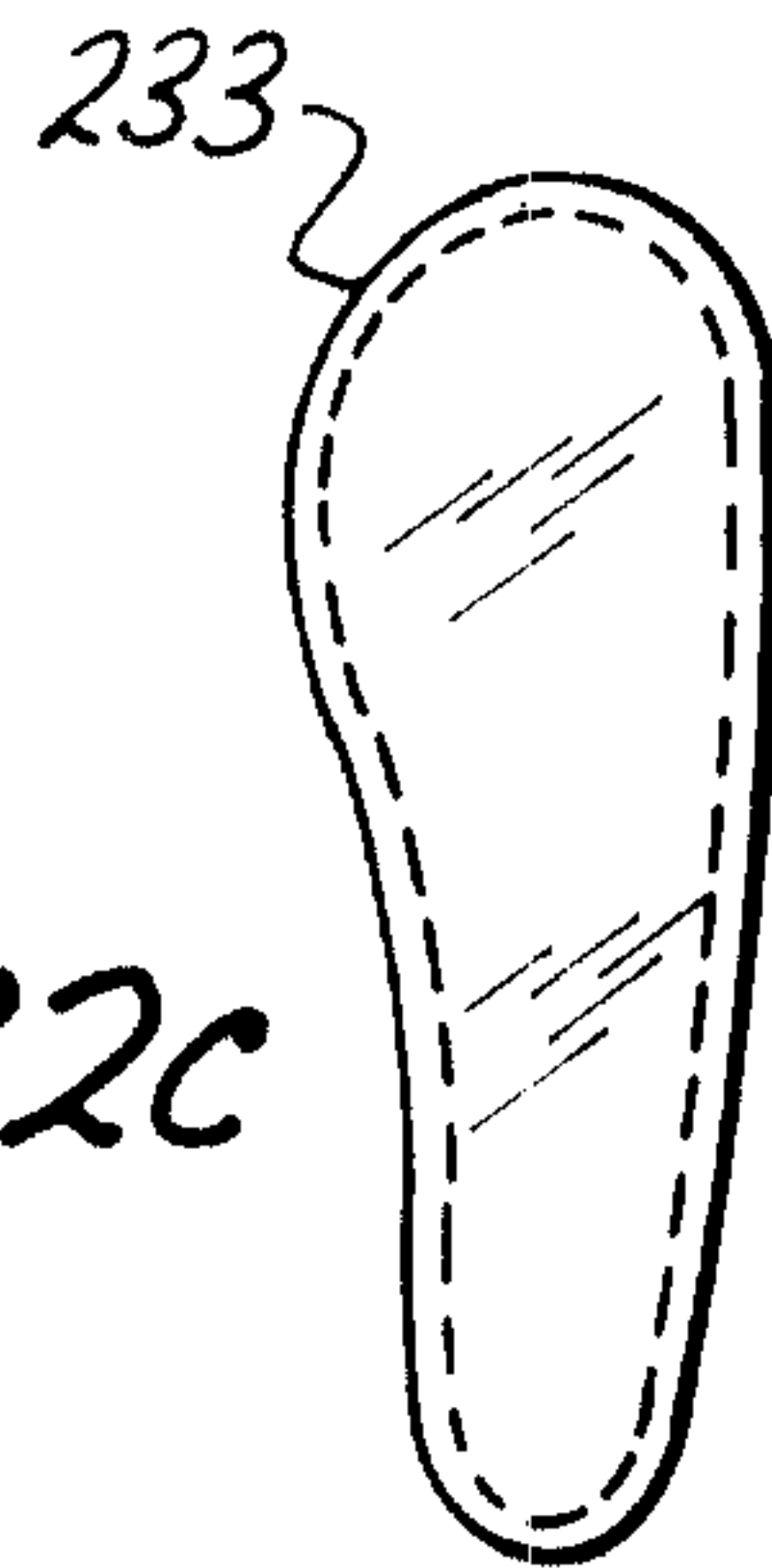
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Fig. 32a



