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(54) **EXPANDABLE TUBING AND METHOD**

(56)

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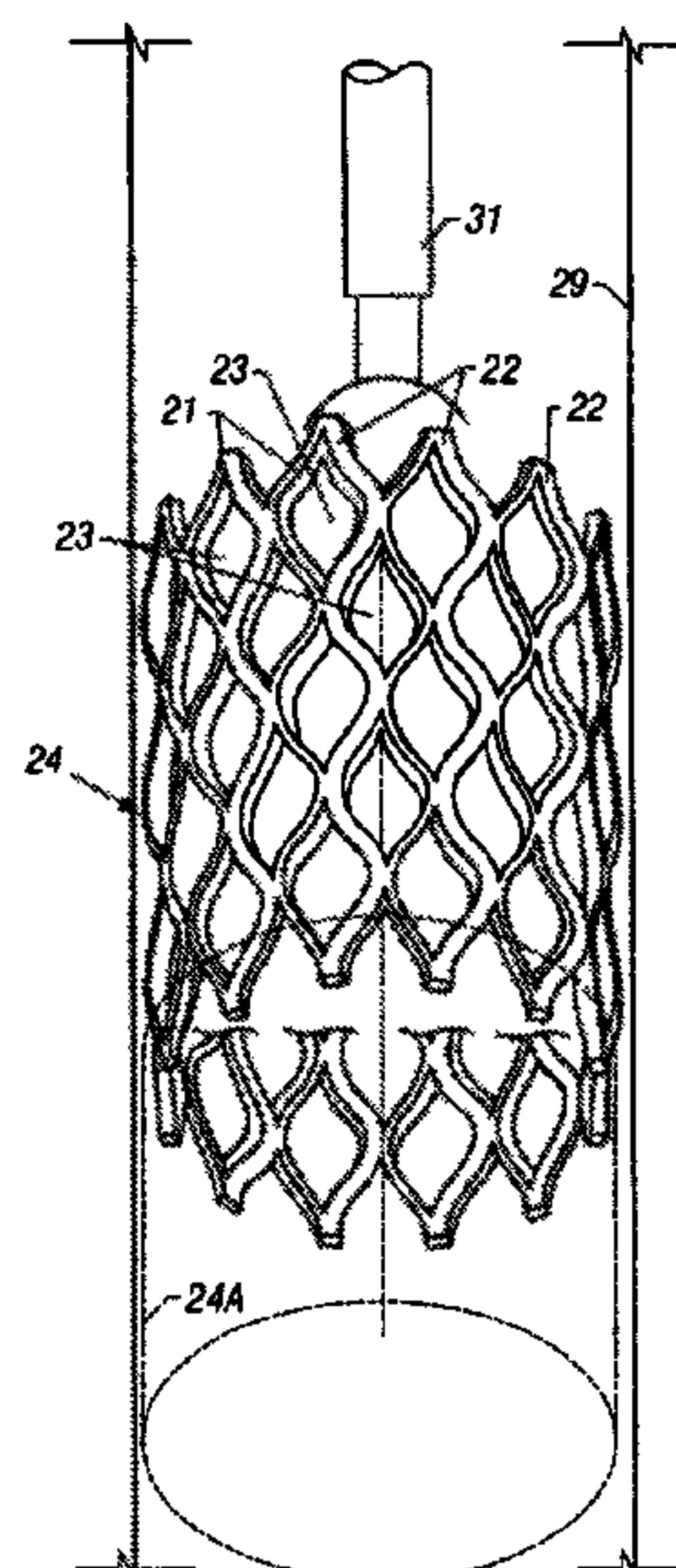
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(57)

**ABSTRACT**

An apparatus suitable for use in a wellbore comprises an  
expandable bistable device. An exemplary device has a plu-  
rality of bistable cells formed into a tubular shape. Each  
bistable cell comprises at least two elongated members that  
are connected to each other at their ends. The device is stable  
in a first configuration and a second configuration.

