Office de la Propriété Intellectuelle du Canada | Canadian Intellectual Property Office
Un organisme d'Industrie Canada | An agency of Industry Canada

CA 2491693 C 2008/08/26

(11)(21) **2 491 693**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) Date de dépôt PCT/PCT Filing Date: 2003/06/30
(87) Date publication PCT/PCT Publication Date: 2004/01/15
(45) Date de délivrance/Issue Date: 2008/08/26
(85) Entrée phase nationale/National Entry: 2004/12/31
(86) N° demande PCT/PCT Application No.: US 2003/020541
(87) N° publication PCT/PCT Publication No.: 2004/005645
(30) Priorité/Priority: 2002/07/02 (US10/188,721)

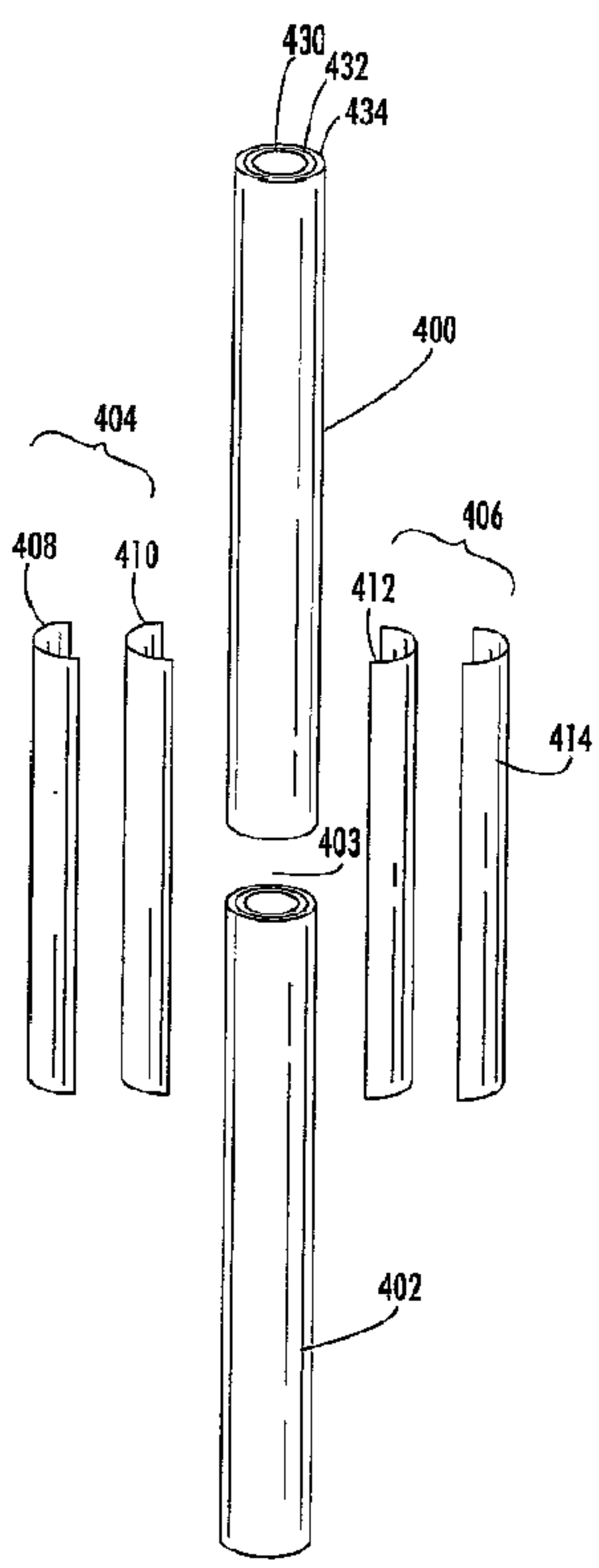
(51) Cl.Int./Int.Cl. *E04C 3/07* (2006.01), *E04C 3/00* (2006.01), *E04C 3/28* (2006.01), *E04C 3/29* (2006.01)

(72) Inventeurs/Inventors:
WARREN, PETER A., US;
ROSENBERG, SARA E., US;
O'REILLY, SEAN, US

(73) Propriétaire/Owner:
FOSTER-MILLER, INC., US

(74) Agent: MACRAE & CO.

(54) Titre : ELEMENT PLIABLE
(54) Title: FOLDABLE MEMBER



(57) Abrégé/Abstract:
A method of manufacturing a foldable member. A plurality of C-section member plies (404, 406) are formed. First and second sets of the C-section member plies (404, 406) are assembled. Two sections of a tube are arranged in an end-to-end manner defining a gap therebetween. The first set of the C-section member plies is secured to one side of the two sections of the tube to bridge the gap therebetween and the second set of C-section member plies is secured to an opposing side of the two tube sections to also bridge the gap therebetween thus forming opposing slots separated by longitudinal strips of material between the slots which fold when subjected to localized buckling forces and which unfold when released. A foldable member manufactured in accordance with this method is also disclosed. Also disclosed is a structure made of one or more such foldable members.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 January 2004 (15.01.2004)

PCT

(10) International Publication Number
WO 2004/005645 A1

(51) International Patent Classification[7]: E04C 3/07

(21) International Application Number: PCT/US2003/020541

(22) International Filing Date: 30 June 2003 (30.06.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10/188,721 2 July 2002 (02.07.2002) US

(71) Applicant: **FOSTER-MILLER, INC.** [US/US]; 350 Second Avenue, Waltham, MA 02451-1196 (US).

(72) Inventors: **WARREN, Peter, A.**; 209 Mt. Vernon Street, Newton, MA 02465 (US). **ROSENBERG, Sara, E.**; 11 Thoreau Court #5, Natick, MA 01760 (US). **O'REILLY, Sean**; 5 Summer Place, East Boston, MA 02128 (US).

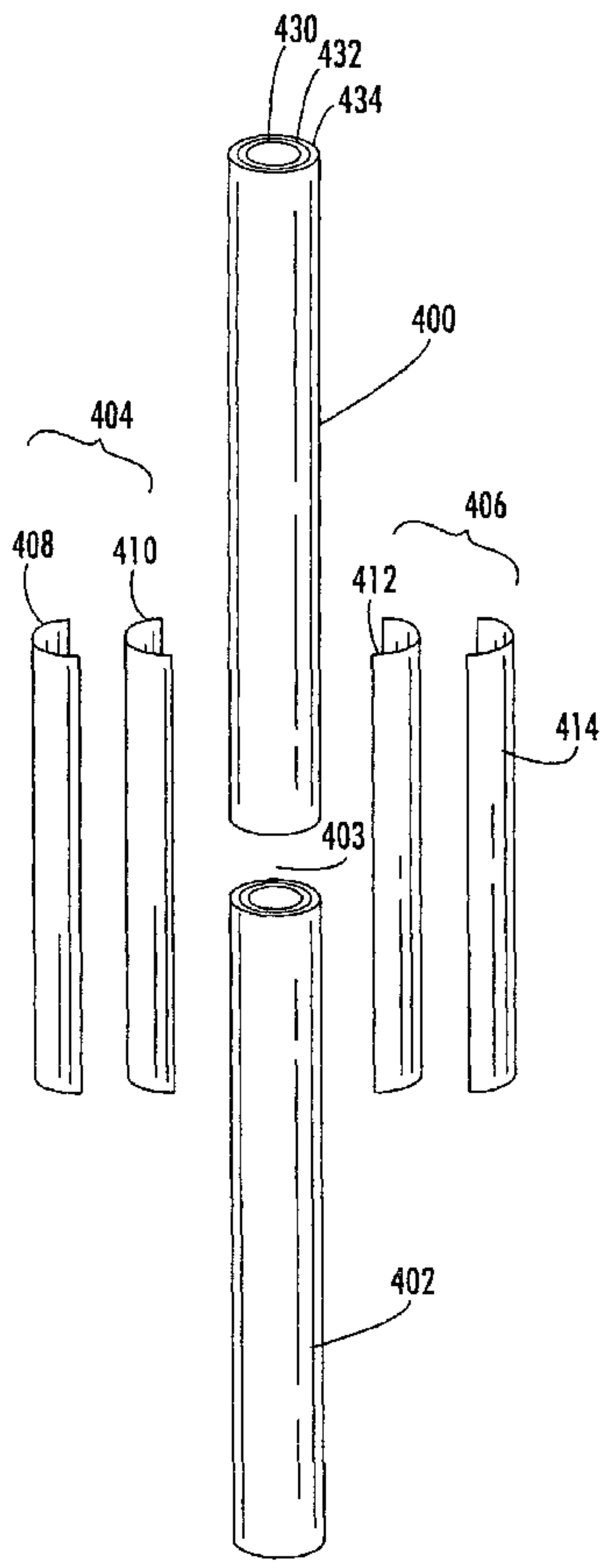
(74) Agents: **THOMPKINS, Thomas E., Jr.** et al.; Landiorio & Teska, 260 Bear Hill Road, Waltham, MA 02451-1018 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: FOLDABLE MEMBER



(57) Abstract: A method of manufacturing a foldable member. A plurality of C-section member plies (404, 406) are formed. First and second sets of the C-section member plies (404, 406) are assembled. Two sections of a tube are arranged in an end-to-end manner defining a gap therebetween. The first set of the C-section member plies is secured to one side of the two sections of the tube to bridge the gap therebetween and the second set of C-section member plies is secured to an opposing side of the two tube sections to also bridge the gap therebetween thus forming opposing slots separated by longitudinal strips of material between the slots which fold when subjected to localized buckling forces and which unfold when released. A foldable member manufactured in accordance with this method is also disclosed. Also disclosed is a structure made of one or more such foldable members.

WO 2004/005645 A1

WO 2004/005645 A1

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

FOLDABLE MEMBER

FIELD OF THE INVENTION

This invention relates to a foldable boom, truss, or longeron member, collapsible truss structures and other similar structures made of such members.

STATEMENT OF GOVERNMENT INTEREST

This invention was made with U.S. Government support under Contract no. F29601-99-C-0010. The U.S. Government may have certain rights in the invention.

RELATED PATENT APPLICATIONS

This application is related to U.S. Patent Publication Number 20020056248 filed January 11, 2002 entitled "Foldable Member" by the same inventor as the subject application which is a divisional application of application Serial No. 09/436,514 filed November 9, 1999 entitled "Foldable Member" now Patent No. 6,374,565, by the same inventor as the subject application. This application is also related to Patent No. 6,321,503.

BACKGROUND OF THE INVENTION

Key optical components of large aperture, space based optical instruments may be deployed on orbit to provide an aperture large enough to increase the resolution and optical performance by several orders of magnitude. The performance of such instruments depends on maintaining the precision and stability of the deployed structural geometry to within nanometers of an ideal shape. Nonlinear contact mechanics and freedom in the components of deployed structures mean that deployed instruments will have the capacity to change shape at the micron and nanometer level of resolution. Eliminating such nonlinearities as load path friction and freeplay would enable a deployed structure to be as linear and precise as a monolithic block of material.

In most mechanically deployed structures, components are moved from their stored positions into their final operational positions by some type of actuator and then locked into place with a deployment latch. For high precision structures, it is critical that the load paths and load predictable for the reliable operation of the instrument.

Existing deployable structure joints have several limitations that either completely prevent them from being used in high precision deployable instruments or require complex analysis and additional launch mass to provide deployment actuation and post deployment locking. Hinge joints previously used in moderate precision structures have relied on high levels of preload and friction to eliminate freeplay and geometric ambiguity. These joints have been shown to be unstable at the micron level, causing the structure to "micro-lurch" or change shape and thus move the instrument's optics far out of alignment.

Existing joints for precision space structures relied on high levels of preload between the many components to eliminate gaps and free play that cause inaccuracies in the structure. Unfortunately, these high levels of preload introduce correspondingly high levels of friction both during the deployment and after deployment has been completed. Friction mechanisms are nonlinear and thus are more difficult to control and less predictable.

Other hinge designs such as latch and actuator type systems suffer from the same disadvantages.

Recently, foldable truss members have been developed so that a truss structure can be collapsed and compactly packaged to save space during delivery and then released to expand and return to its original shape in orbit. All of these mechanisms add to the mass, expense and complexity of the structure and to the difficulty and expense of transporting it. These foldable members reduce the mass (and the delivery cost) of the structure by replacing the hinge, latch and actuator mechanisms with one single device. See, e.g., U.S. Patent No. 4,334,391.

Solid rods are joined on their ends forming a truss structure (a square frame for a solar panel array or a superstructure for a communications satellite antenna, for example) and pre-selected rods are cut in sections to form a hinge between the two sections. The rod sections are joined with spring steel elements similar to if not actually lengths of a carpenter's tape measure.

The rod sections can be folded with respect to each other by imparting a localized buckling force to one of the spring steel elements. Simply letting go of one rod section, returns the two rod sections to an end to end alignment due to the potential energy stored in the biased spring steel hinge elements.

In this way, a truss structure made up of several of these foldable rods can be designed on earth, collapsed for delivery to space, and then released once in position in space where the foldable rods flex back into position forming the truss structure designed and constructed on earth.

In use, this spring steel hinge design suffers from a number of shortcomings.

First, hinges formed of spring steel elements require joining the ends of each spring steel element to a rod section. These joints and the spring steel elements themselves add significantly to the overall weight of the truss structure which is an undesired factor in space launch capability.

The spring steel elements also result in dimensionally unstable truss structures. The dimensional instability is caused by the relative motion of the internal components including the joints between the spring elements and the rod sections and permanent yielding of different areas of the spring elements themselves.

The result is that the shape of the truss structure may change when it is erected in space from the shape of the truss structure before it was collapsed on earth. This can have disastrous effects on instrument performance as even a ten nanometer to ten micrometer displacement can severely affect the performance of primary and secondary optics attached to the truss structure.

SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a foldable member and a collapsible structure made of a number of foldable members that is lighter than prior art foldable members and collapsible structures.

It is a further object of this invention to provide such a member and such a structure which is more dimensionally stable.

It is a further object of this invention to provide such a foldable member which eliminates numerous sources of imprecision.

It is a further object of this invention to provide such a member and such a structure which eliminates the need for deployment actuators and mechanical latches to further reduce system mass.

It is a further object of this invention to provide such a member and such a structure which have tailorable thermal expansion and conductivity properties and which thus can be designed for a multitude of performance requirements.

It is a further object of this invention to provide such a member which can be made of a variety of different types of materials.

It is a further object of this invention to provide such a member which is simple to manufacture and use.

It is a further object of this invention to provide a collapsible tube useful in variety of applications.

This invention results from the realization that a lighter and more dimensionally stable foldable member can be constructed by forming longitudinal slots in a tube around the perimeter thereof at a location where the member is designed to bend thereby forming separated, longitudinal strips of material at that location which easily buckle allowing the member to fold without adding a separate hinge which would add weight to the member and which would also result in dimensional instability.

This invention features a method of manufacturing a foldable member, the method comprising forming a plurality of C-section member plies, assembling a first set of the C-section member plies, assembling a second set of the C-section member plies, arranging two sections of a tube in an end-to-end manner defining a gap therebetween, securing the first set of C-section member plies to one side of the two tube sections to bridge the gap therebetween, and securing the second set of C-section member plies to an opposing side of the two tube sections to bridge the gap therebetween thus forming opposing elongated slots in the tube separated by longitudinal strips of C-section member plies material between the slots which fold when subjected to localized buckling forces and which unfold when released.

In one example, the step of assembling the first and second sets of C-section member plies includes securing all the plies of each set together first before the sets of plies are attached to the two tube sections. Preferably, the plies are made of composite material pultruded into a C-section cross sectional shape and the two tube sections are also made of composite material.

If other materials are used, it is preferred that the material of the first and second set of C-section members is the same as the material of the two tube sections.

In another embodiment, a third tube section is arranged in an end-to-end manner with the two tube sections to define a gap therebetween and third and fourth sets of C-section member plies are secured to opposing sides of the third tube section and the two tube sections thus forming sets of longitudinally adjacent opposing elongated slots.