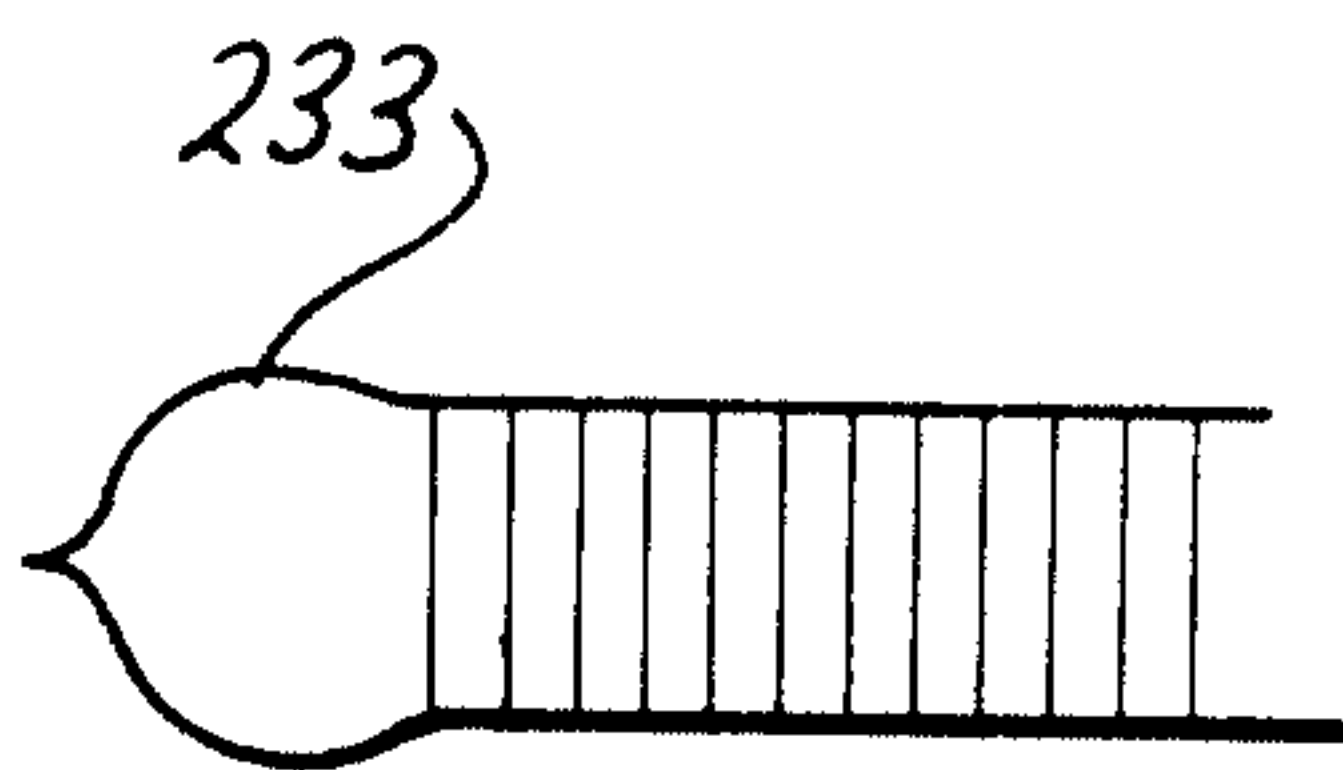
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Fig. 32b