**10 Claims, 17 Drawing Sheets**



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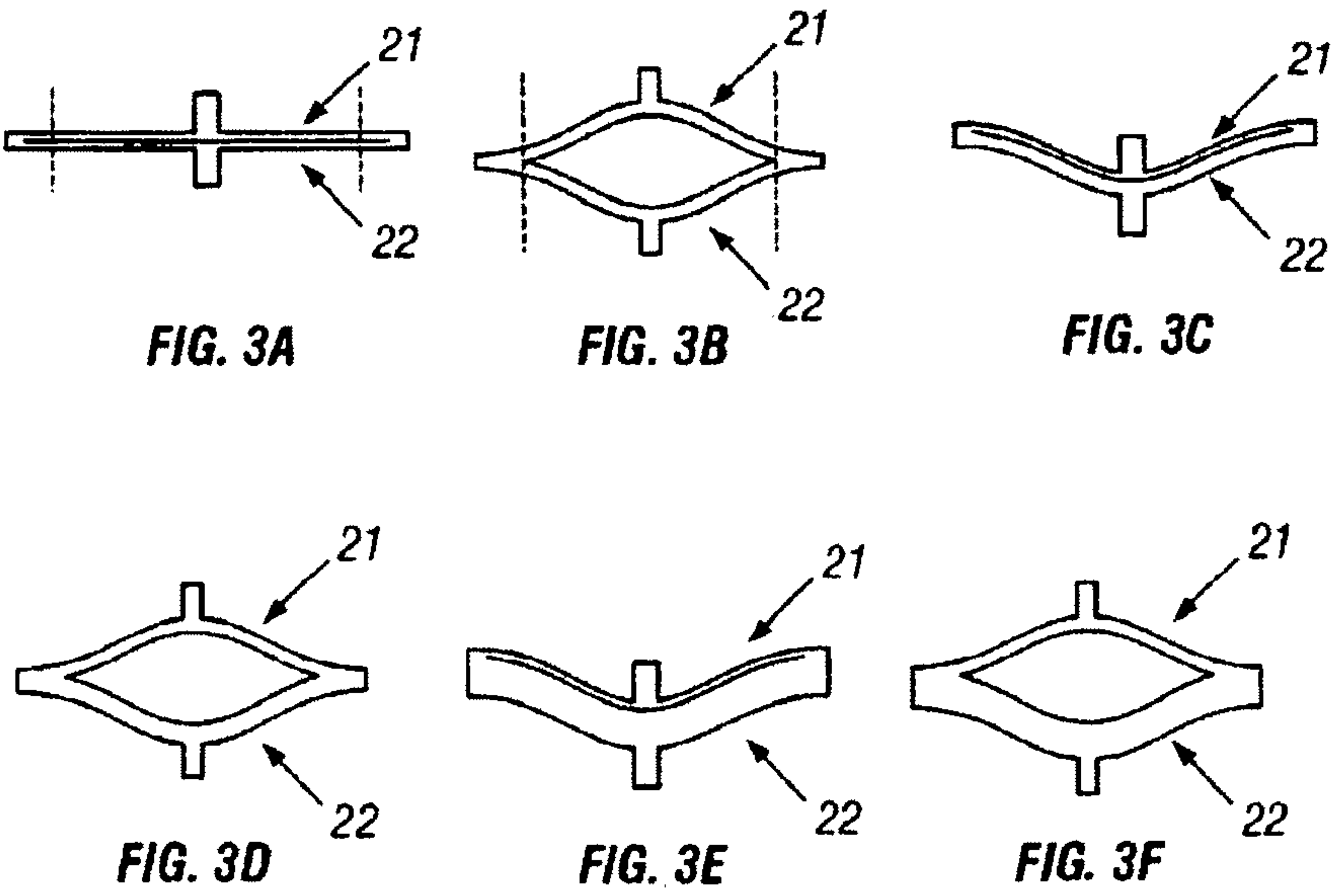
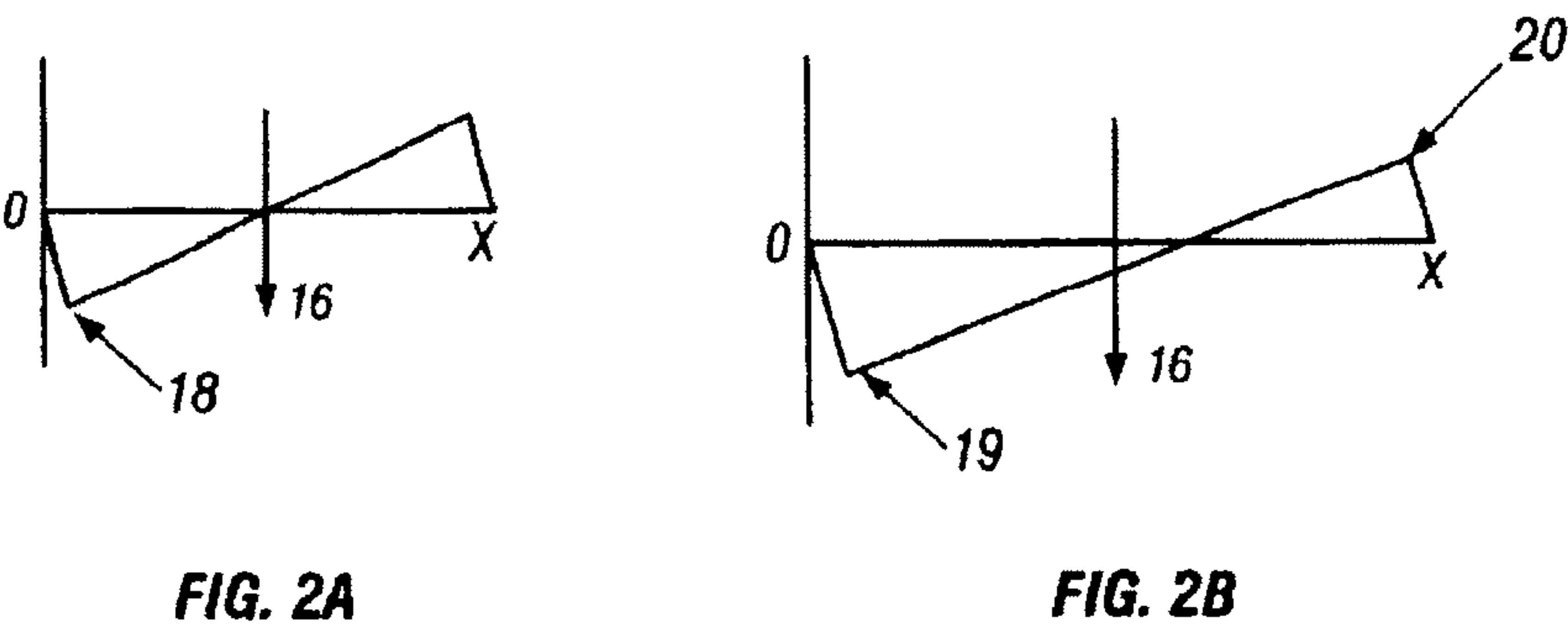