This invention also features a foldable member comprising two sections of a tube arranged in an end-to-end manner defining a gap therebetween, and opposing conforming members each made of multiple plies attached to both tube sections and bridging the gap therebetween defining opposing elongated slots and separated longitudinal strips of material between the slots which fold when subjected to localized buckling forces and which unfold when released. Typically, the conforming members have a C-cross sectional shape and the material of the conforming members is the same as the material of the two tube sections. Preferably, the conforming members are made of composite material and the two tube sections are also made of composite material.

In one example, both sections of the tube comprise a plurality of layers. There may be two diametrically opposing elongated slots and two diametrically opposing longitudinal strips or even three opposing elongated slots and three opposing elongated strips wherein each longitudinal strip diametrically opposing an elongated slot.

In one embodiment, the conforming members have a neck down region and the conforming members are secured together only at the neck down region. Also, the conforming members may be centrally secured together only where they attach to the tube sections. In another embodiment, an intermediate rigid member is provided interconnecting the conforming members with a tube section. The intermediate member typically has spaced fingers and each conforming member is received between two spaced fingers.

In lengthy foldable members, there may be a plurality of hinge areas longitudinally spaced from each other along the length of the tube, each hinge area including opposing elongated slots. Further included may be a third tube section and sets of longitudinally adjacent opposing elongated slots.

A truss type structure in accordance with this invention features a plurality of joined truss members wherein a selected number of said truss members each include a foldable member as discussed above: two sections of a tube arranged in an end-to-end manner defining a gap therebetween and opposing conforming members each made of multiple plies attached to both tube sections and bridging the gap therebetween defining opposing elongated slots and separated longitudinal strips of material between the slots which fold when subjected to localized buckling forces and which unfold when released.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a perspective view of a structure made of a number of foldable members in accordance with the subject invention;

Fig. 2 is a schematic view of the structure shown in Fig. 1 in a collapsed state;

Fig. 3 is a perspective view of the structure of Fig. 2 after it expands from the collapsed condition;

Fig. 4 is a front elevational view of a prior art foldable device;

Fig. 5 is a view of the prior art device shown in Fig. 4 in the folded position;

Fig. 6 is a side elevational view of the foldable member of the subject invention;

Fig. 7 is a front elevational view of the foldable member shown in Fig. 6;

Fig. 8 is a schematic view of the foldable member shown in Figs. 6 and 7 in a folded position;

Fig. 9 is a front elevational view of another embodiment of the foldable member of this invention;

Fig. 10 is a side elevational view of another embodiment of the foldable member of the subject invention;

Fig. 11 is a view similar to Fig. 11 showing the interior rear side wall of the foldable member of the subject invention;

Fig. 12 is a front elevational view of a single elongated foldable member with multiple hinge areas in accordance with this invention;

Fig. 13 is a schematic view of the member of Fig. 13 in folded position;

Fig. 14 is a schematic view of another embodiment of a foldable member in accordance with the subject invention;

Fig. 15 is a schematic view of still another embodiment of a foldable member in accordance with the subject invention;

Fig. 16 is a schematic exploded view of still another embodiment of a foldable member in accordance with the subject invention showing the use of conforming members connected between two tube sections;

Fig. 17 is a schematic view showing the embodiment of the foldable member of Fig. 16 in the assembled state;

Fig. 18 is a schematic partially exploded view showing another embodiment of the subject invention;

Fig. 19 is a schematic view showing an assembled foldable member in accordance with the embodiment shown in Fig. 18;

Fig. 20 is a schematic partially exploded view of still another embodiment of the foldable member of this invention;

Fig. 21 is a schematic view showing an assembled foldable member in accordance with the embodiment of Fig. 20;

Figs. 22-23 are schematic views showing conforming members in accordance with this invention having neck down regions;

Fig. 24 is a schematic view showing one method of securing the conforming members to the two tube sections in accordance with this invention;

Fig. 25 is a cross sectional view of a portion of Fig. 24; and

Fig. 26 is a schematic view showing the use of an intermediate member used to join the conforming members of this invention to a tube section.

DISCLOSURE OF THE PREFERRED EMBODIMENT

Truss structure 10, Fig. 1, of this invention includes a plurality of joined truss members 12 and 14 as shown. Truss structure 10, for example, may be 1.25 meters tall but collapsible to a height of 27 centimeters as shown in Fig. 2 due to the foldable nature of truss member 12 (and other selected truss members) which includes hinge areas 16, 18, and 20 along its length.

Depending on its specific design, hinge area 16 may fold downward, hinge area 20 may fold upward, and hinge area 18 may fold in the direction out of the plane of the drawing.

When collapsed as shown in Fig. 2, the volume of truss structure 10 is sharply reduced resulting in significant space savings for space flight.

Upon deployment in outer space, however, truss structure 10 automatically expands as shown in Fig. 3 to its original configuration and may be used as a frame for solar panels, various optical devices, or as a part of a superstructure when joined to similar structures.

As shown in Fig. 3, the truss structure is strong under compression and can support several hundred pounds. Its also strong against bending and torque since the individual hinge areas can only be actuated by intentional localized buckling force applied directly to the hinge areas.

In the prior art, hinges are formed in a truss member by cutting the truss members at the desired hinge area and attaching single clam shell shaped steel spring elements 40, 42, and 44, Fig. 4 to truss member sections 46 and 48.

The spring steel elements are similar to lengths of carpenter's tape from a tape measure. When a localized buckling force is imparted to one spring element as shown at 50 and the two truss member sections are subjected to a bending force, the spring elements readily bend, collapsing the truss member as shown in Fig. 5. If one truss member section is released, the clam shell shape of the spring steel elements spring the truss members into the configuration shown in Fig. 4.

However, these and other such truss members suffer from numerous shortcomings as discussed in the Background of the Invention above, including the fact that they are not thermally stable. Also, the joints between each spring steel element and the truss member sections can shift slightly and/or a spring steel element may yield while the truss structure is in the collapsed condition. When this truss structure is deployed in space it may not return to its original shape, resulting in dimensional instability which can severely affect the performance of sensitive equipment and optical devices. Other prior art devices added significantly to the overall weight of the system, were not dimensionally stable, and/or were complex, and/or costly.

In contrast, the subject invention solves these problems in part by a foldable member with a hinge preferably constructed of the same material as the member. In one example, foldable member 60, Fig. 6, includes tube 62 having at least one predetermined hinge area 64. Hinge area 64 includes opposing, elongated slots 66 and 67 (see Fig. 7) forming separate longitudinal strips 70 and 72 of material between the slots. These strips 70 and 72 fold when subjected to localized buckling forces as shown in Fig. 8, thereby allowing the member to fold at the hinge area about axis 74, Fig. 7. “Slots” as used herein means openings, slits, and cuts of any configuration.

Member 60 is dimensional stable and extremely reliable. In addition, by tailoring the material of tube 62, the thermal expansion and/or conductivity of member 60 can be precisely tailored to meet various performance requirements. At the same time, member 60 is sufficiently strong with respect to torsion, shear, and buckling for numerous applications.

Slots 66 and 67, as shown in Figs. 6 and 7, are diametrically opposing but this is not a limitation of the present invention. For example, in the embodiment shown in Fig.

9, there are three opposing elongated slots 90, 92, and 94 and three opposing longitudinal strips 96, 98, and 100 (see also Fig. 10). Longitudinal strip 96 is diametrically opposed to elongated slot 94, longitudinal strip 98 is diametrically opposed to slot 90 and longitudinal slot 100 diametrically opposes slot 92. Therefore, the slots are spaced around the circumference of the tube in a generally opposing configuration, but a given slot may not diametrically oppose another slot even if there are only two slots. Also, although the slots are each shown to be of the same construction, this is not a limitation of the present invention as the length and opening width of the slots at a given hinge area may be different depending on the specific design. Furthermore, the slots may vary from a mere slit to a wide elongated opening. For example, slots 66 and 67, Figs. 6 and 7, are simply a 4 inch long formed in a 1 3/4 inch tube. Slots 90, 92, and 94, Fig. 9, on the other hand, are elliptically shaped and approximately 11/16 inches wide at their widest point.

As shown in Fig. 1, a given truss member may include a plurality of hinge areas such as hinge areas 16, 18, and 20 along the length of truss member 12. Therefore, any one member may include a number of hinge areas, each hinge area including two or more opposing elongated slots.

Tube 62, Figs. 6-9 may be made of plastic material such as a polycarbonate material, but polyurethane, Delrin, or nylon tubes may also be constructed. Also, for space applications in particular, composite materials may be used including a braided fiber structure embedded in a resin matrix. In one early example, carbon fibers were braided using a round braider to form a triaxial braid in a tubular shape which was then impregnated with a polycarbonate resin. A thin wall aluminum tube was wrapped in Teflon and over wrapped with a sheet of Lexan material. A triaxial carbon braid was formed over the Lexan sheet and additional layers of Lexan were added over triaxial braid. A combination of pressure and elevated temperature was used to consolidate the Lexan material into the fibers. The slots were then formed in the tube in the desired configuration. The tube may also be made of metal.

When structure 10, Fig. 1 was constructed of 1.5 inch diameter tubes similar to those shown in Fig. 9, it weighed 3.9 lbs. and supported a static load of more than 200 lbs. This 4 ft. tall structure is collapsible to an 11 inch tall folded package. Therefore, a 100 foot long structure could be packaged into a "Delta class" space vehicle for space deployment and would weigh less than 100 lbs. Since material is actually removed from each foldable member when the opposing slots are formed, the resulting structure weighs significantly less than prior art structures constructed of members including spring steel elements 40, 44, and 42, Fig. 4 or prior art structures with mechanical hinges.

In another embodiment, member 120, Fig. 10 includes opposing sets 122 and 124 of elongated slots. Thus, set 122 includes two slots, slot 126 and slot 128 separated by bridge element 130; and set 124 includes two slots, slot 132 and slot 134 separated by bridge element 136. Each slot was about 1/8" wide and about 5/8" long in a 1⅝ inch diameter Lexan tube. Each bridge element was about 3/16 inches long.

In one embodiment, slot 126 is diametrically opposed from slot 132 and slot 128 is diametrically opposed from slot 134 although this is not a limitation of the present invention.

Also, stress relieving member 138 (e.g. a dowel) may be attached to each bridge element 130 and 136 on the inside of the tube for relieving the stress of each bridge member and to prevent them from tearing or cracking when the tube is folded.

The foldable member shown in Figs. 10 and 11 proved to be generally stronger in and torsion than the members shown in Figs. 6-9.

By including the hinges of this invention in a longeron twenty feet in length, it may be collapsed to a three foot long package, convenient for storage. A 3-4 inch diameter tube would typically have about a 1/16th inch wall thickness while a 1 1/2 inch diameter tube would typically have a .020 inch wall thickness, although many different combinations of wall thickness and diameters are possible over a wide variety of tube lengths and tube materials for specific applications.

The result is a foldable truss member, or longeron, or tube with no moving parts or joints and thus a lighter and more dimensionally stable structure. The hinge means or elements are preferably made of the same material as the tube unlike the spring steel elements of the prior art.

The members shown in Figs. 6-11 could be a component of truss structure 10, Fig. 1 made of like truss members joined together as shown or instead could be a longeron of a frame or bulkhead or even a solitary boom or portion of an arm or other member.

In addition, the members shown in Fig. 6-11 could be a part of other mechanical structures such as collapsible mobile bridges, erectable civil engineering structures for emergency response and disaster relief, tent poles, police barricades, and the like.

Figs. 12 and 13 show foldable structural member 150 with elongated slots placed at different locations to allow the member to be folded at different angles of bend to accommodate unique storage and/or deployment requirements or sequencing.

Foldable member 300, Fig. 14 includes tube 302 made of layers 303, 304, 306, etc. of material, plastic (e.g. Lexan or composite material), for example, formed by wrapping a sheet of the material around itself several perhaps even 20 or more times. An adhesive, for example a double sided tape, may be used to secure the layers of plastic material to each other at selected locations along the length of the tube for example at locations 310 and 312, shown in phantom. If the sheet of material comes off a round roll of stock material, it will have a tendency to roll up into a tube due to memory, an advantageous feature of this embodiment of the subject invention.

As with the other embodiments, slot 314 and an opposing slot (not seen in Fig. 14) is formed through all of layers 303, 304, and 306 forming longitudinal strips of layers of material 318 and 320 which fold when subjected to localized buckling forces. In this embodiment, additional strength is provided by virtue of the many individual columns of tube material.

In the embodiment shown in Fig. 15, the individual tube layers are laminated to each other in areas A and B but not at hinge area C. As such, the layers of material may be made of plastic or composite materials subjected to conventional lamination processes.

There is yet another method of forming opposing elongated slots in accordance with this invention to achieve a configuration similar to that of Figs. 14 or 15. Fig. 16 shows two sections 400 and 402 of a composite material tube arranged in an end-to-end manner defining gap 403 therebetween.

One set 404 of C-section member plies 408 and 410 is assembled and ply 408 is bonded or otherwise secured to ply 410 but typically only at the ends thereof. Set 406 of C-section member plies 412 and 414 is likewise assembled. Then, as shown in Fig. 17, set 404 is bonded or otherwise secured to one side of tube sections 400 and 402 to bridge the gap therebetween and set 406 is secured to an opposite side of tube sections 400 and 402 to also bridge the gap therebetween.

This construction results in opposing elongated slots such as slot 420 (and a slot, not shown, opposite slot 420) separated by longitudinally running strips of material, i.e., the material of ply set 404 and 406 which fold when subjected to localized buckling forces and which unfold, typically, automatically, when released.

In Fig. 16, only two plies for each set of C-section members are shown for clarity but typically numerous (e.g., 8 or more) plies are used for increased strength and stiffness as shown in Fig. 17. The C-cross sectional shape is typically obtained by pultrusion techniques. Preferably, the material of plies 408, 410, 412, and 414 are the same as the material of tube sections 402 and 400 although this is not a necessary limitation of the subject invention. In this way, all of the components of Figs. 16-17 discussed above may be made of composite materials (e.g., carbon/PEEK compositions). In other examples, tube sections 400, 402 and plies 408, 410, 412, and 414 are made of plastic such as Lexan. It is also preferred that the tube sections 400, 402, Fig. 16 each include a plurality of layers or plies 430, 432, 434 as shown for tube section 400. See also Figs. 14-15.

As with the designs discussed above with reference to Figs. 6-15, there may be two diametrically opposing slots, three opposing slots, and many hinge areas in a given foldable member.

For example, as shown in Figs. 18-19, there are three sets 340, 342, 344 of conforming members each made of three plies as shown and another set (not shown) on the side opposite ply set 344 resulting in foldable member 350, Fig. 19 with four slots two of which are shown at 352 and 354 in Fig. 19.

The design of Figs. 10-11 wherein there are sets of longitudinally adjacent opposing slots may be effected by tube sections 360 and 362, Figs. 20-21 and intermediate tube section 364. Sets 368 and 370 of conforming C-section plies secure the bottom of tube section 360 to the intermediate bridge element section 364 while sets 372 and 374 secure the top of tube section 362 to intermediate section 364 to form a set of longitudinally adjacent slots 380 and 382, Fig. 21 separated by bridge element 364 and a similar set of circumferentially located axially adjacent slots (not shown) opposite slot set 380, 382. As shown for ply 371, it may be preferential that select or even all the individual plies of sets 368 and 370 be continuous.

In accordance with the designs and method of Figs. 16-21, the number, thickness, length, width and material used for the conforming plies which ultimately form the slots can be tailored to the specific implementation. Similar variations exist with the respect to the material used for, the length and diameter of, and the number of plies or layers of the tube sections.

The curvature of the cross section of each member relative to its thickness is governed by the tensile and compression yield strength of the material. The maximum amount of stress is seen by the material at the surface of the cross section. For this reason, the surface of the cross section should be as free from defects as possible.

The amount of strain seen is given as:

$$\sigma = \frac{t}{2R} \quad (1)$$

where t is the thickness of the cross-section and R and the radius of curvature either of the curved cross-section that is to be flattened or of the cross-section to which a flat element is to be curved.