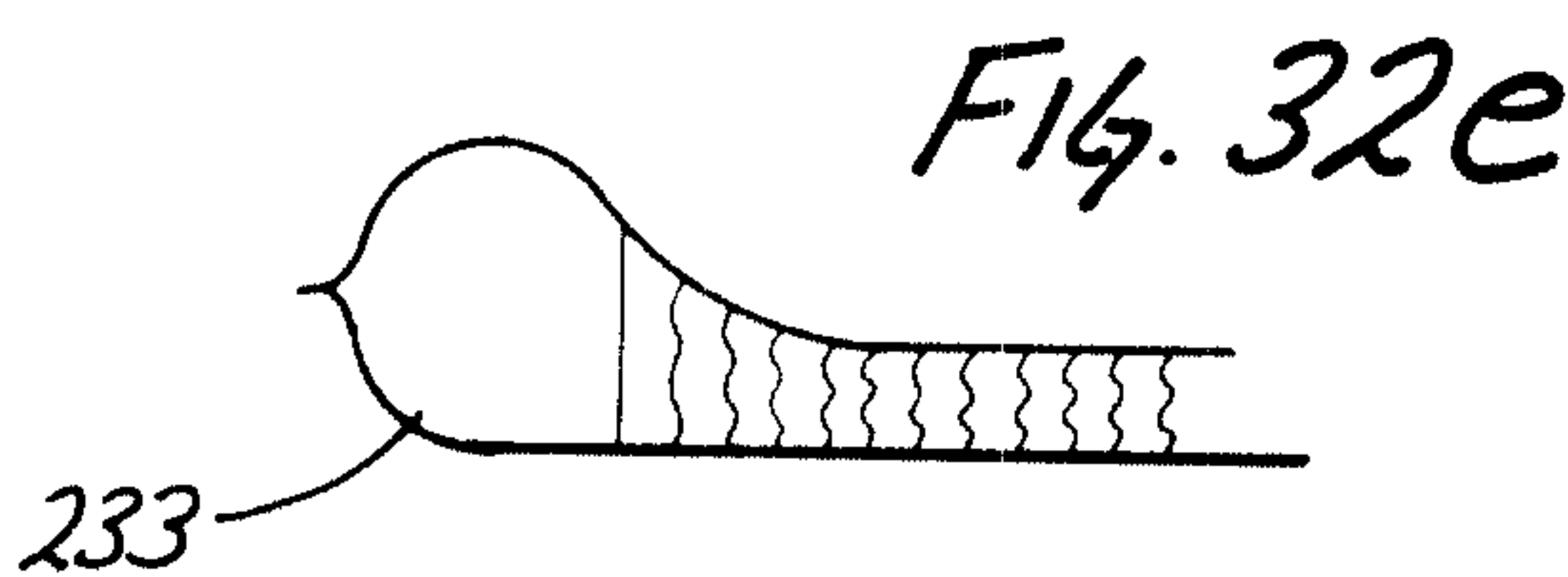
233

Fig. 32c



233

Fig. 32d



233

Fig. 32e