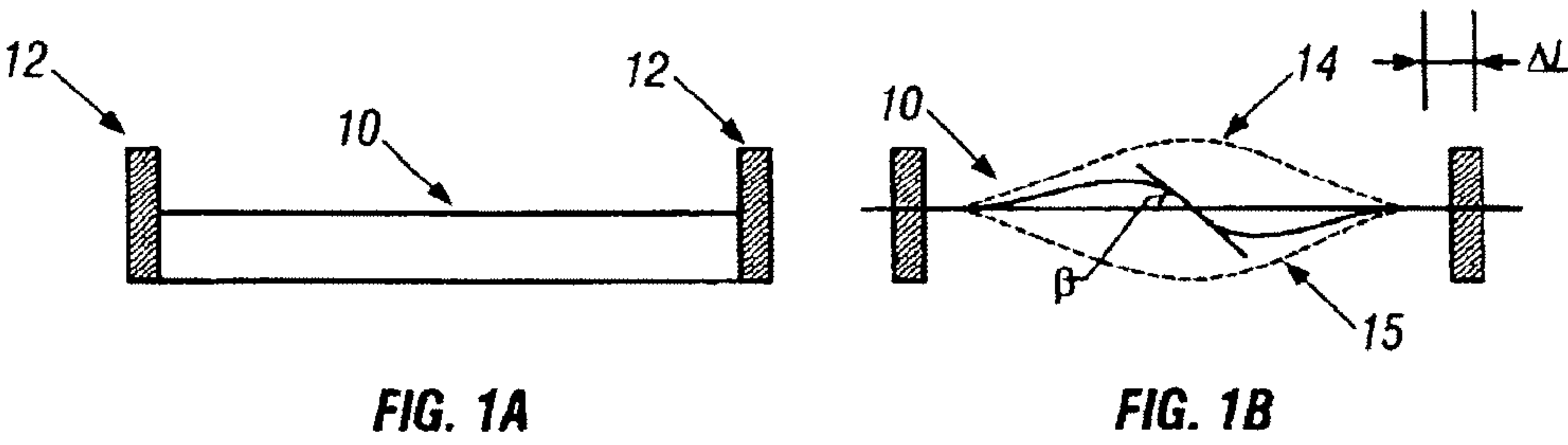
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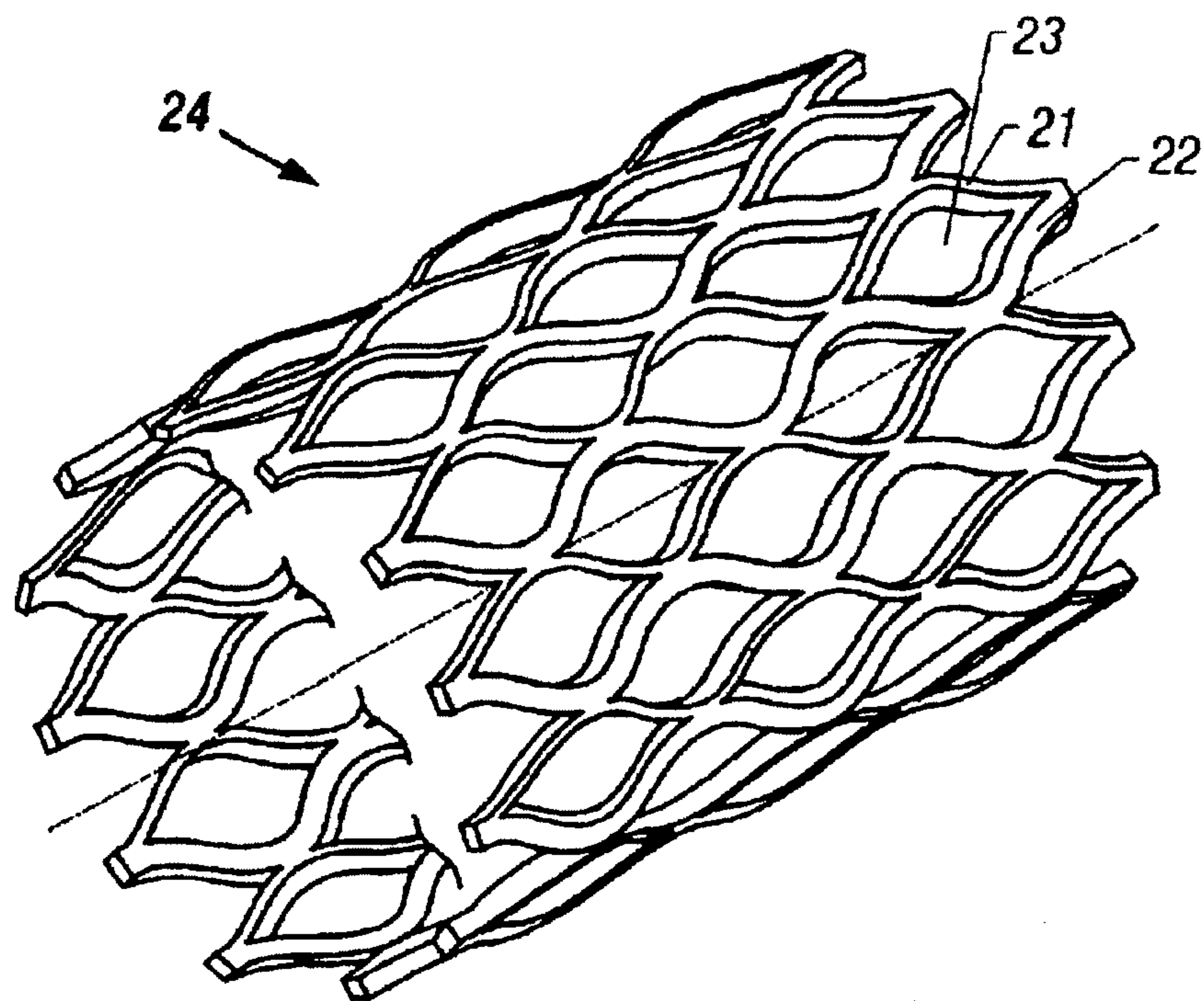