For completely elastic storage, the value of the strain may be selected to be below the yield strength of the material in the direction of the curvature.

In the case of shape memory or super-elastic materials, the strain value is selected so that the value $\frac{t}{2R}$ is below the limit of elongation and compression recovery of those materials.

For precision applications, these values of t and R should be selected so the strain $\frac{t}{2R}$ is sufficiently below the yield strain so that creep, stress relaxation and micro-yield are reduced to acceptable limits. The acceptable limits are defined by the material section and the specific needs of the application.

In Fig. 22, set 404a of conforming members 410a and 408a between tube sections 400 and 402 includes neck down regions 502, 504 designed to control the location of the folding of the conforming members and to prevent delamination or deformation of the conforming members. The same result is shown in Fig. 23 by neck down regions 506, 508, 510, and 512. Preferably, it is only at these neck down regions that the individual conforming members are adhered together and the set of conforming members are then adhered and optionally fastened using fastener 516 to the tube sections at the neck down region.

In Fig. 24, conforming members 410c and 408c are secured together only at central end regions 520 where they attached to the tube sections 400, 402 and central end regions 520 is capped with plate 522, which may be made of metal, through which fastener 516 extends. In cross section, film adhesive 526, as shown in Fig. 25, centrally secures cap 522 to conforming member 408c, film adhesive 528 centrally secures conforming member 408c to conforming member 410c and film adhesive layer 530 centrally secures conforming member 410c to the outer wall of tube section 400. Typically, tube section 400 includes multiple plies or layers as shown in Figs. 14 and 16.

In Fig. 26, intermediate rigid (e.g., metal) member 540 is used and has spaced fingers 542, 544, and 546. One end of conforming member 410d is received and secured (e.g., adhered) between fingers 542 and 544 and one end of conforming member 408d is secured between fingers 546 and 544. Intermediate member 540 is then attached to the outer wall of tube section 400. A similar rigid member, not shown, is secured between the adjacent spaced tube section and the opposite ends of conforming members 408d and 410d. In still another embodiment, intermediate member fingers 542, 544, and 546 are integral layers of the tube sections themselves.

Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention. The words "including", "comprising", "having", and "with" as used herein are to be interpreted broadly and comprehensively and are not limited to any physical interconnection. Moreover, any embodiments disclosed in the subject application are not to be taken as the only possible embodiments.

Other embodiments will occur to those skilled in the art and are within the following claims:

What is claimed is:

CLAIMS

1. A method of making a foldable member and deploying the same, the method comprising:

forming a plurality of foldable C-section member plies;

assembling a first set of the C-section member plies;

assembling a second set of the C-section member plies;

arranging two sections of a tube in an end-to-end manner defining a gap therebetween;

securing the first set of C-section member plies to one side of the two tube sections of the tube to bridge the gap therebetween;

securing the second set of C-section member plies to an opposing side of the two tube sections to bridge the gap therebetween thus forming opposing elongated slots in the tube separated by longitudinal strips of C-section member ply material between the slots;

folding the longitudinal strips of C-section member ply material to fold the member; and

deploying the member whereupon the longitudinal strips of C-section member ply material unfold and the two tube sections return to an end-to-end configuration.

2. The method of claim 1 in which assembling the first set of C-section member plies includes securing all the plies of the first set together.

3. The method of claim 1 in which assembling the second set of C-section member plies includes securing all the plies of the second set together.

4. The method of claim 1 in which the plurality of C-section member plies are made of composite material.

5. The method of claim 1 in which the two tube sections are made of composite material.

6. The method of claim 1 in which the plurality of C-section member plies are pultruded into a C-section cross sectional shape.

7. The method of claim 1 in which the material of the first and second set of C-section members is the same as the material of the two tube sections.

8. The method of claim 1 further including the steps of arranging a third tube section in an end-to-end manner with the two tube sections to define a gap therebetween and securing third and fourth sets of C-section member plies to opposing sides of the third tube section and the two tube sections thus forming sets of longitudinally adjacent opposing elongated slots.

9. A foldable member comprising:

two sections of a tube arranged in an end-to-end manner defining a gap therebetween; and

opposing foldable members each made of multiple plies attached to both tube sections and bridging the gap therebetween defining opposing elongated slots and separated longitudinal strips of material between the slots, said longitudinal strips of members material having a folded configuration when subjected to localized buckling forces and an unfolded deployed configuration when released for returning the two tube sections to an end-to-end configuration.

10. The foldable member of claim 9 in which the opposing foldable members have a C-cross sectional shape.

11. The foldable member of claim 9 in which the material of the opposing foldable members is the same as the material of the two tube sections.

12. The foldable member of claim 11 in which the opposing foldable members are made of composite material and the two tube sections are made of composite material.

13. The foldable member of claim 9 in which both sections of the tube comprise a plurality of layers.

14. The foldable member of claim 9 in which there are two diametrically opposing elongated slots and two diametrically opposing longitudinal strips.

15. The foldable member of claim 9 in which there are a plurality of hinge areas longitudinally spaced from each other along the length of the tube, each hinge area including opposing elongated slots.

16. The foldable member of claim 9 in which there are three opposing elongated slots and three opposing elongated strips each longitudinal strip diametrically opposing an elongated slot.

17. The foldable member of claim 9 further including a third tube section and sets of longitudinally adjacent opposing elongated slots.

18. The foldable member of claim 9 in which the opposing foldable members have a neck down region.

19. The foldable member of claim 18 in which the opposing foldable members are secured together only at the neck down region.

20. The foldable member of claim 9 in which the opposing foldable members are secured together only where they attach to the tube sections.

21. The foldable member of claim 20 in which the opposing foldable members are centrally secured together only where they attach to the tube section.

22. The foldable member of claim 9 further including an intermediate rigid member interconnecting the opposing foldable members with a tube section.

23. The foldable member of claim 22 in which the intermediate member has spaced fingers, each opposing foldable member received between two spaced fingers.

24. A structure comprising:

a plurality of joined truss members;

a selected number of said truss members each including a foldable member comprising:

two sections of a tube arranged in an end-to-end manner defining a gap therebetween; and

opposing foldable members each made of multiple plies attached to both tube sections and bridging the gap therebetween defining opposing elongated slots and separated longitudinal strips of material between the slots, said longitudinal strips of members material having a folded configuration when subjected to localized buckling forces and an unfolded configuration when released for returning the two tube sections to an end-to-end configuration.

25. The structure of claim 24 in which the opposing foldable members have a C-cross sectional shape.

26. The structure of claim 24 in which the material of the opposing foldable members is the same as the material of the two tube sections.

27. The structure of claim 26 in which the opposing foldable members are made of composite material and the two tube sections are made of composite material.

28. The structure of claim 24 in which both sections of the tube comprise a plurality of layers.

29. The structure of claim 24 in which there are two diametrically opposing elongated slots and two diametrically opposing longitudinal strips.

30. The structure of claim 24 in which there are a plurality of hinge areas longitudinally spaced from each other along the length of the tube, each hinge area including opposing elongated slots.

31. The structure of claim 24 in which there are three opposing elongated slots and three opposing elongated strips each longitudinal strip diametrically opposing an elongated slot.

32. The structure of claim 24 in which the multiple plies are secured together before the opposing foldable members are attached to the tube sections.

33. The structure of claim 24 including pultruded plies having a C-section cross sectional shape.

34. The structure of claim 24 further including a third tube section and longitudinally adjacent slots opposing each other around the circumference of the foldable member.

35. A foldable member comprising:

a first member;

a second member aligned with the first member;

a gap between the first member and the second member;

a first set of plies of foldable material secured to the first and second members and bridging the gap therebetween;

a second set of plies of foldable material secured to the first and second members and bridging the gap therebetween opposite the first set of plies;

the foldable material configured to have a folded configuration when subjected to localized bucking forces and an unfolded configuration when released releasably locking the first and second members in an end-to-end configuration.

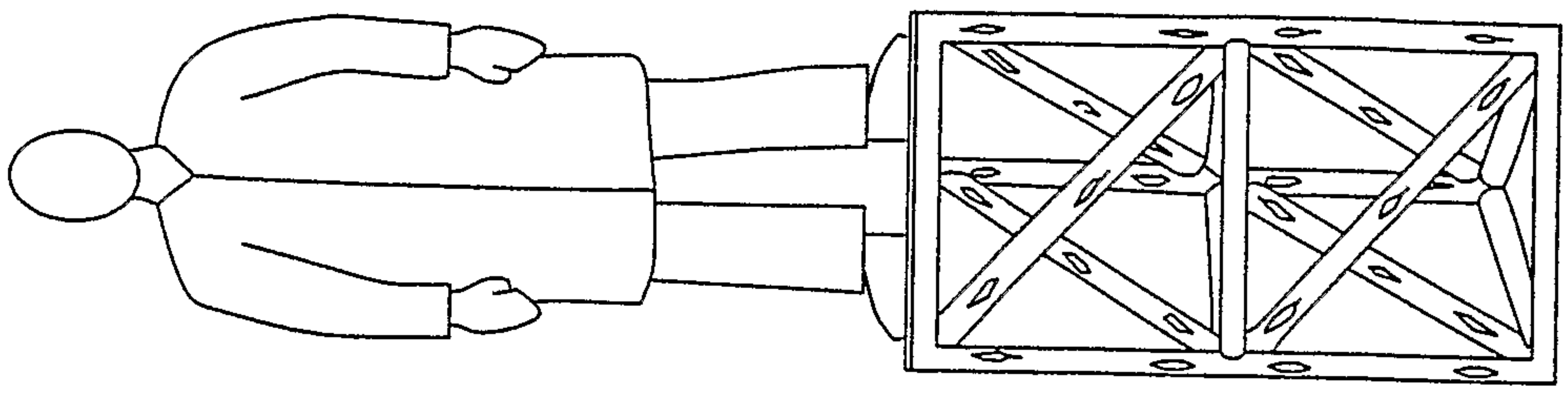


FIG. 3.

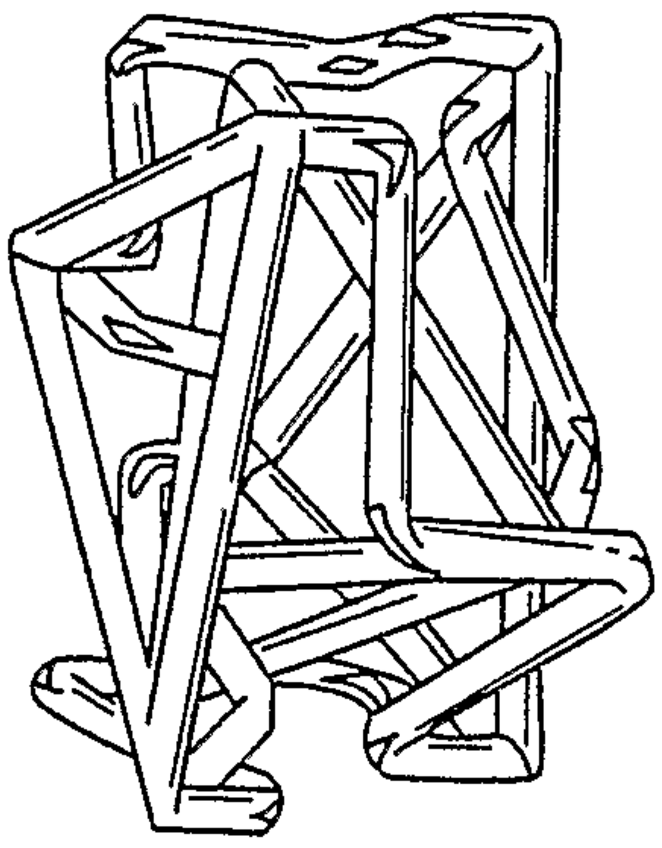


FIG. 2.

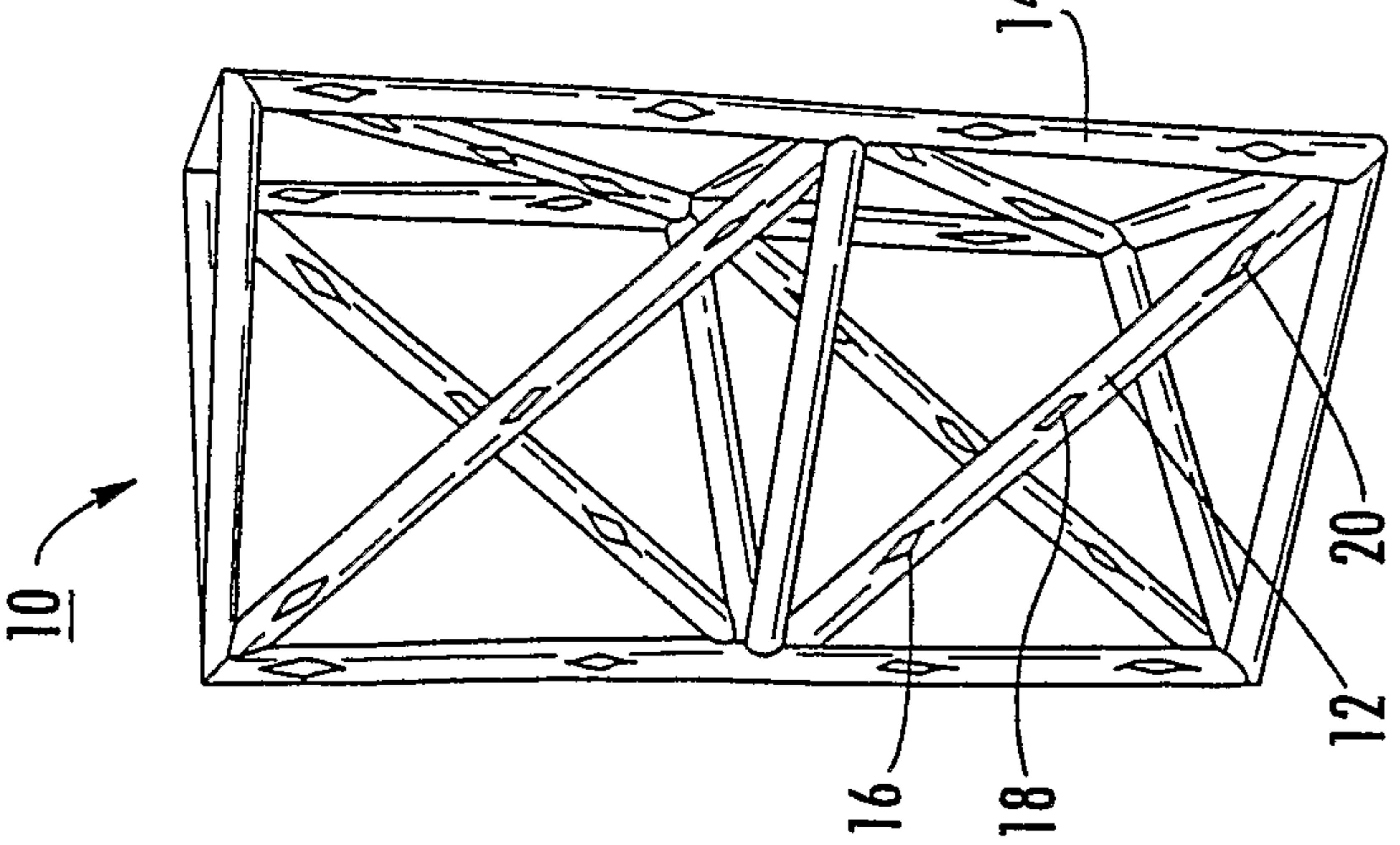


FIG. 1.