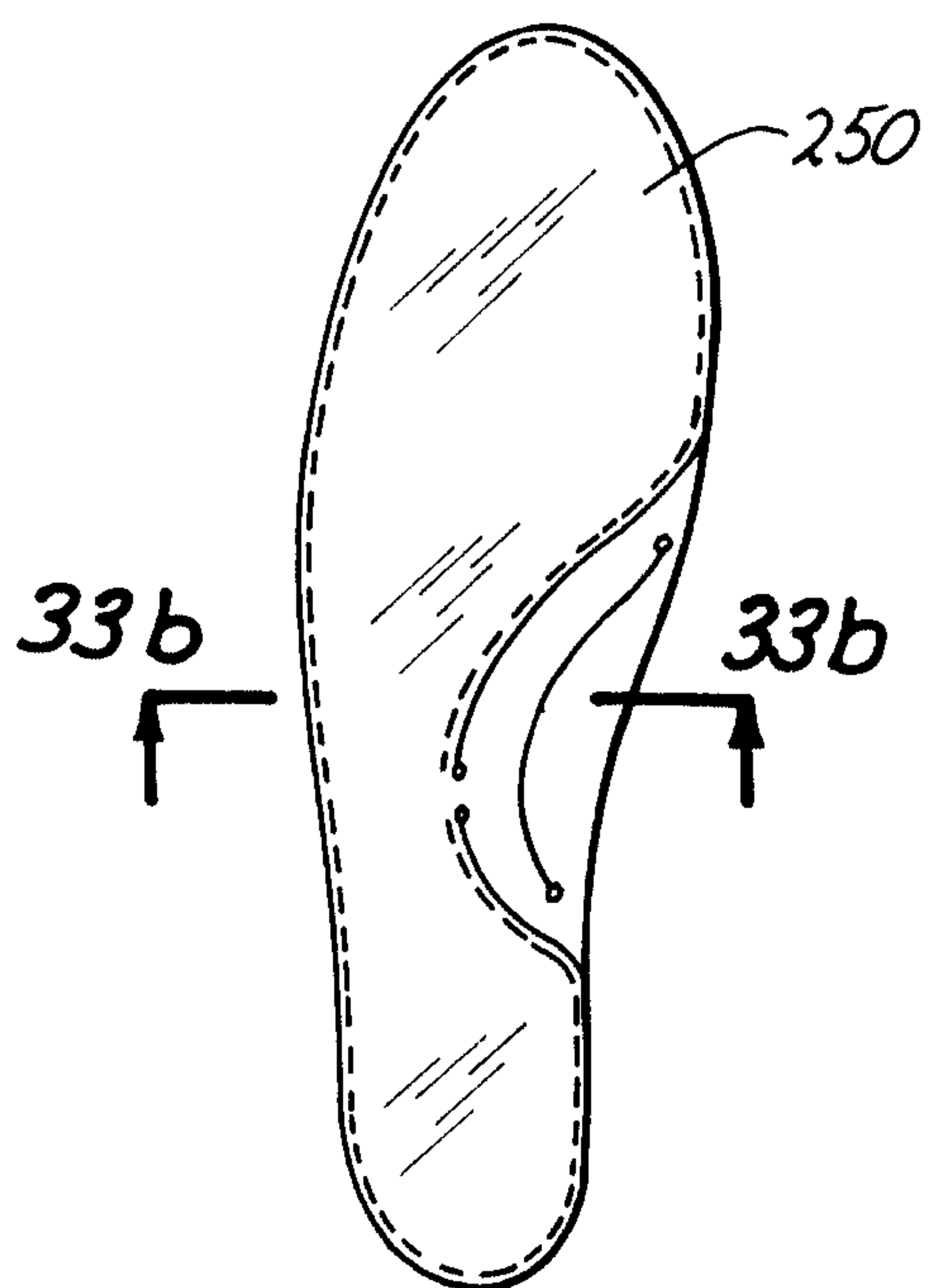


Fig. 33a

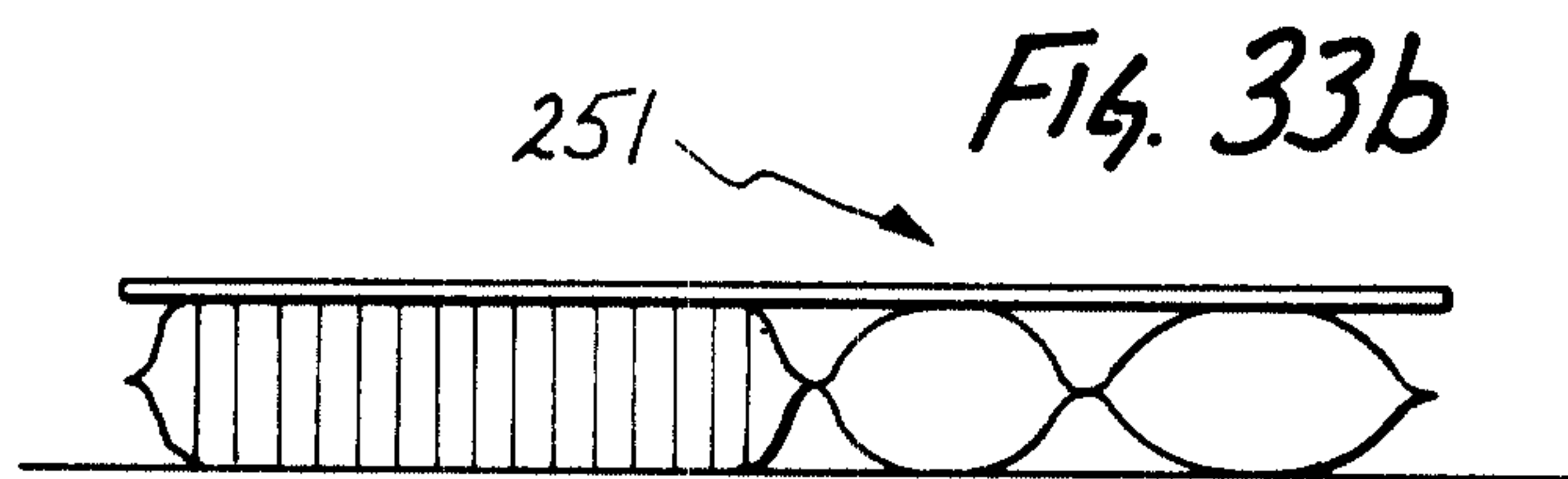