FIG. 4A

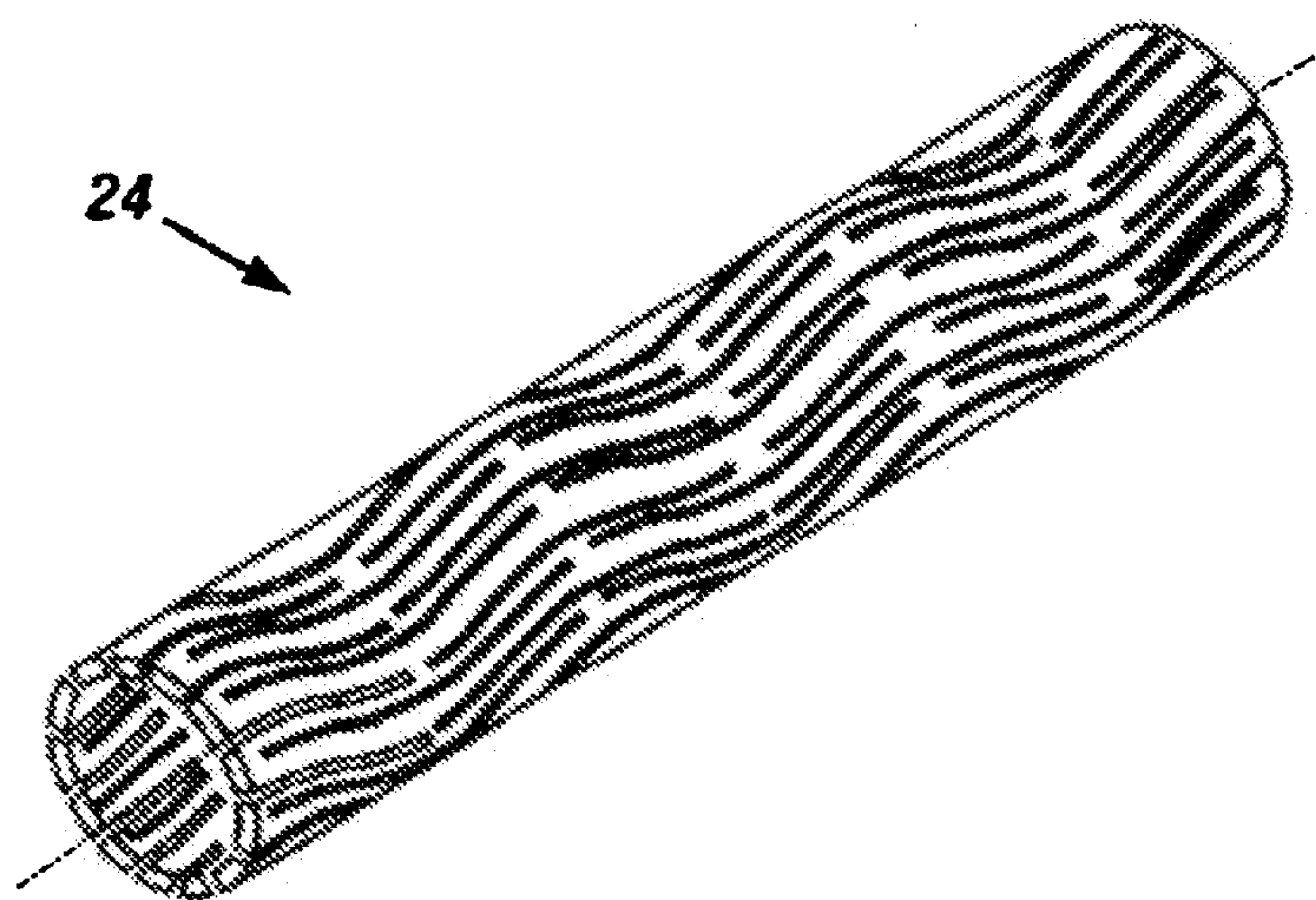
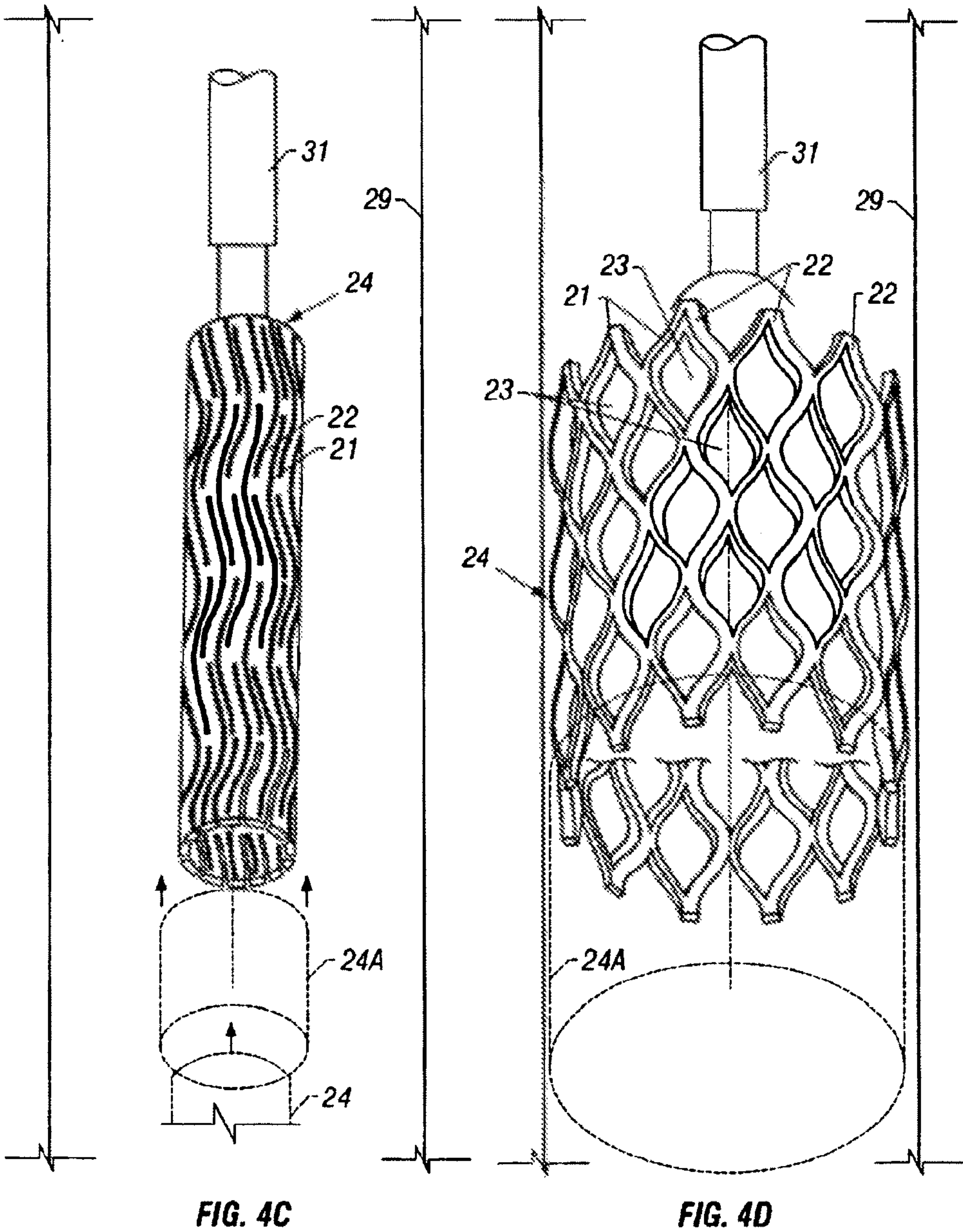