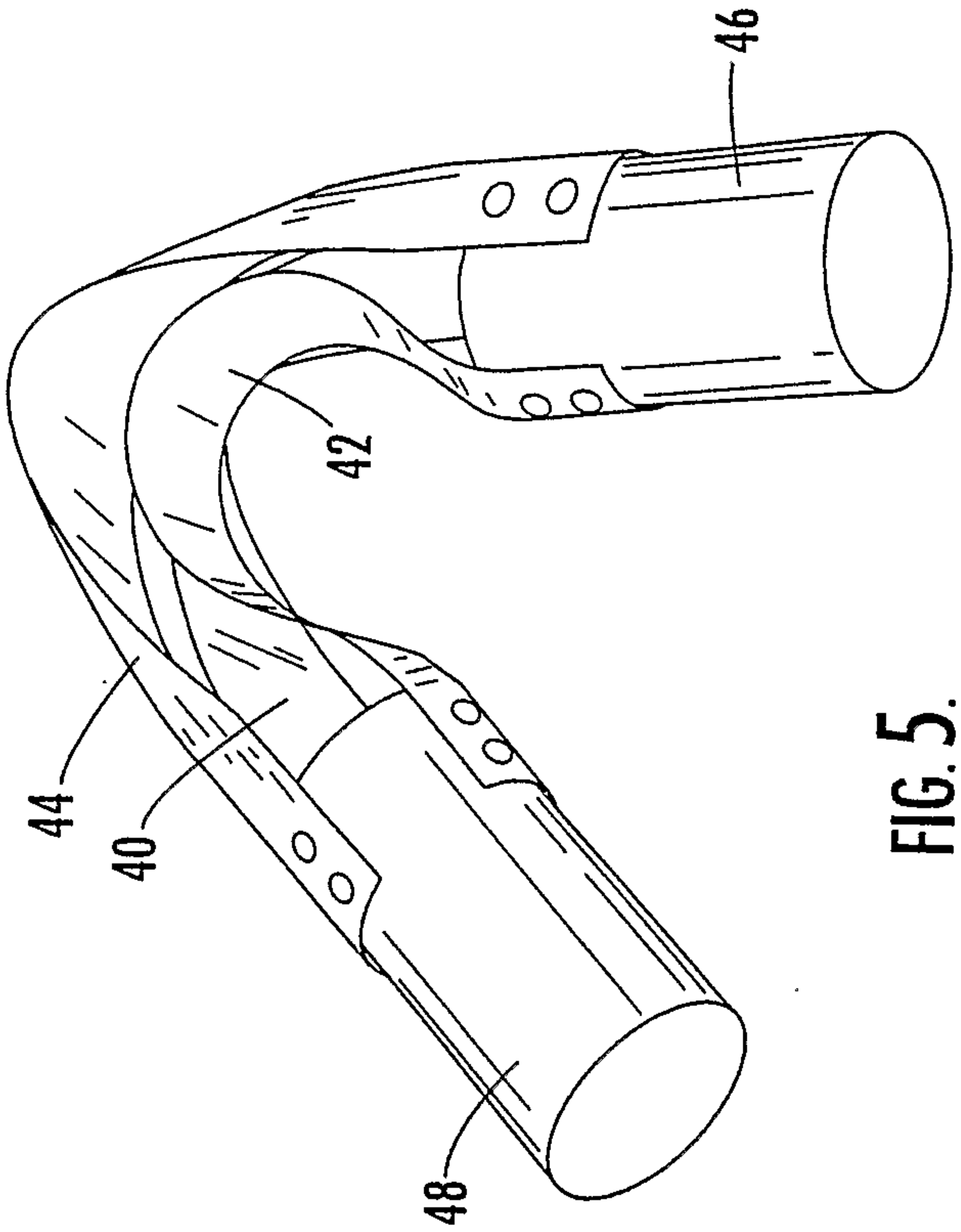


FIG. 5.
(PRIOR ART)

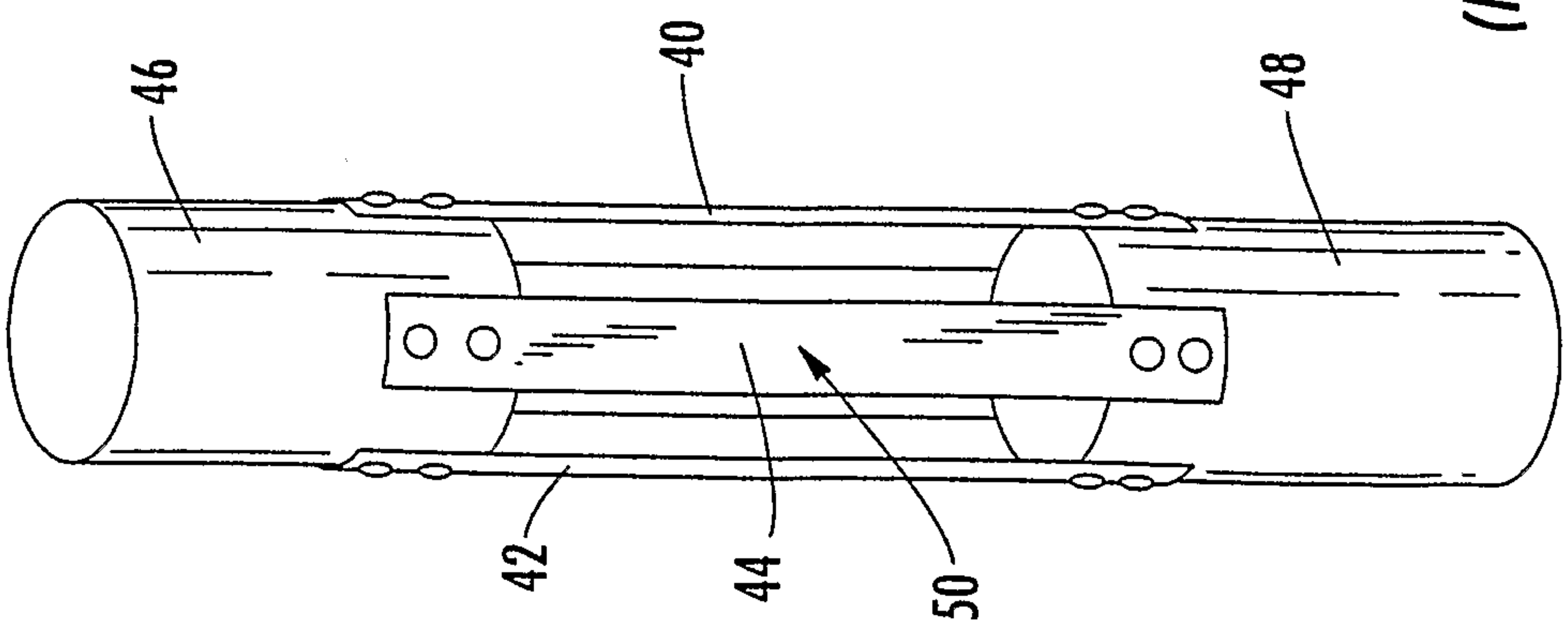


FIG. 4.
(PRIOR ART)

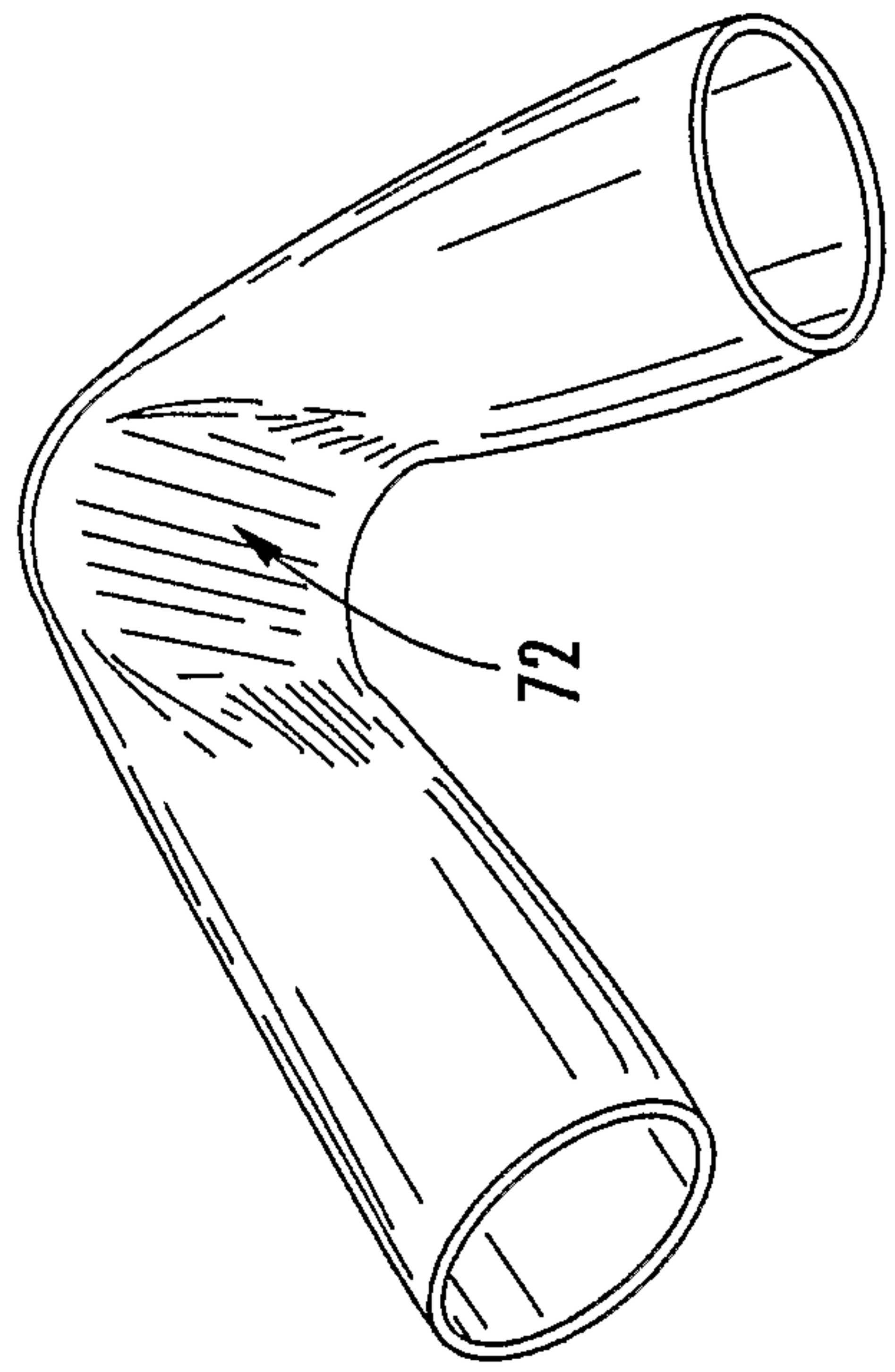


FIG. 8.

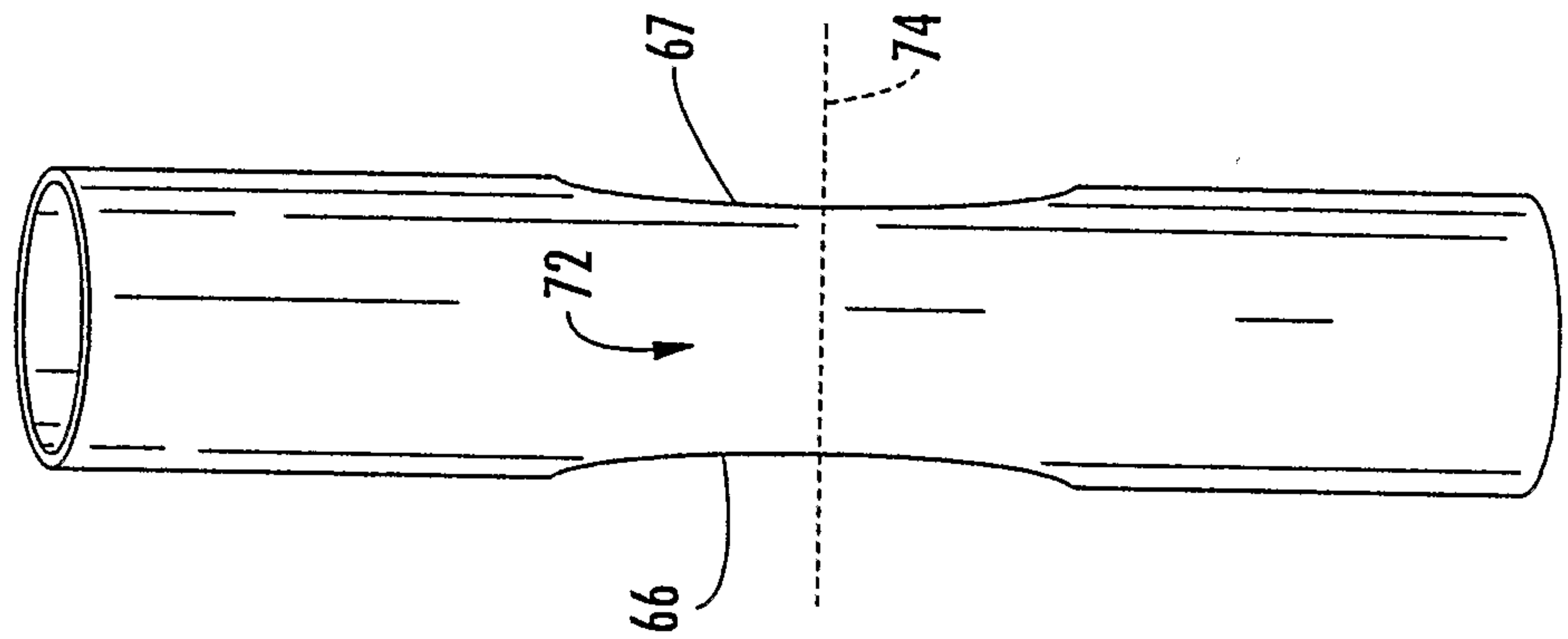


FIG. 7.

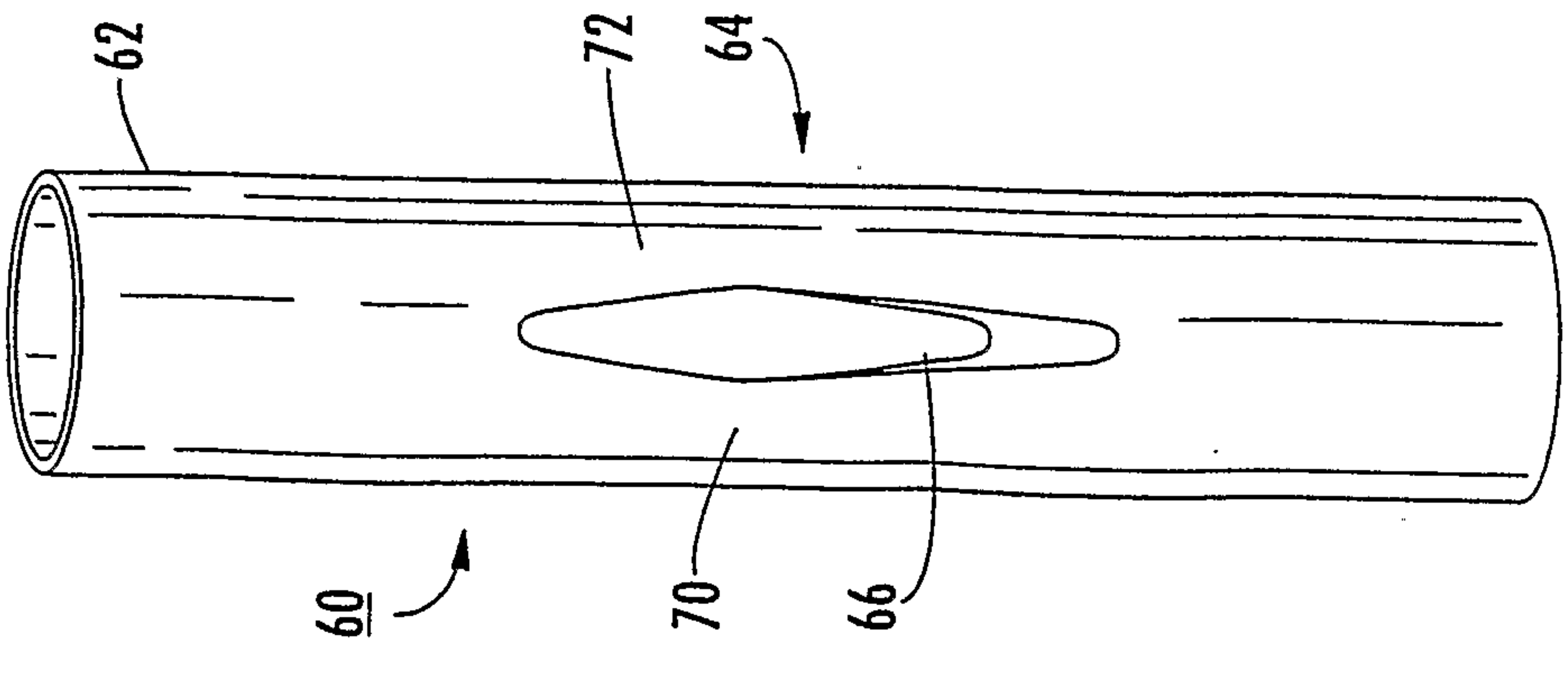


FIG. 6.