Fig. 33b

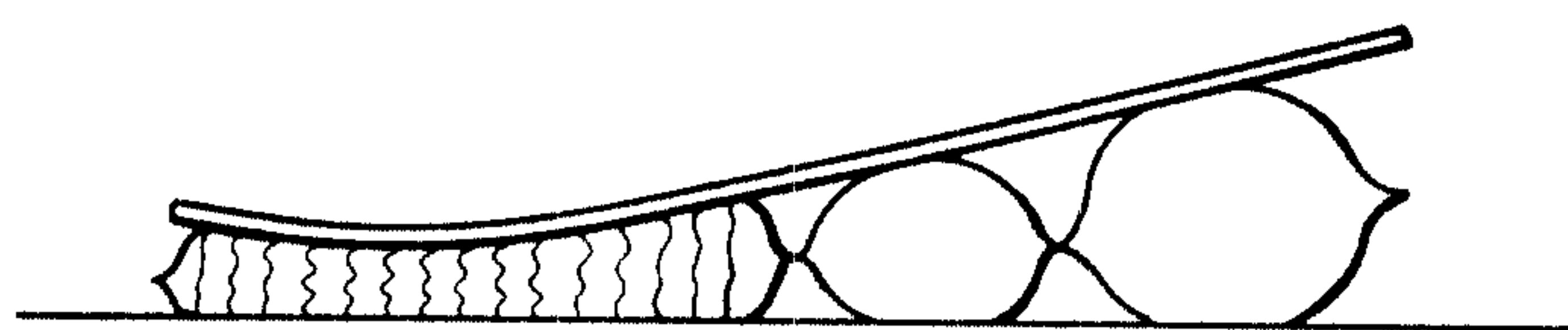


Fig. 33c