FIG. 4B





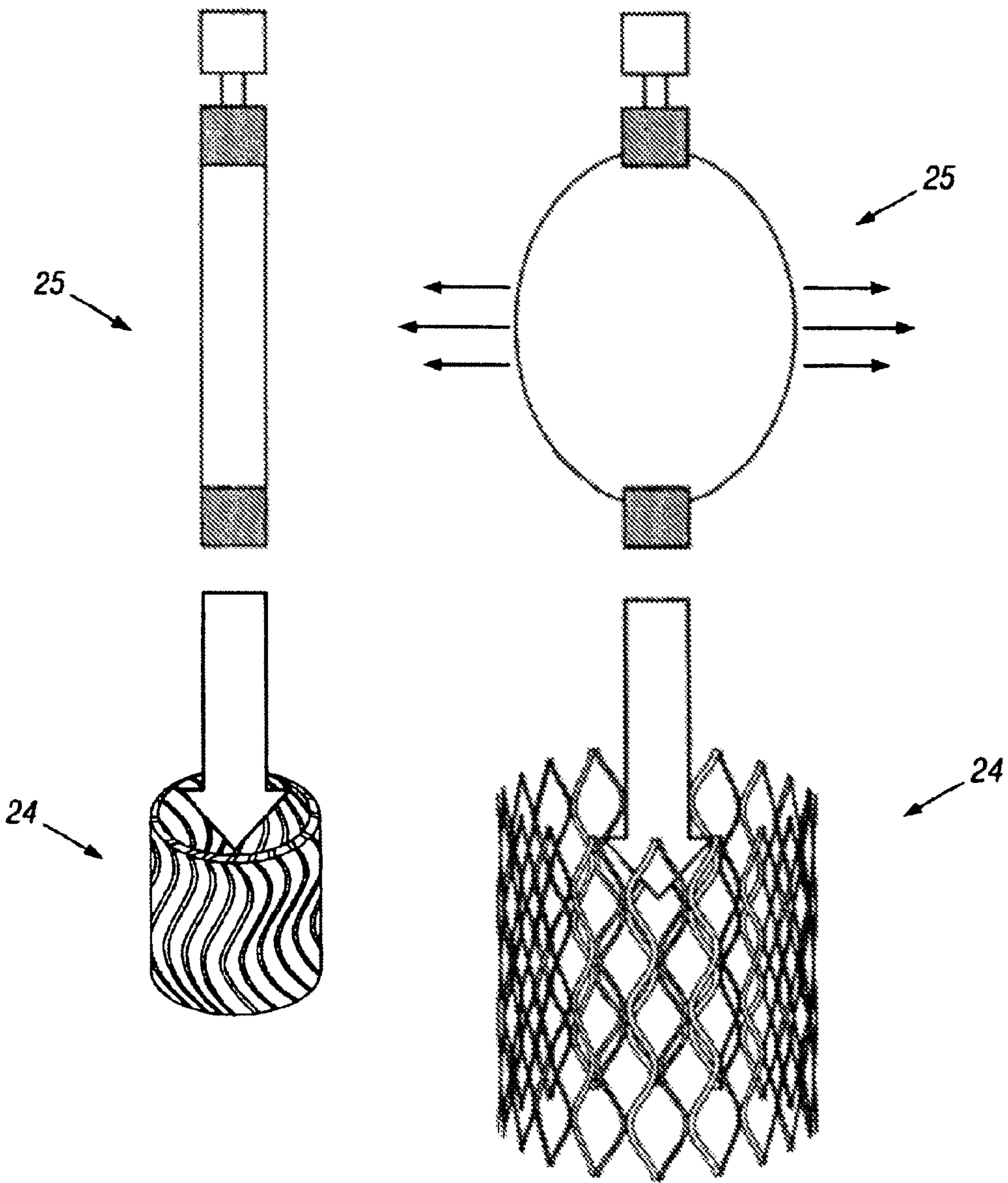


FIG. 5A

FIG. 5B



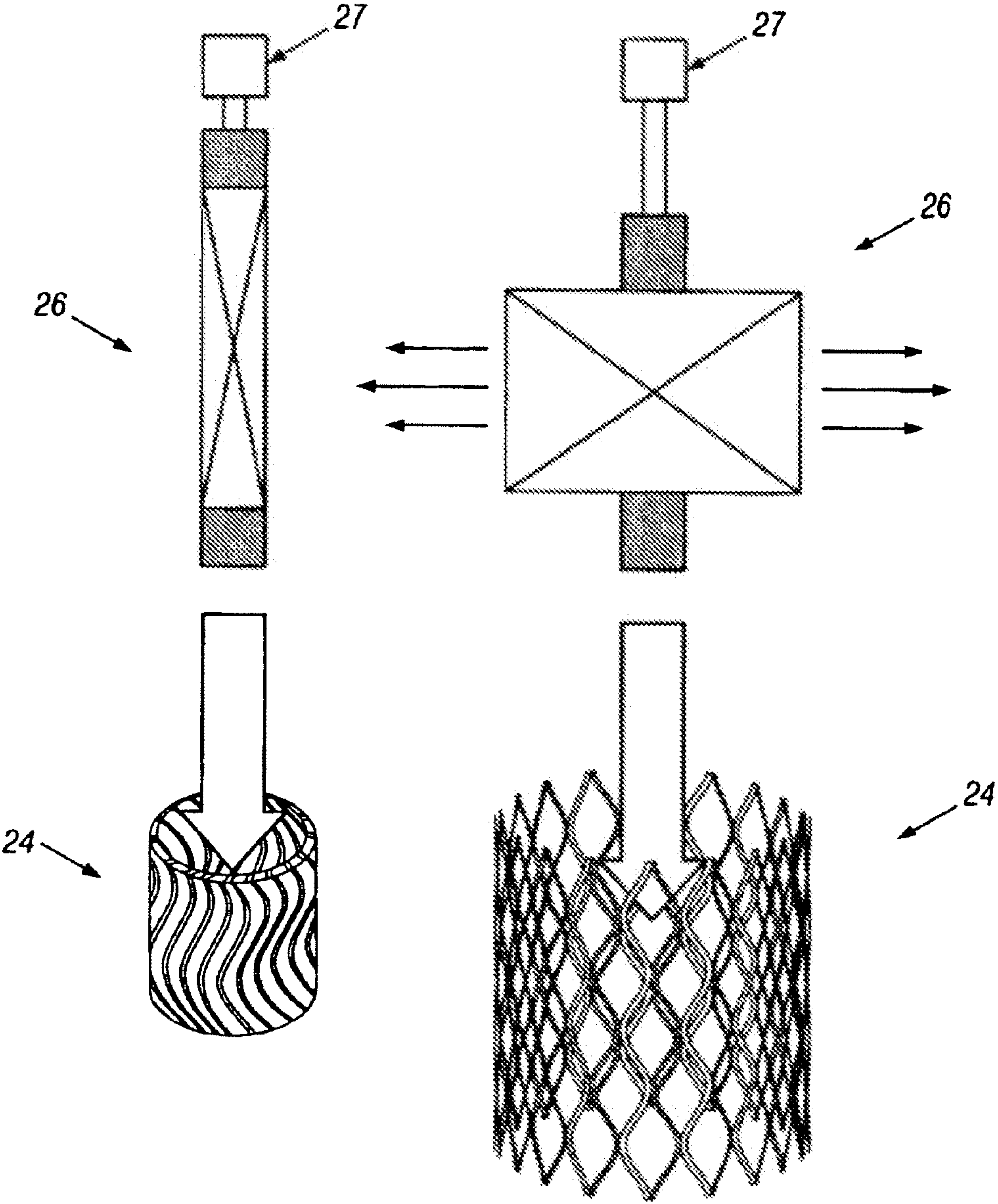