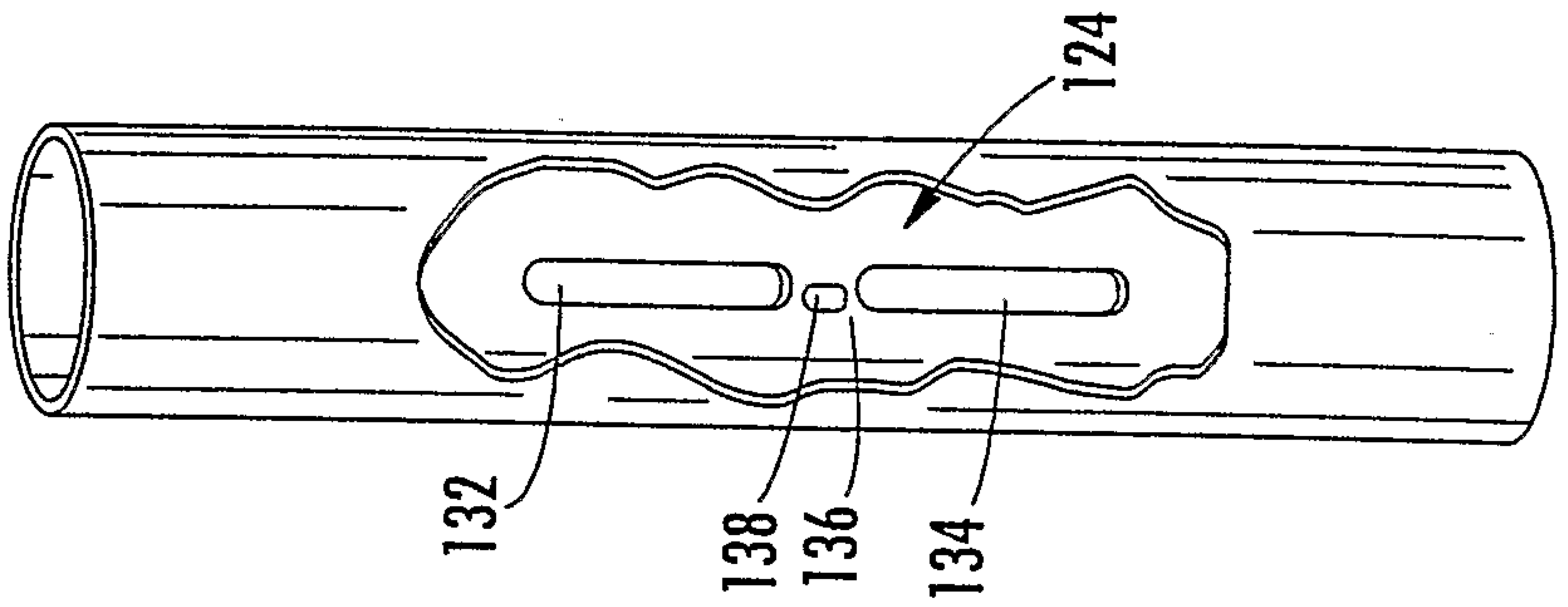


FIG. 11.

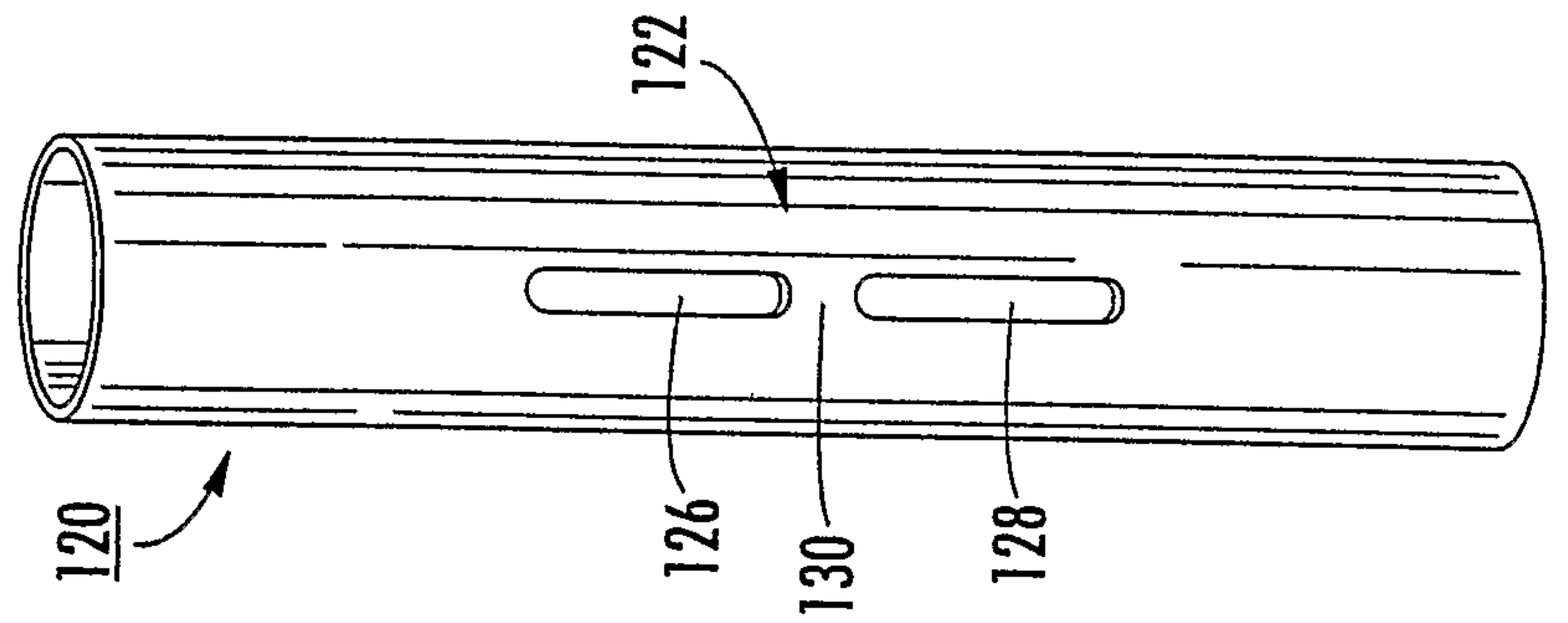


FIG. 10.

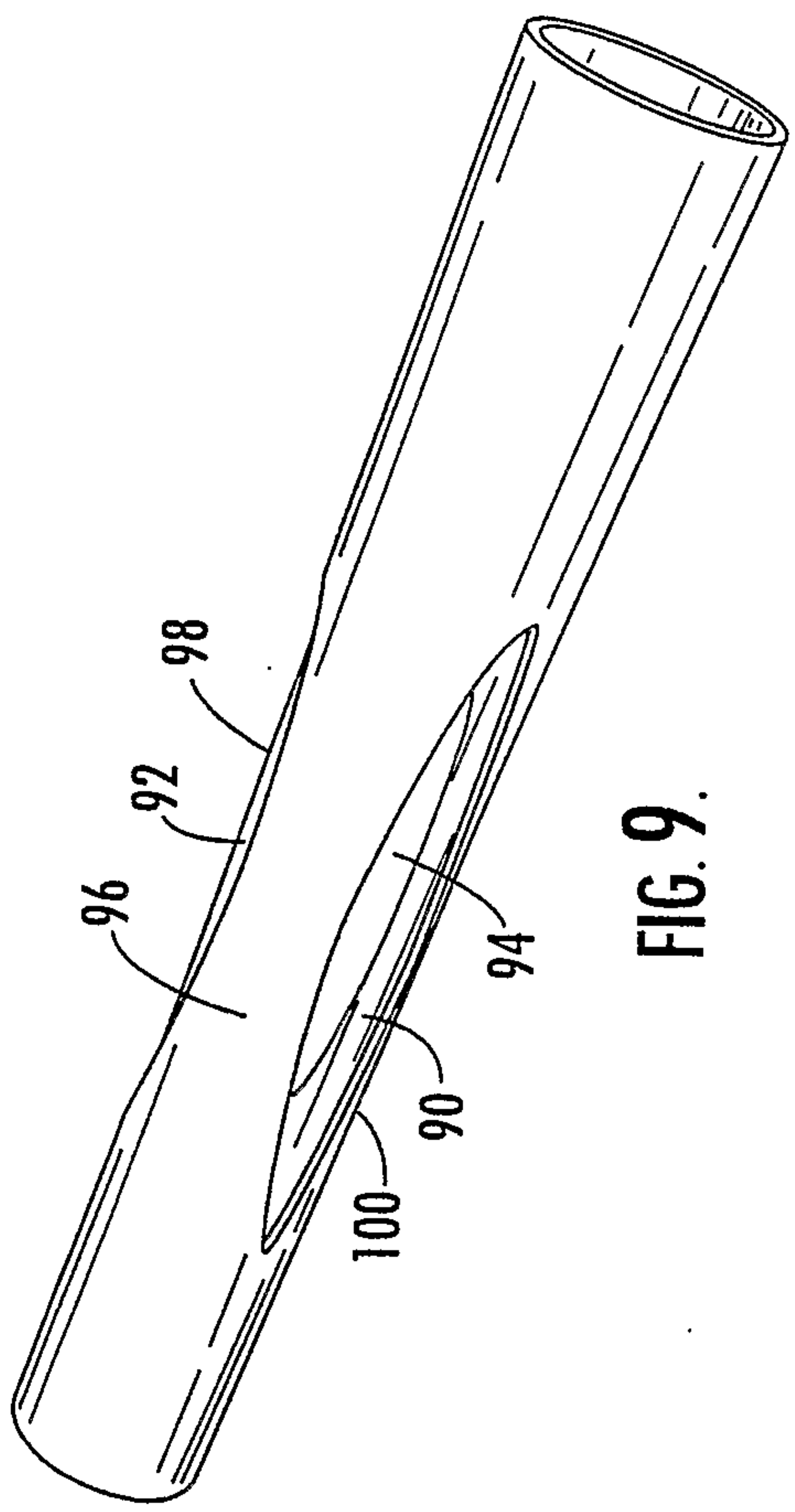


FIG. 9.

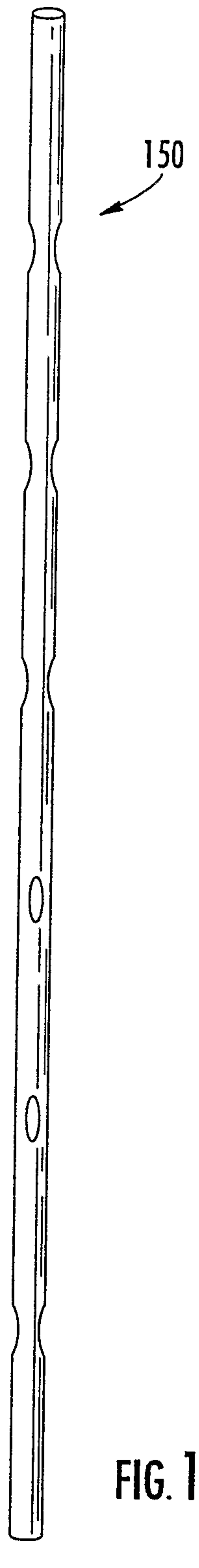


FIG. 12.

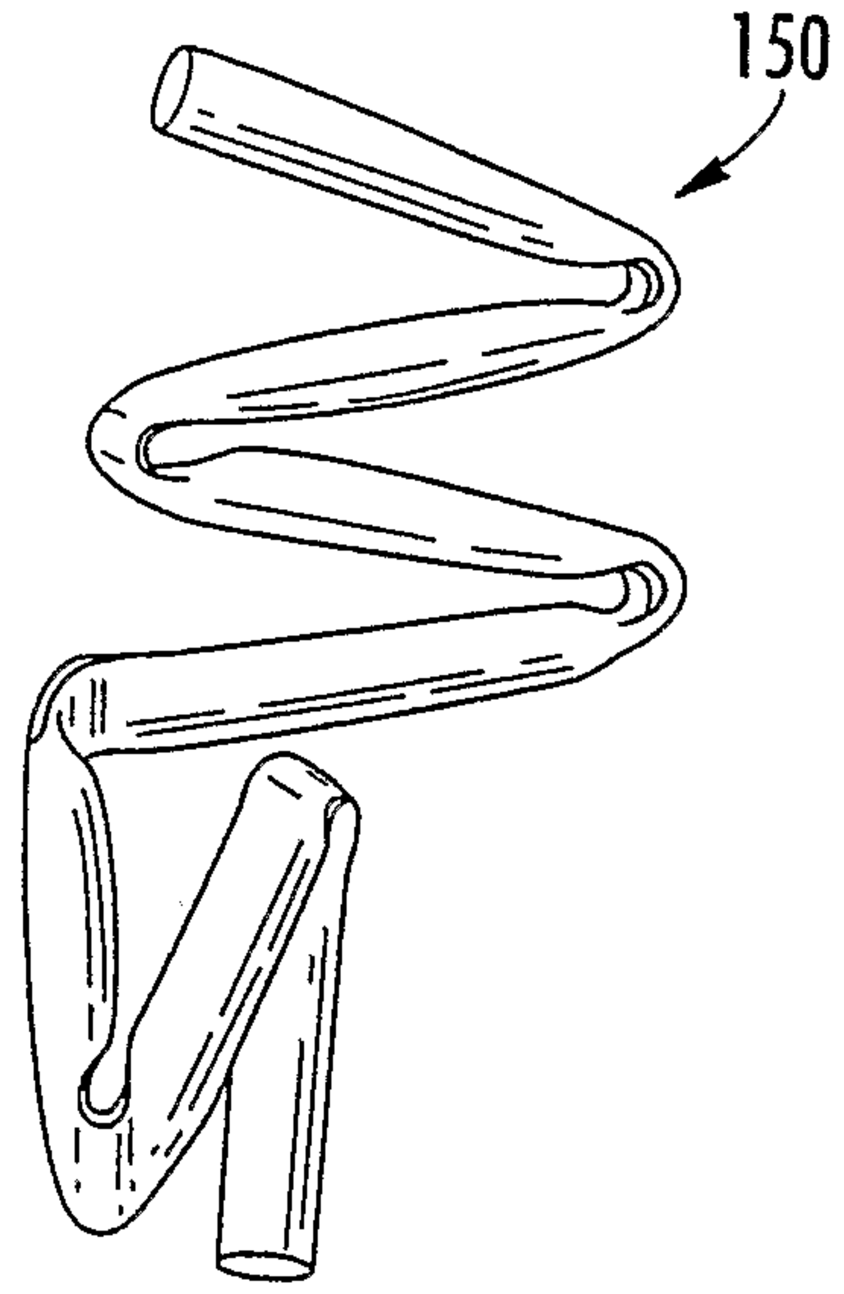


FIG. 13.