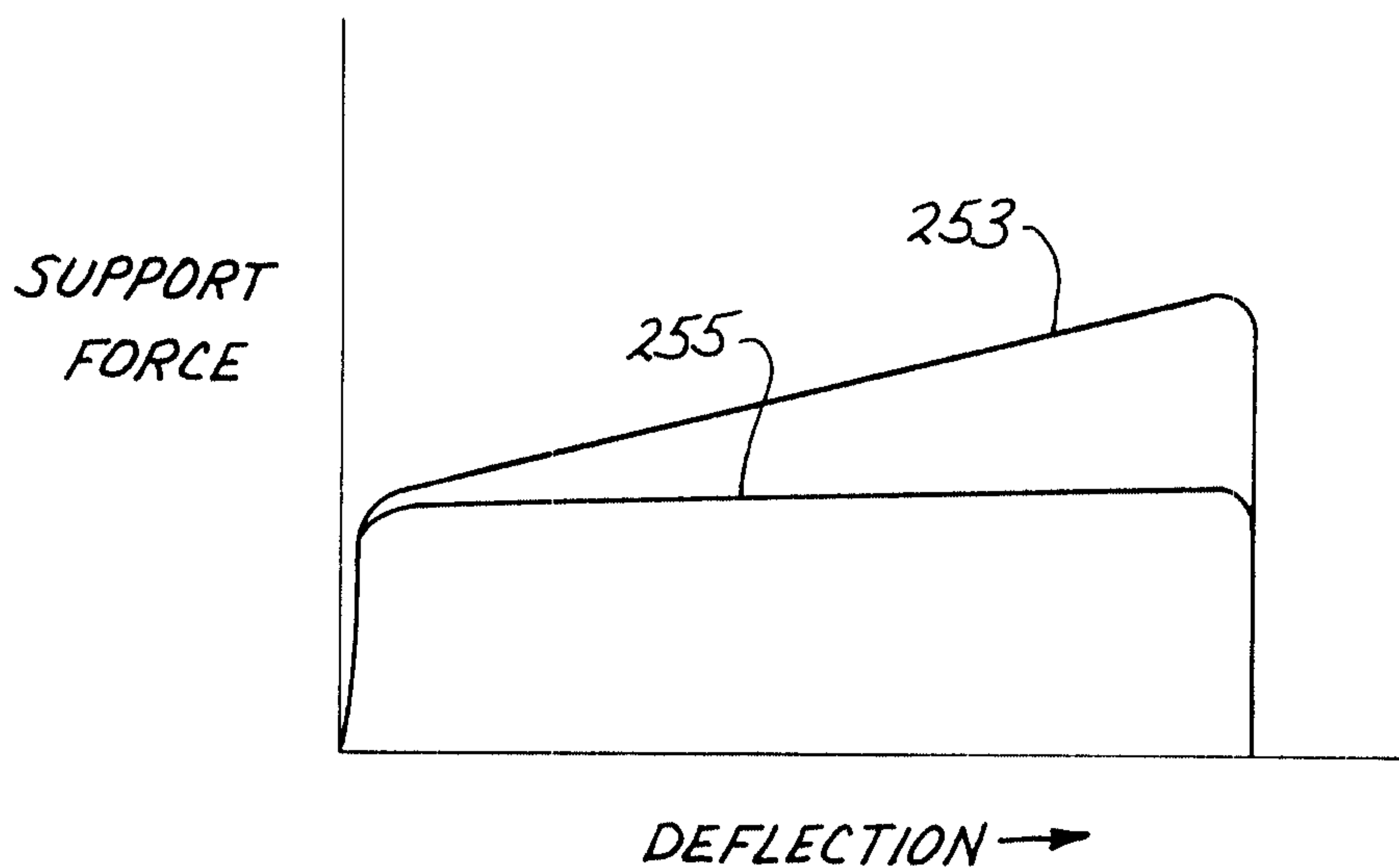


Fig. 33d

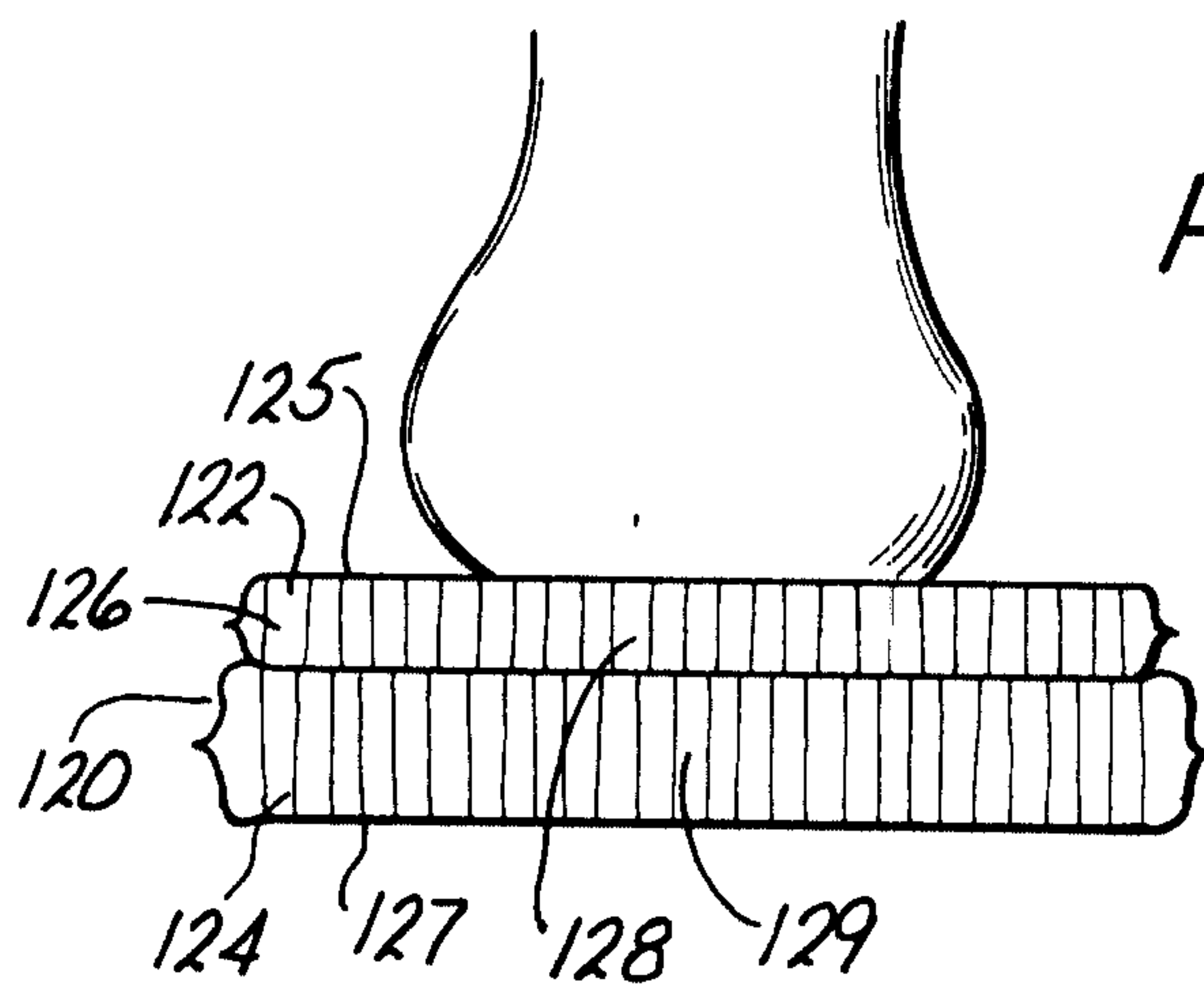