FIG. 6A

FIG. 6B

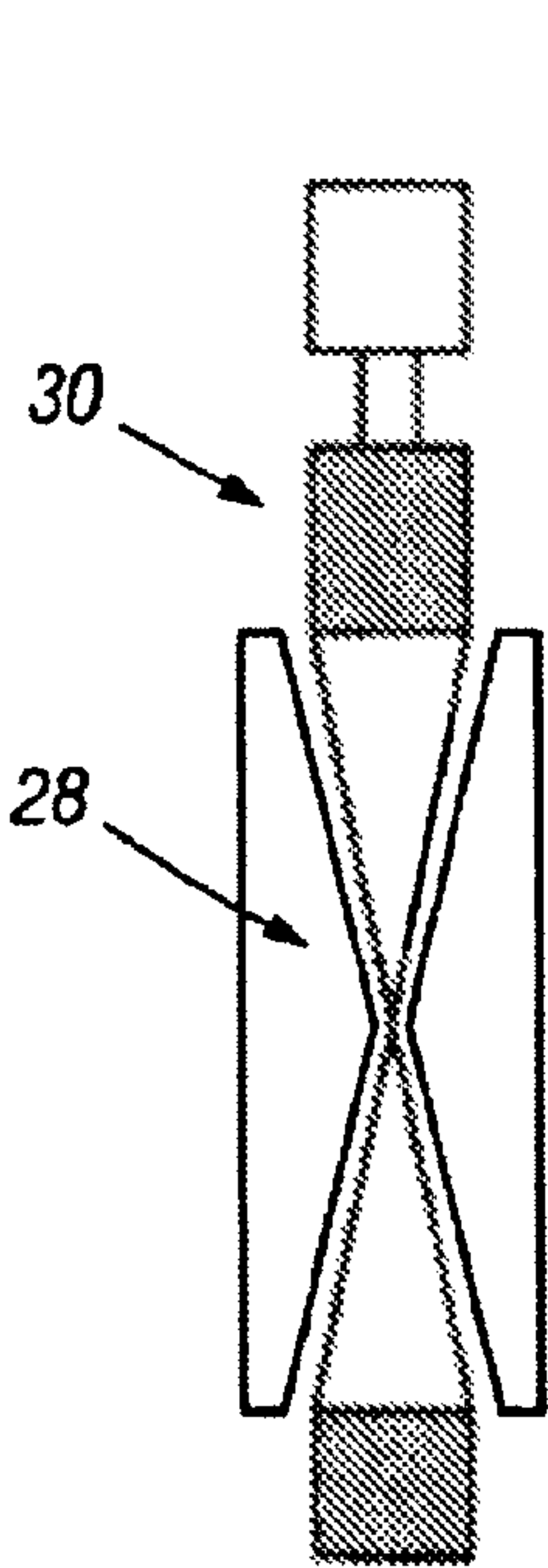


FIG. 7A

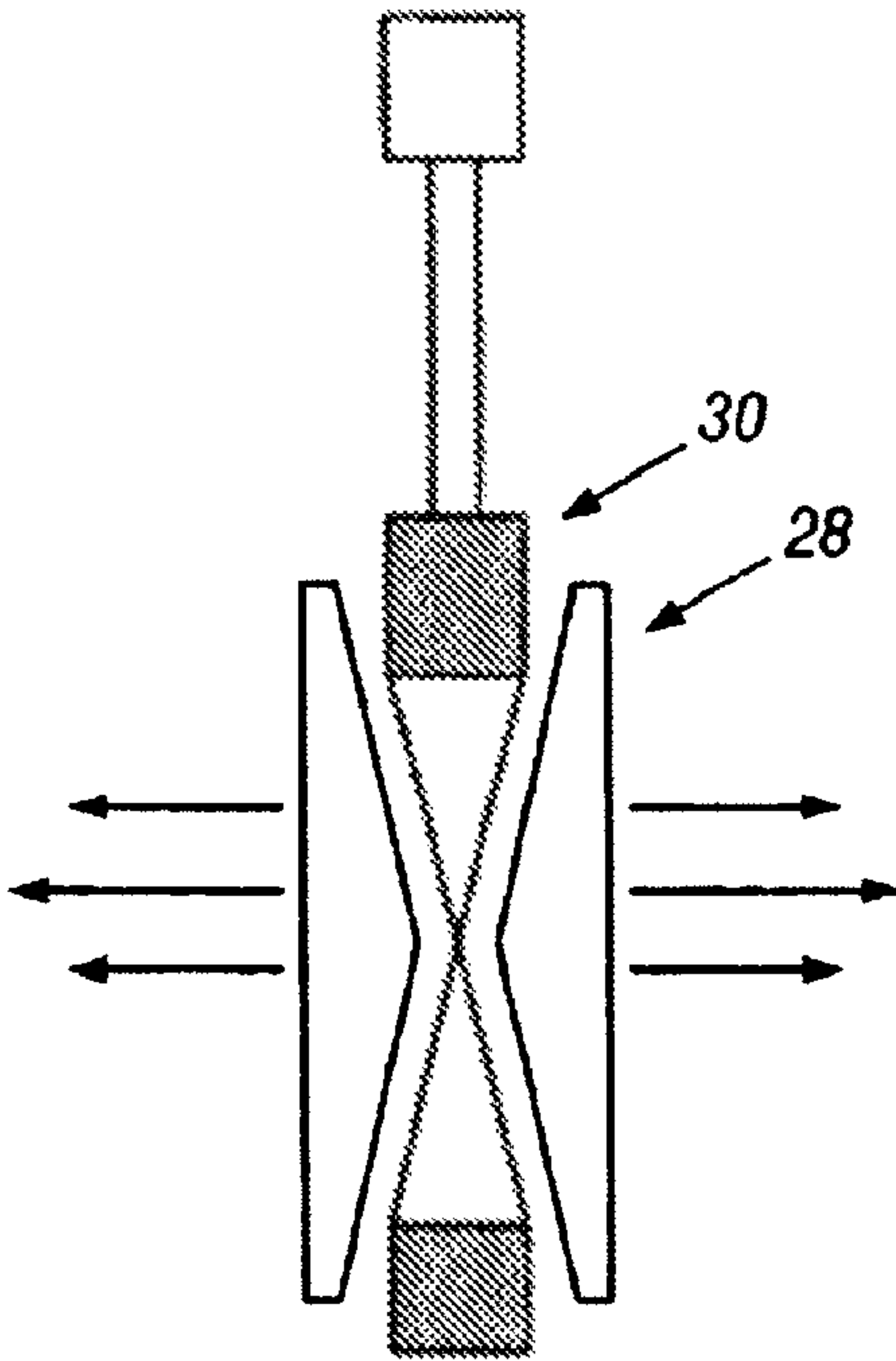