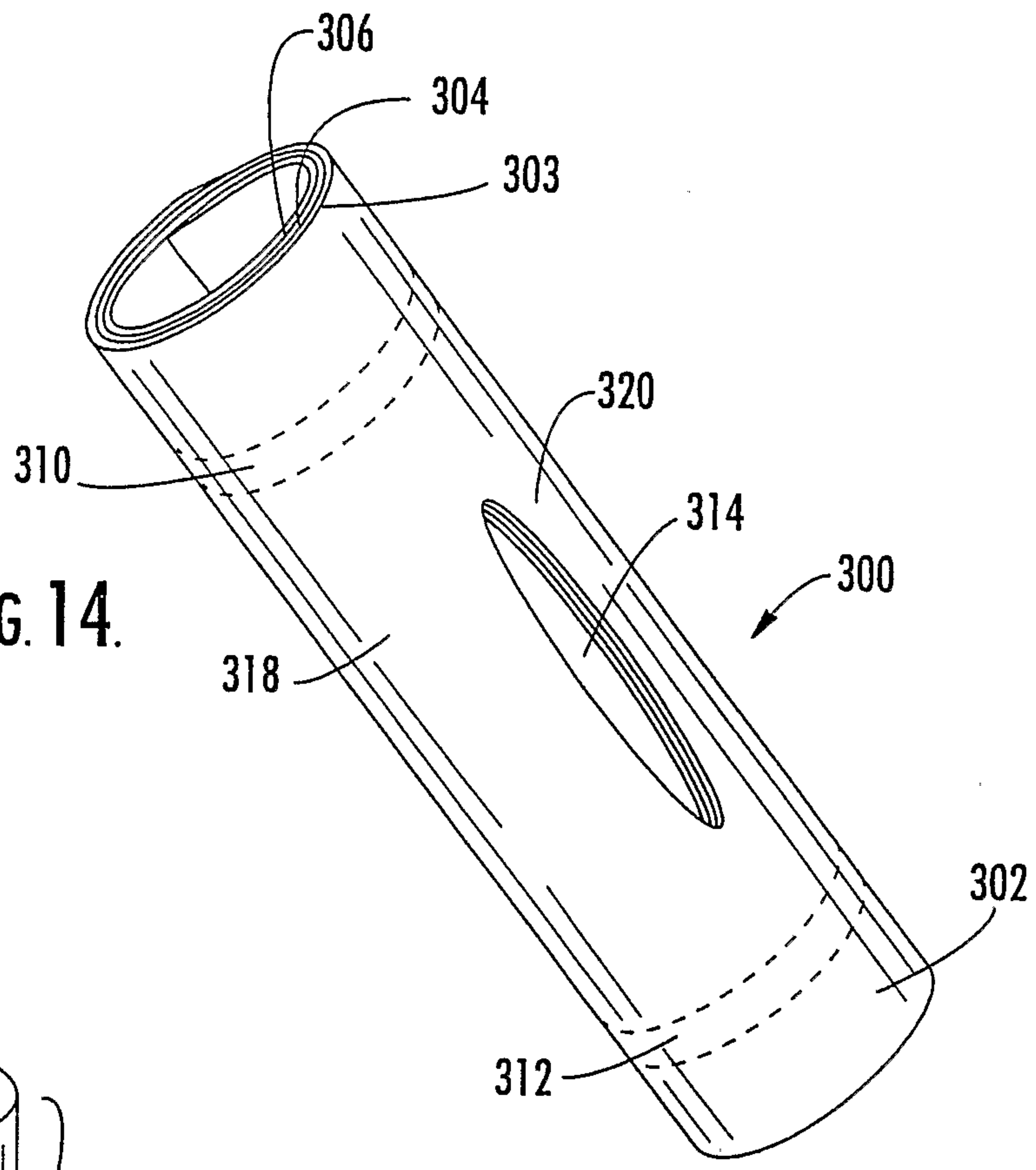


FIG. 14.

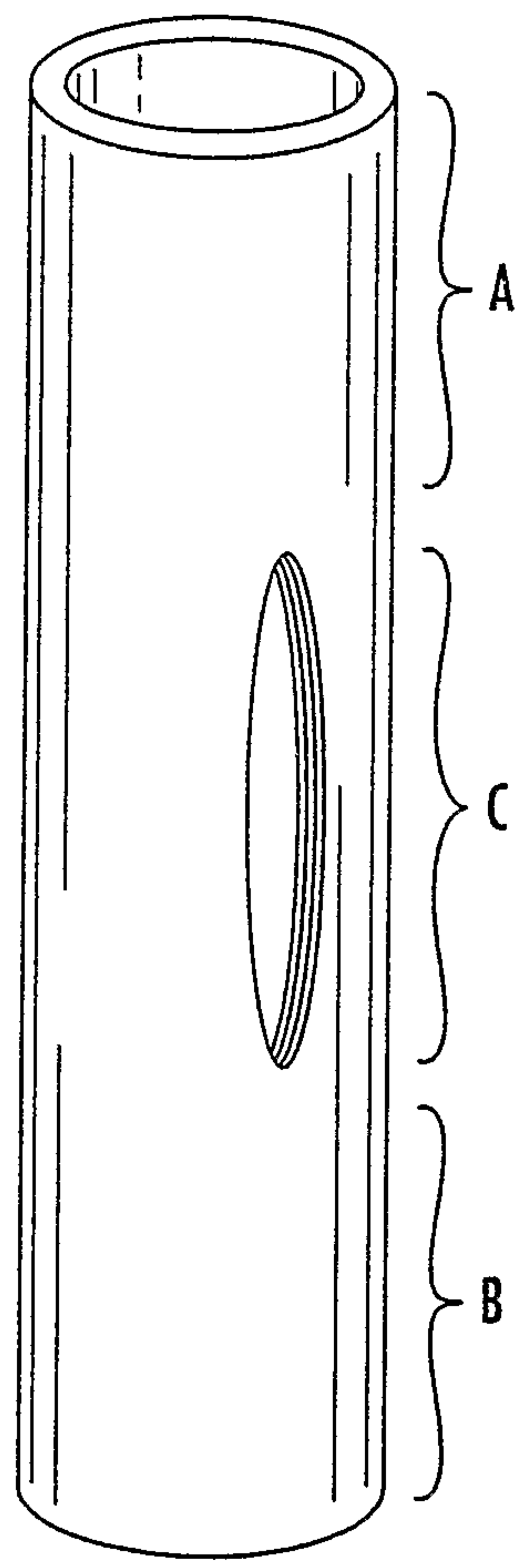


FIG. 15.

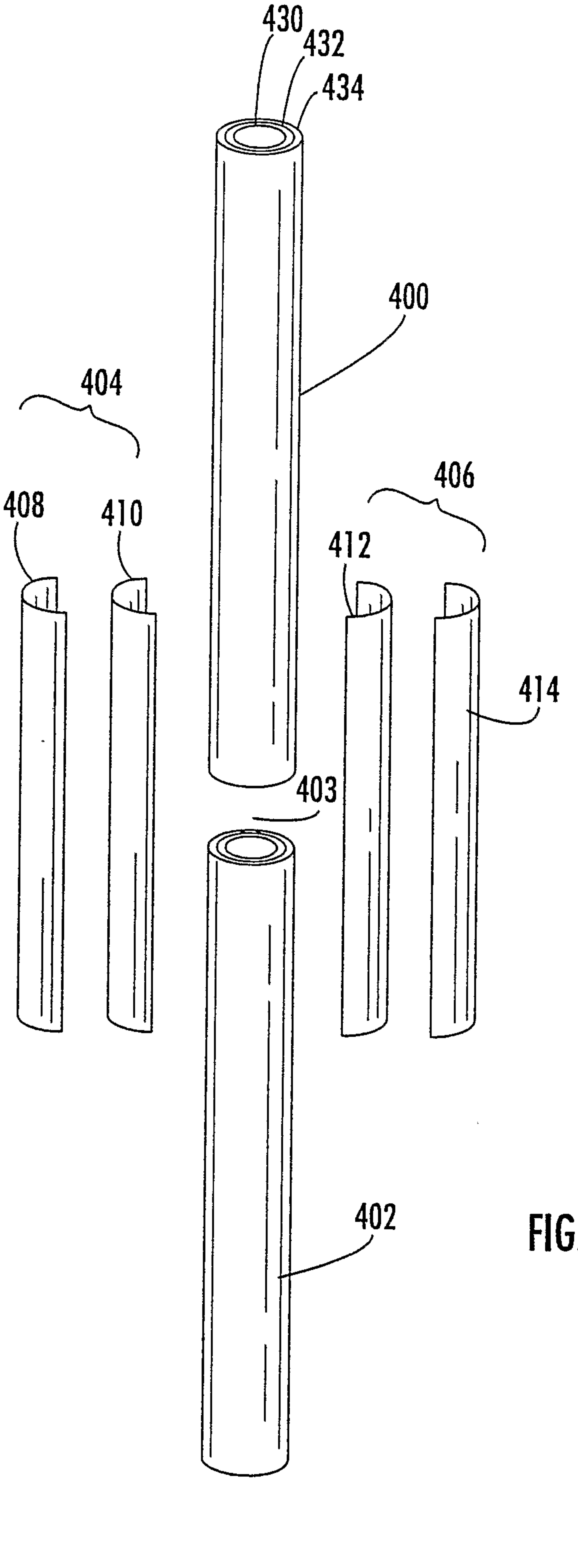


FIG. 16.

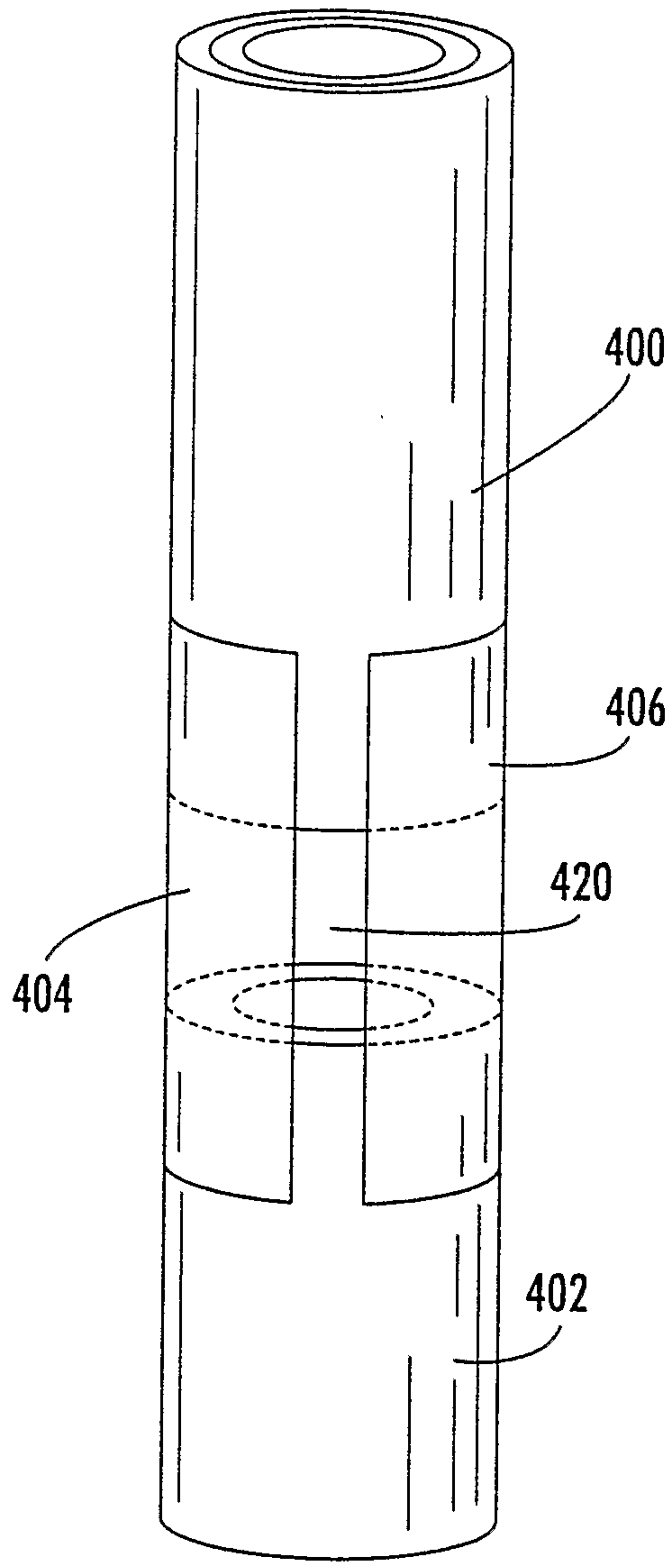


FIG. 17.

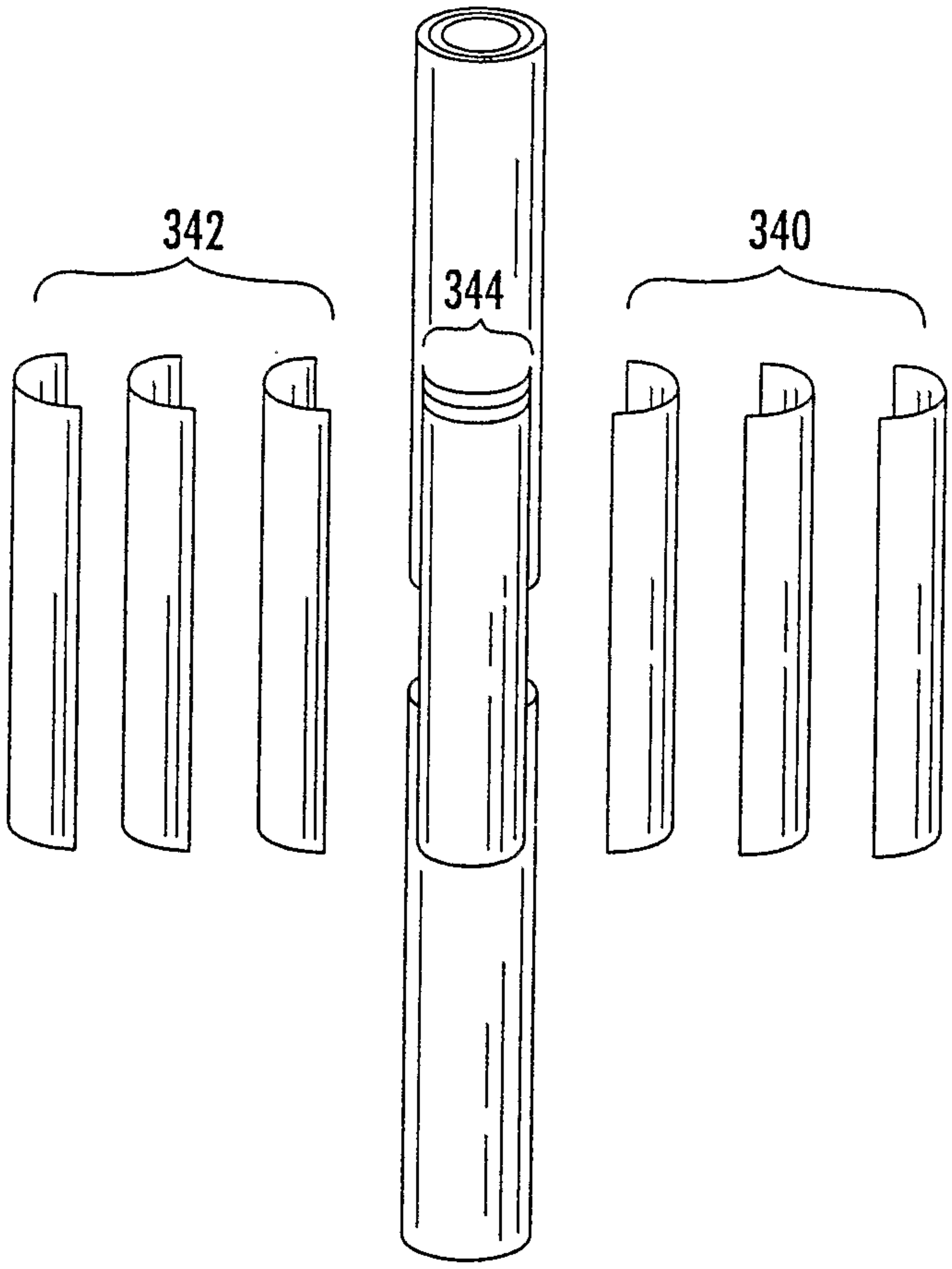


FIG. 18.