Fig. 34a

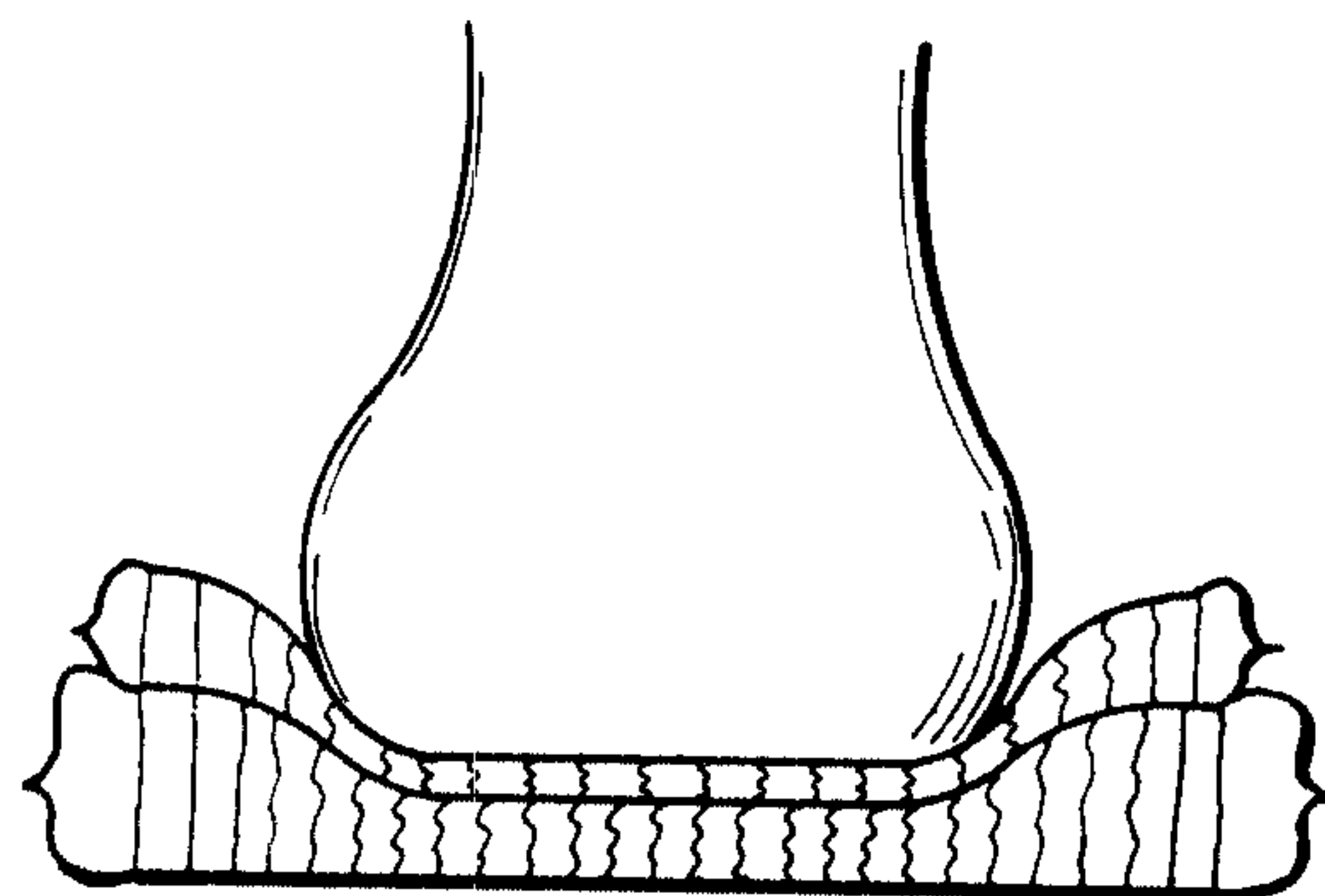


Fig. 34b