FIG. 7B

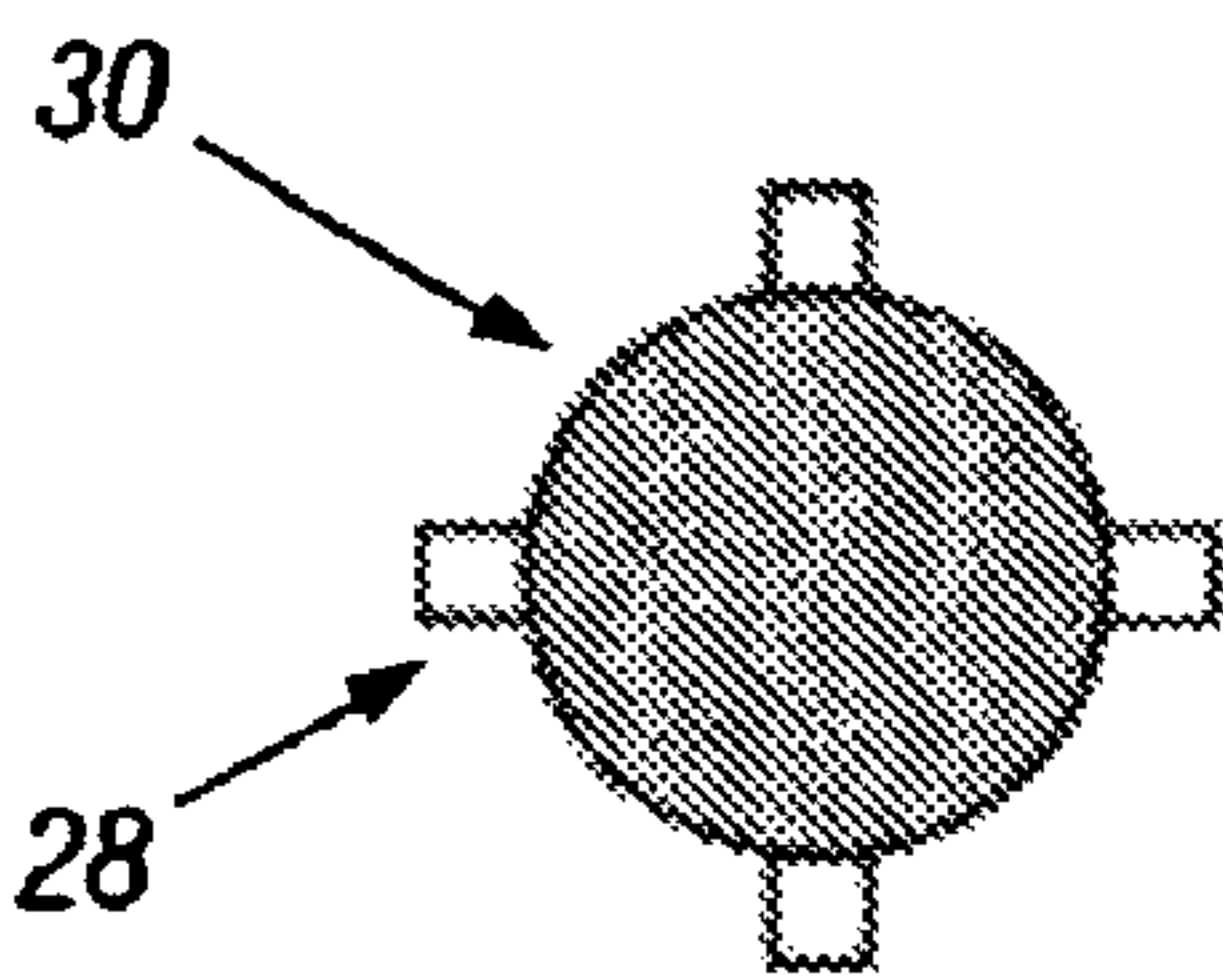


FIG. 7C

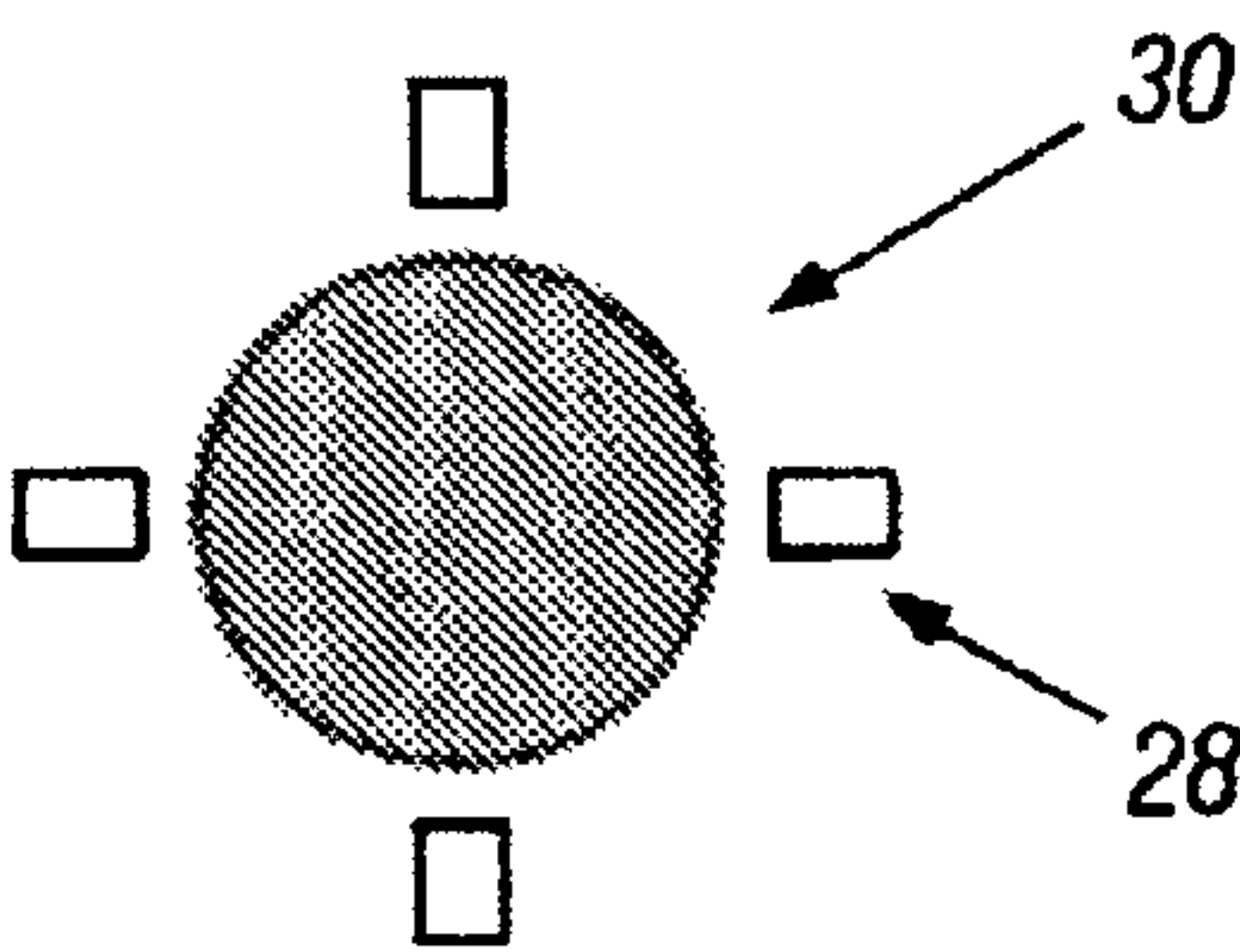