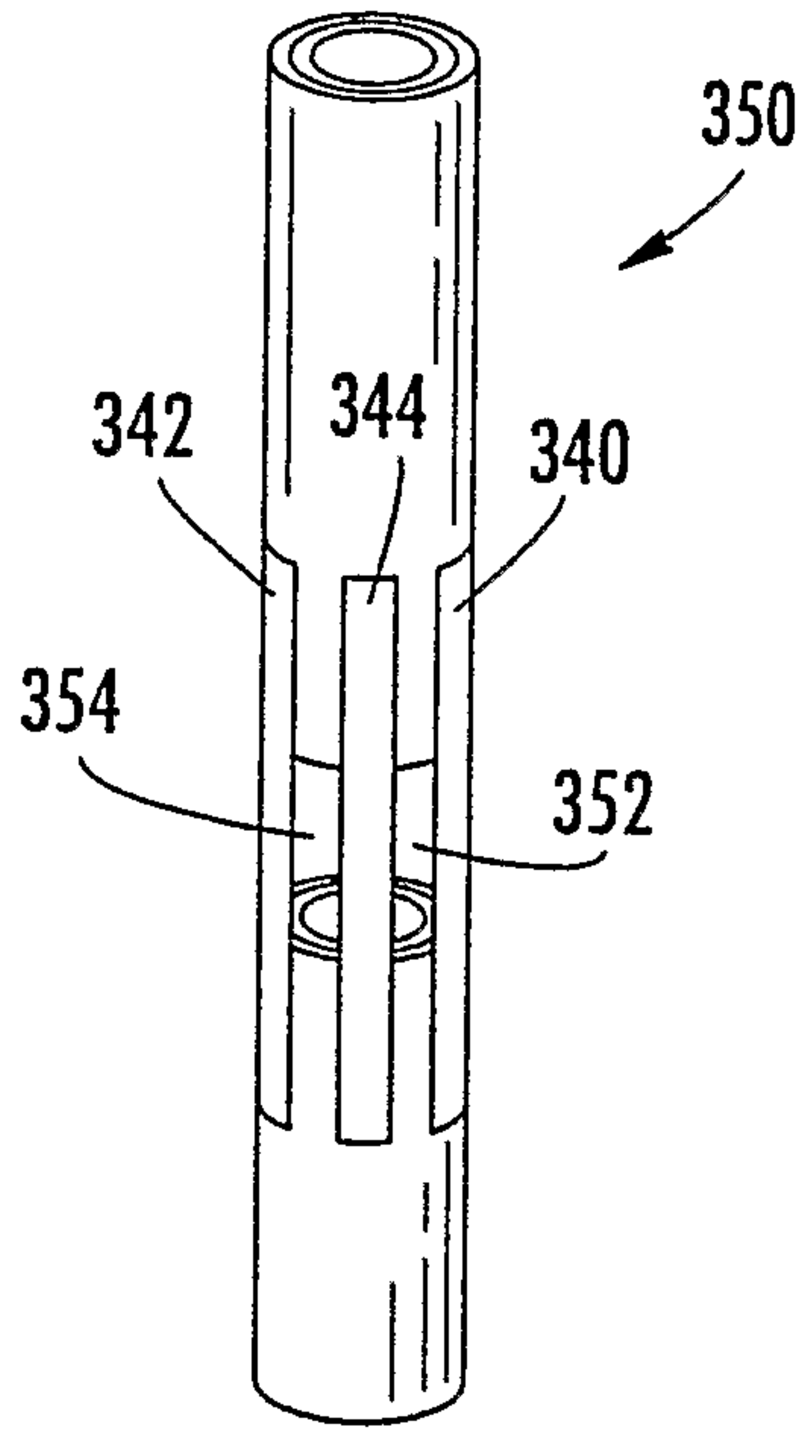


FIG. 19.

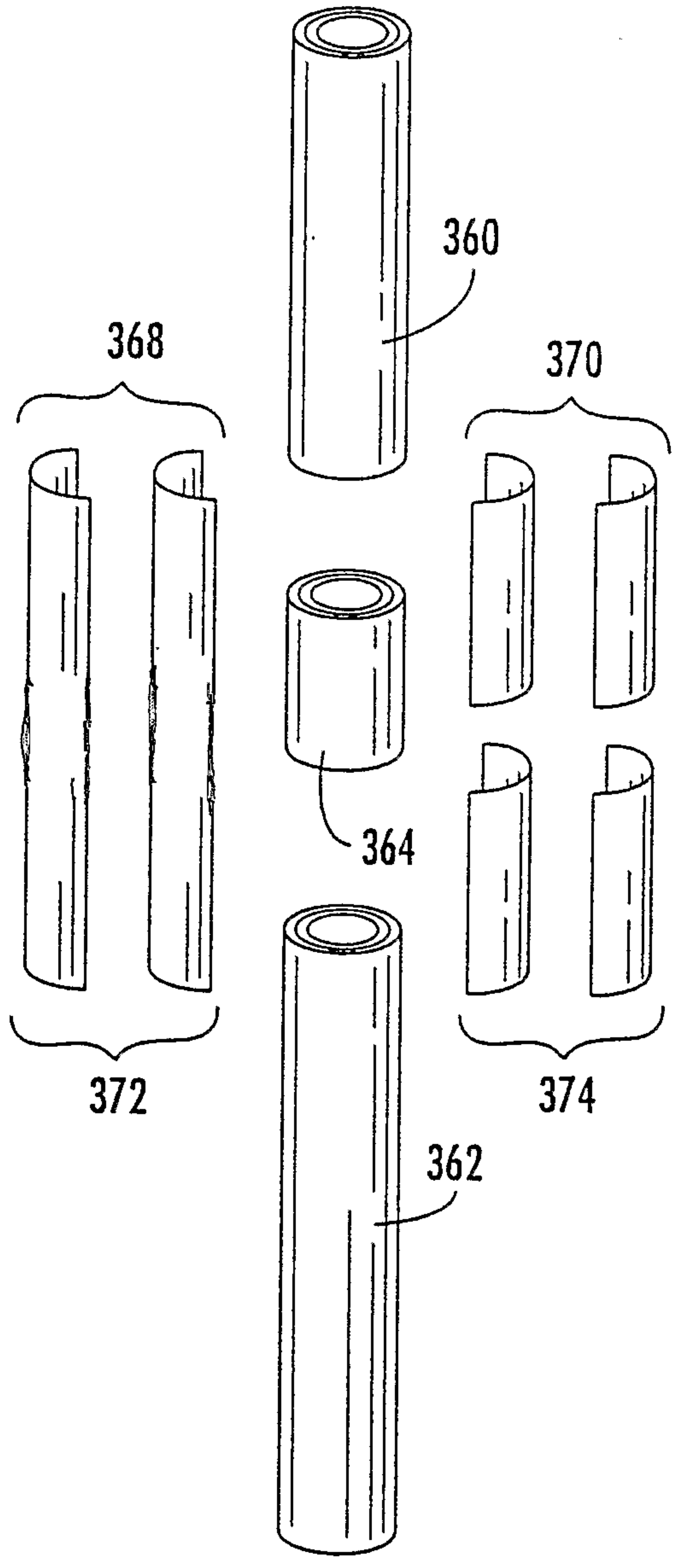


FIG. 20.

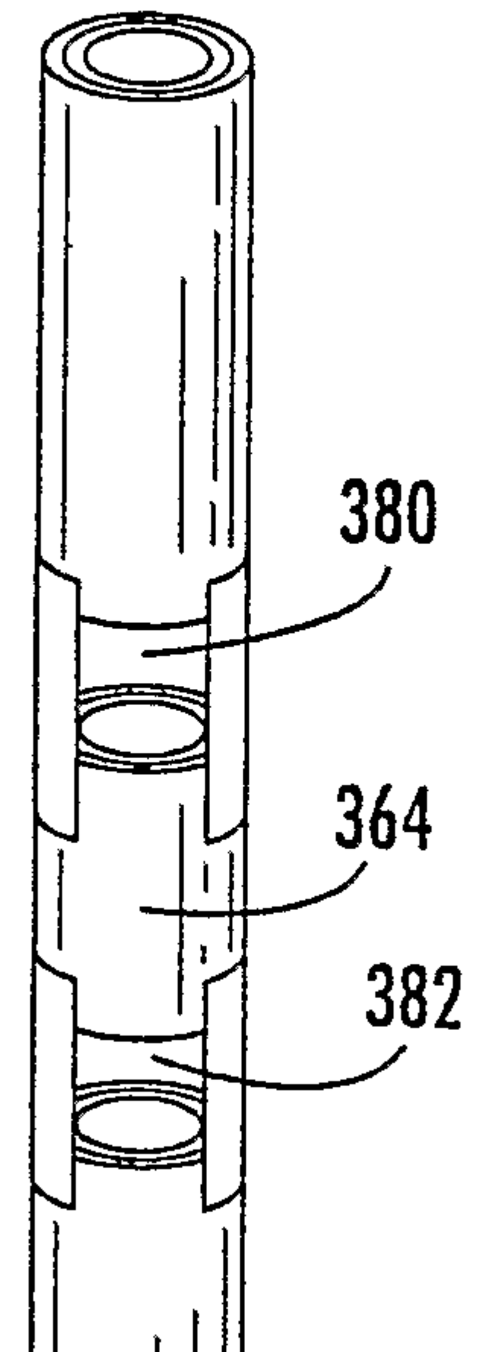


FIG. 21.

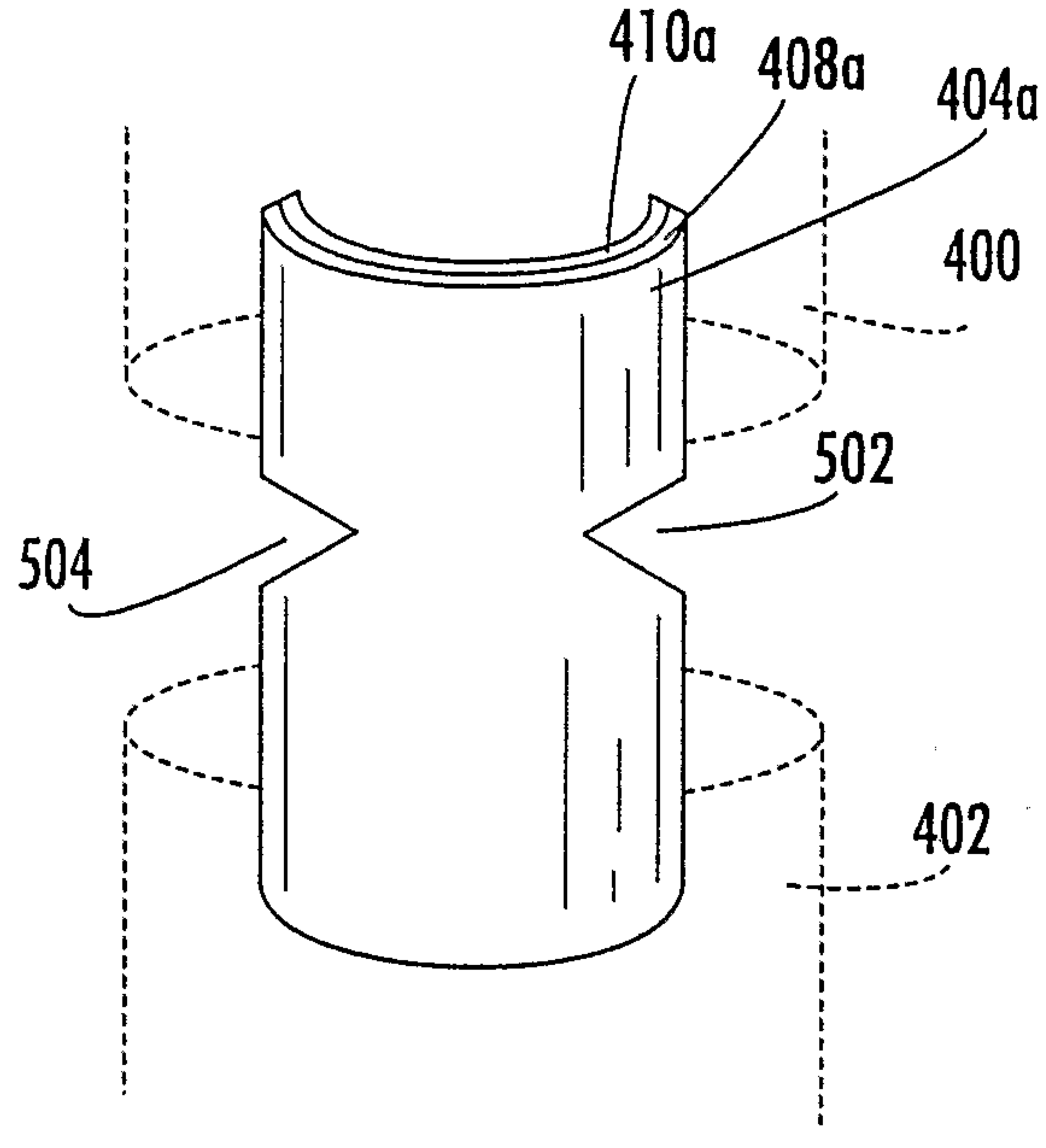


FIG. 22.

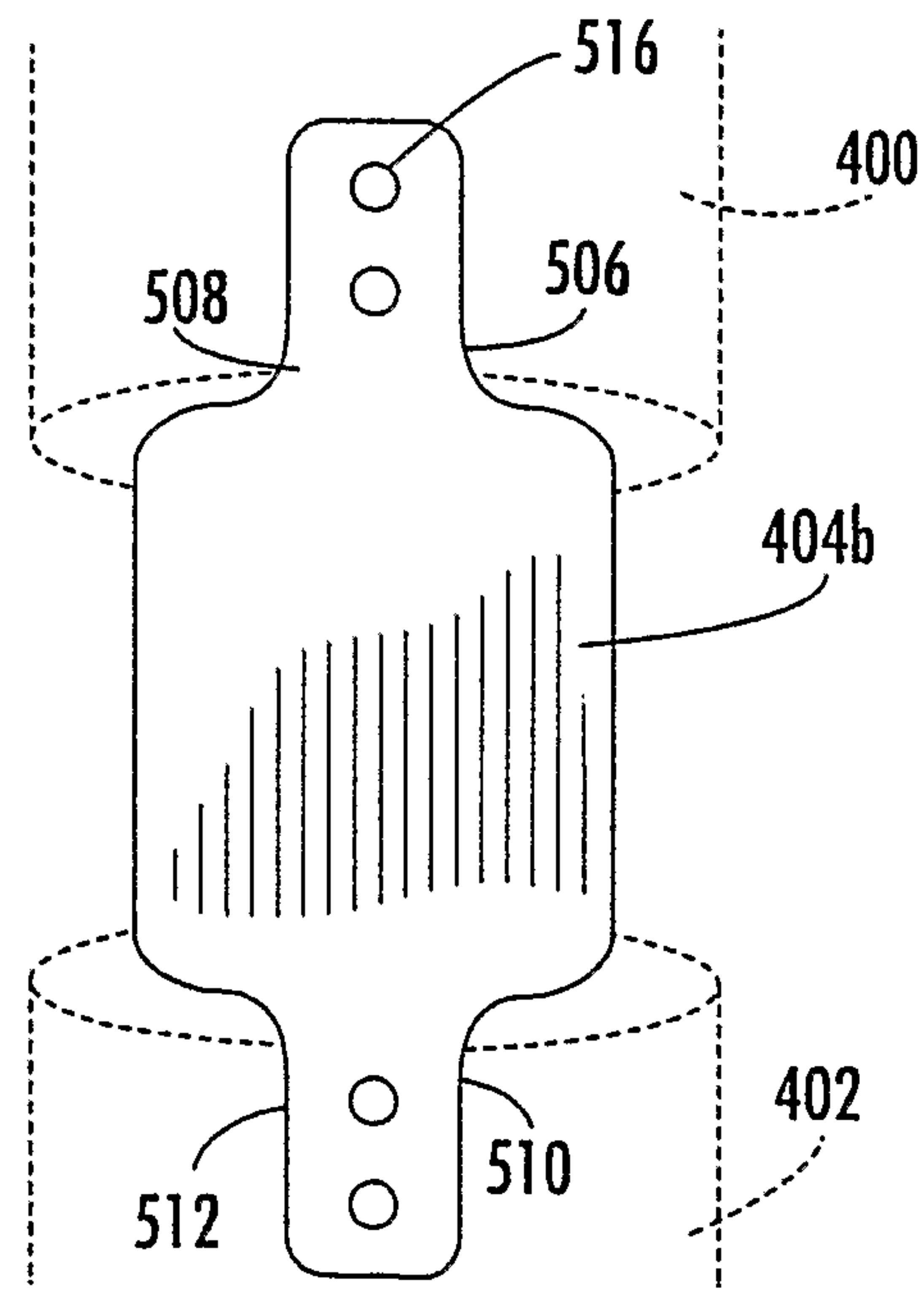


FIG. 23.