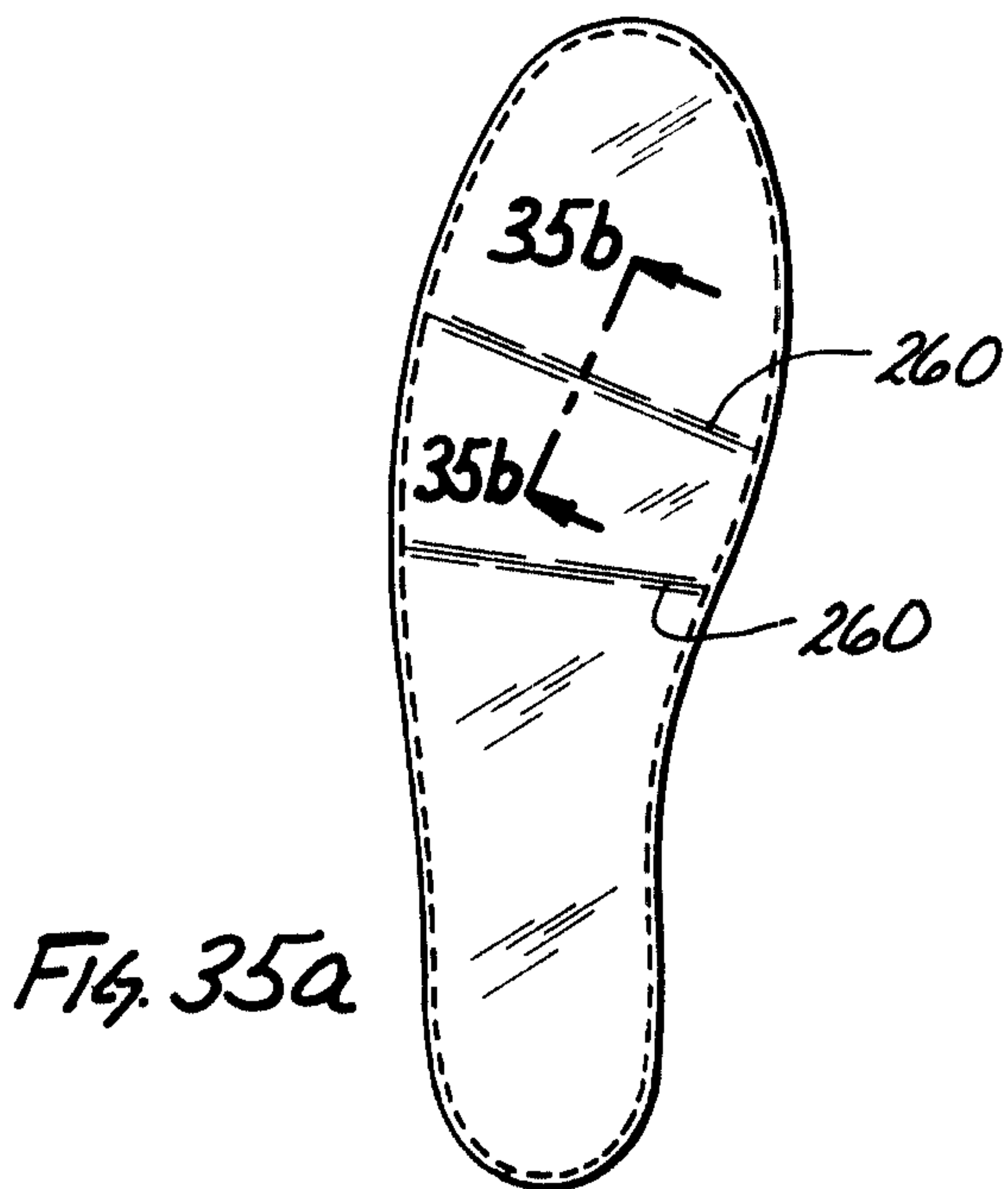


Fig. 35a

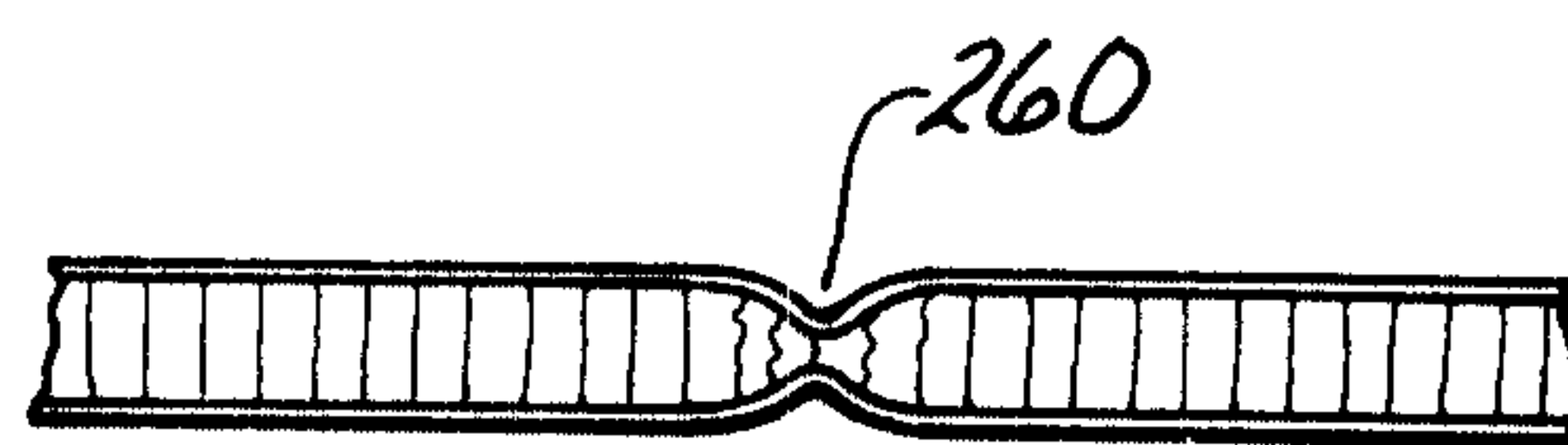


Fig. 35b