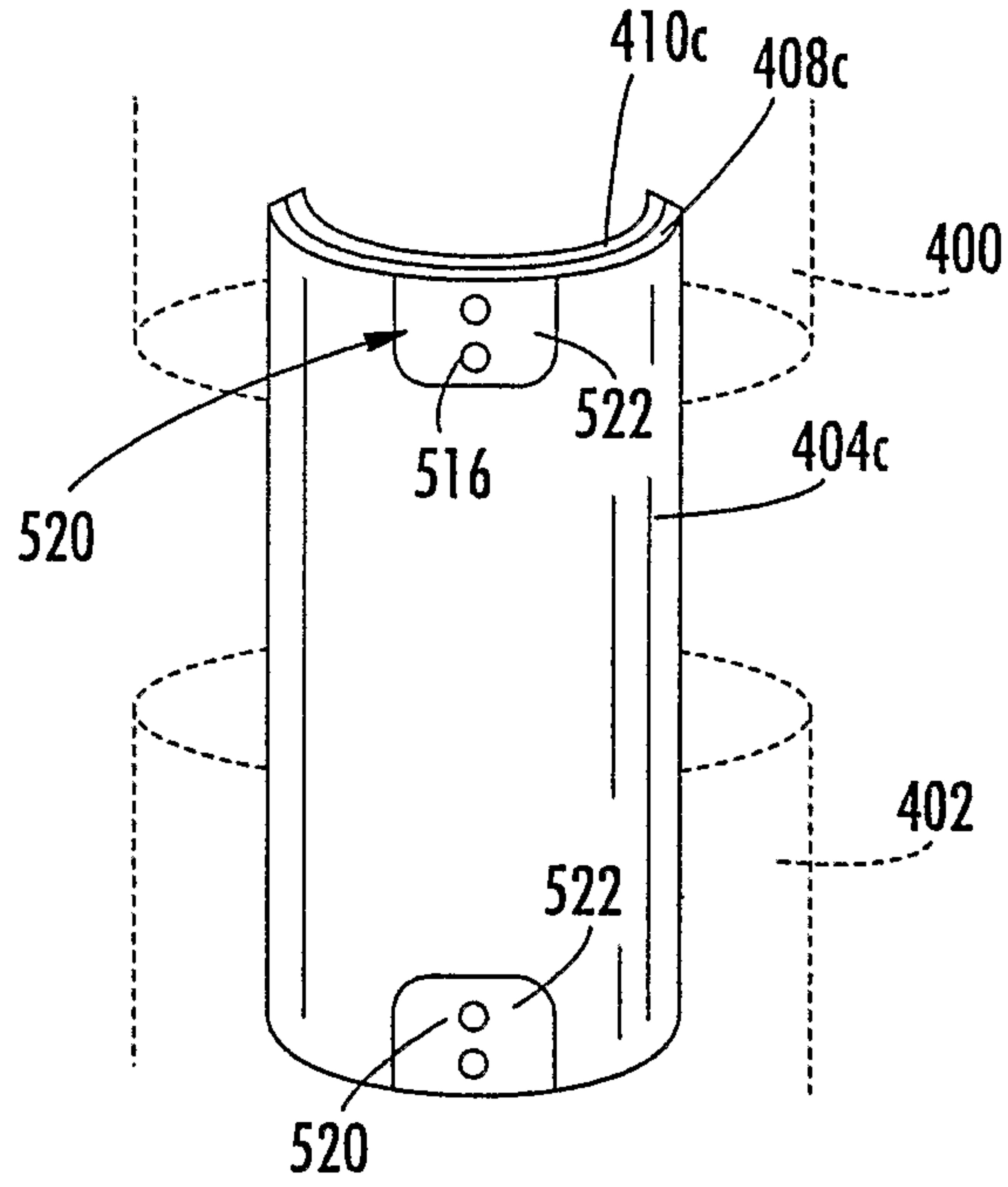

410c
408c
400
522
516
520
404c
402
522
520

FIG. 24.

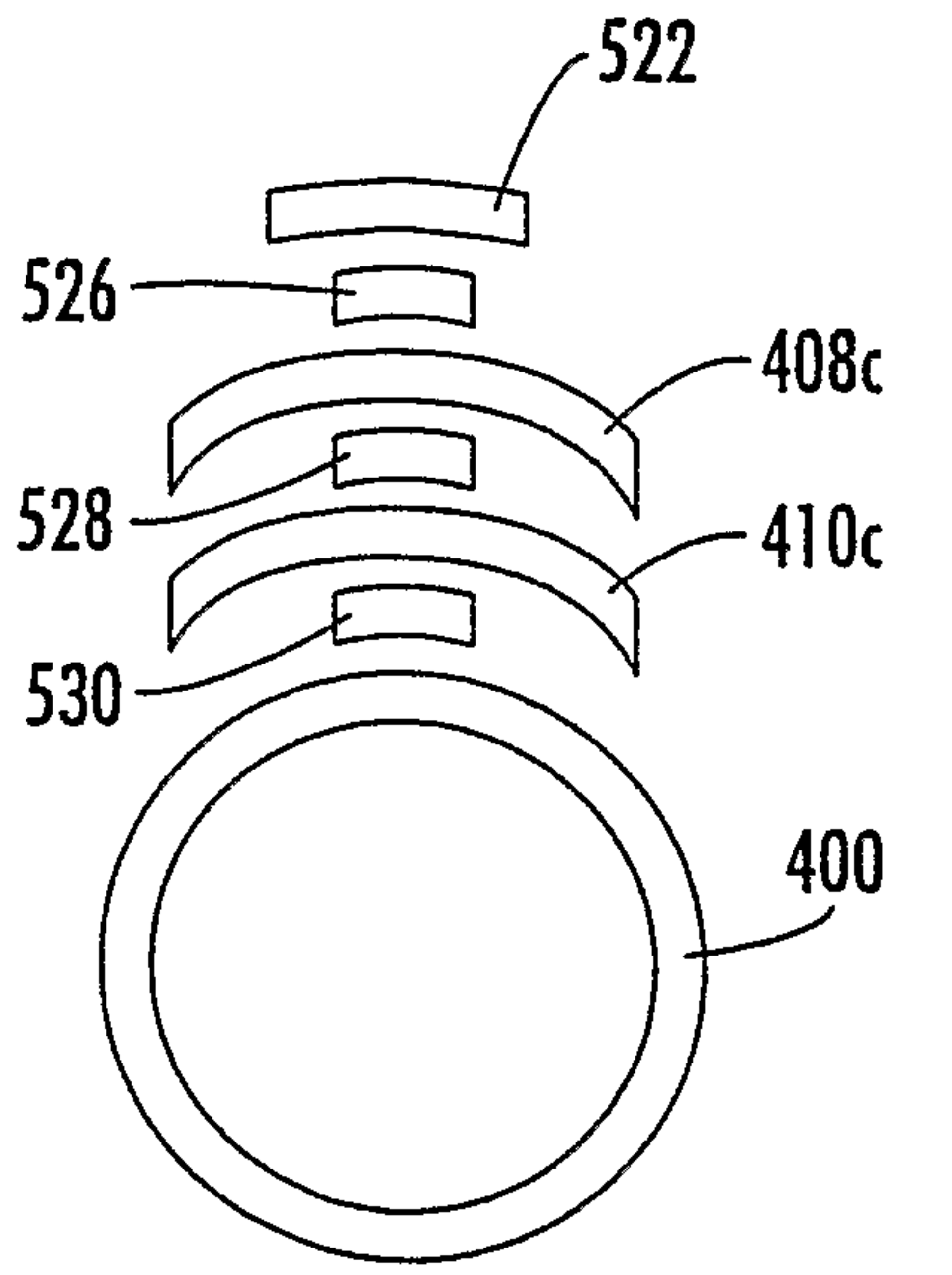

522
526
408c
528
410c
530
400

FIG. 25.

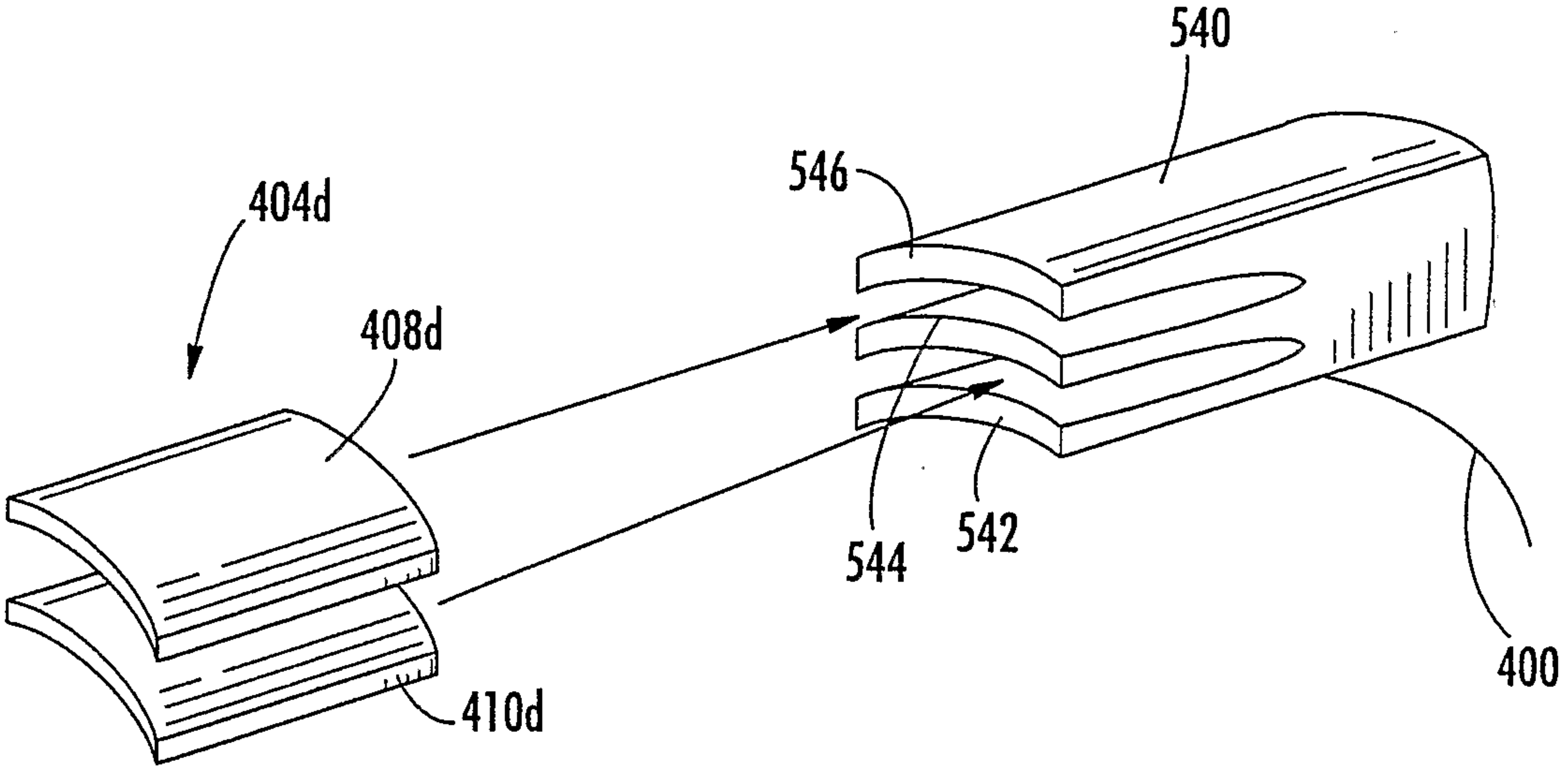
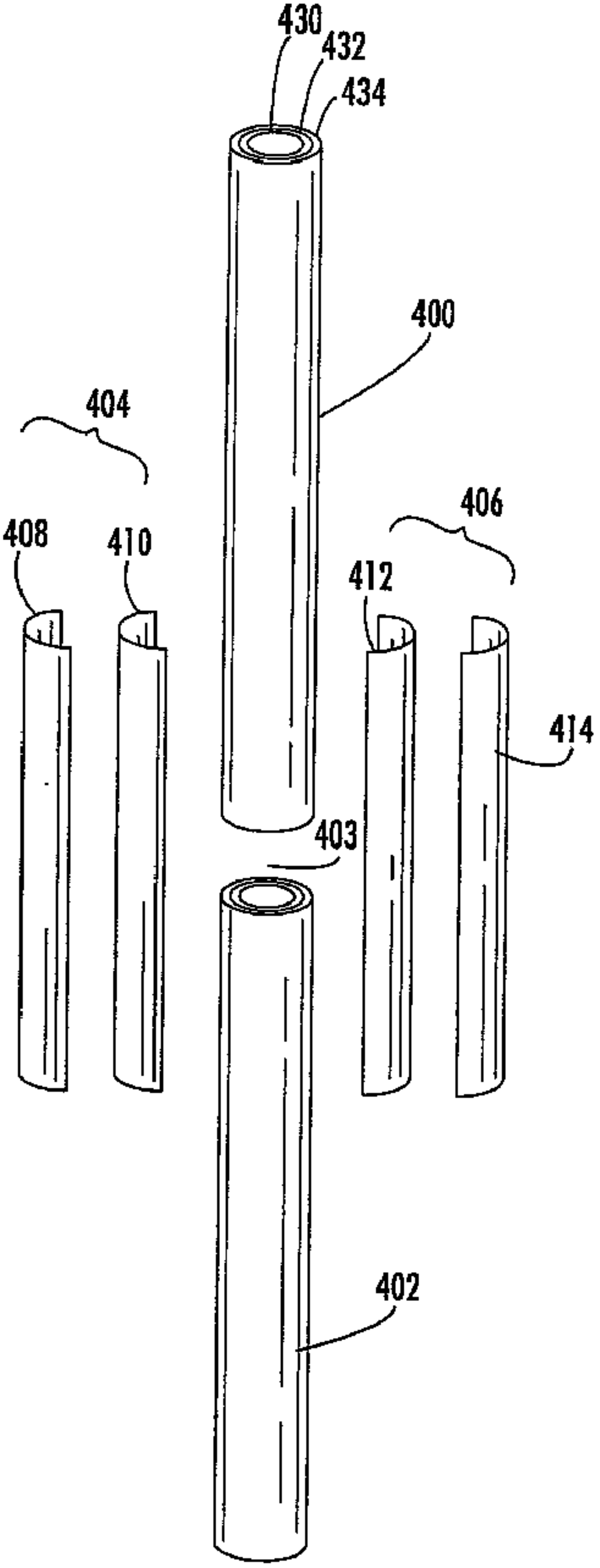


FIG. 26.



430
432
434
400
404
406
408
410
412
414
403
402