FIG. 7D



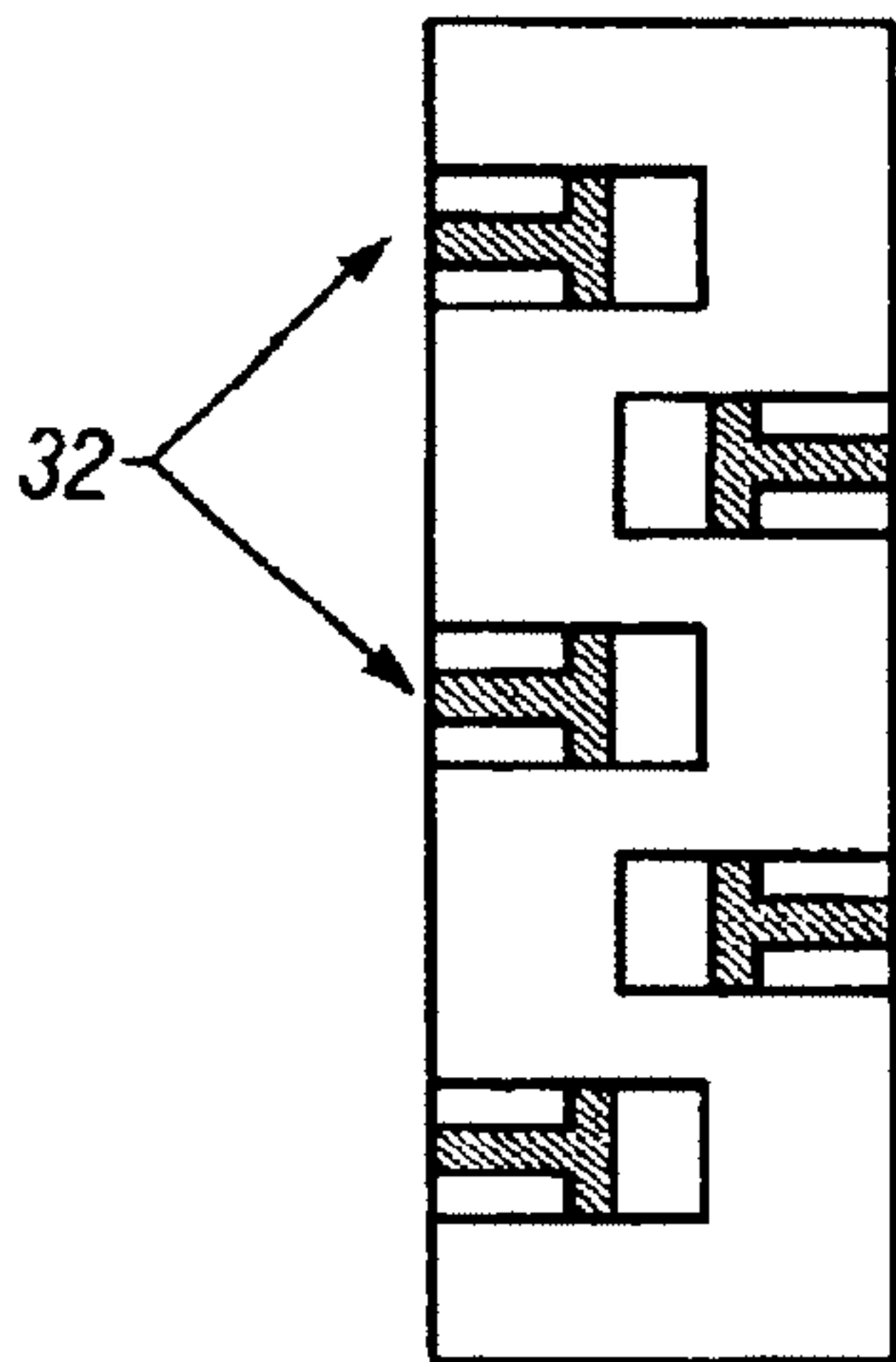


FIG. 8A

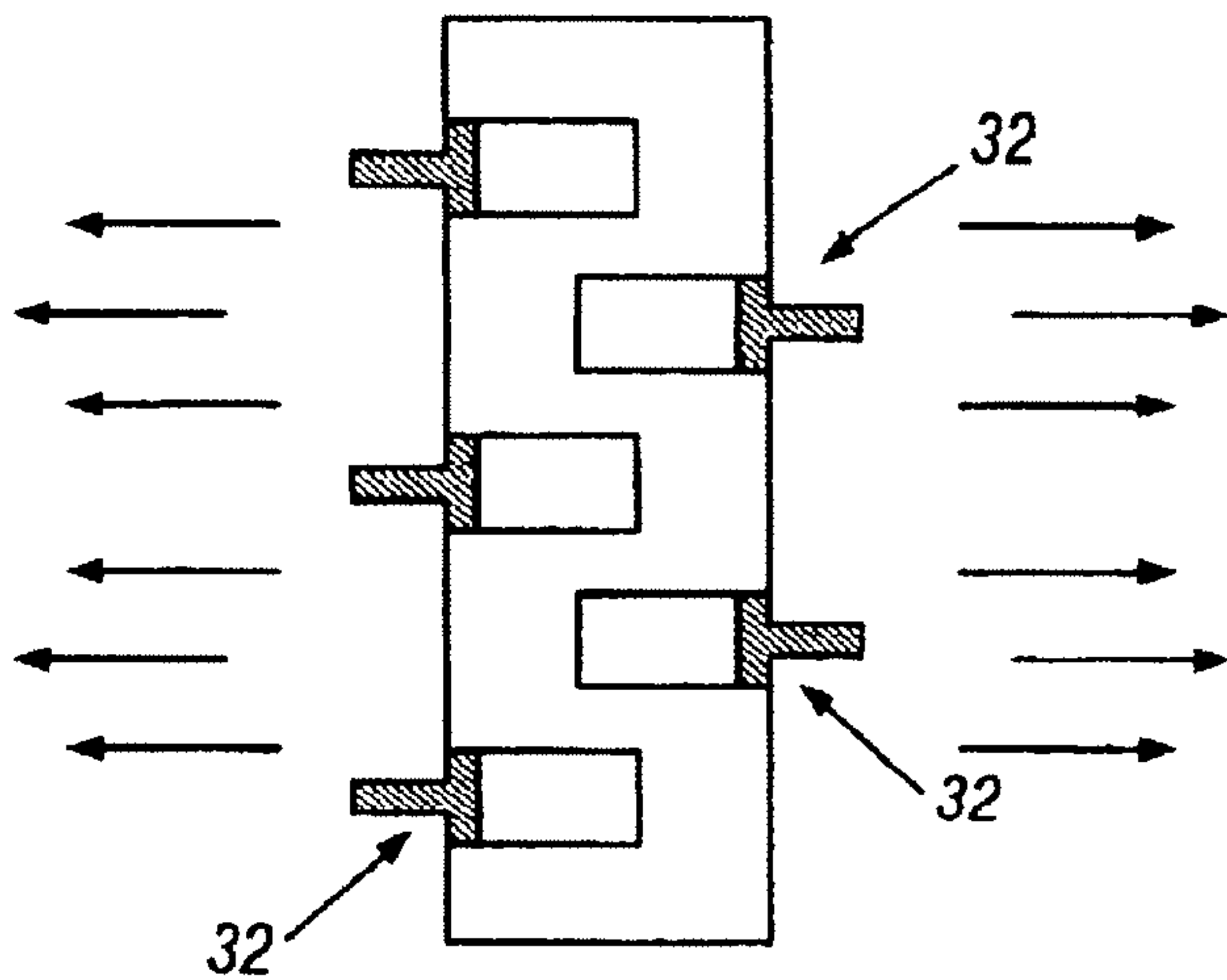


FIG. 8B

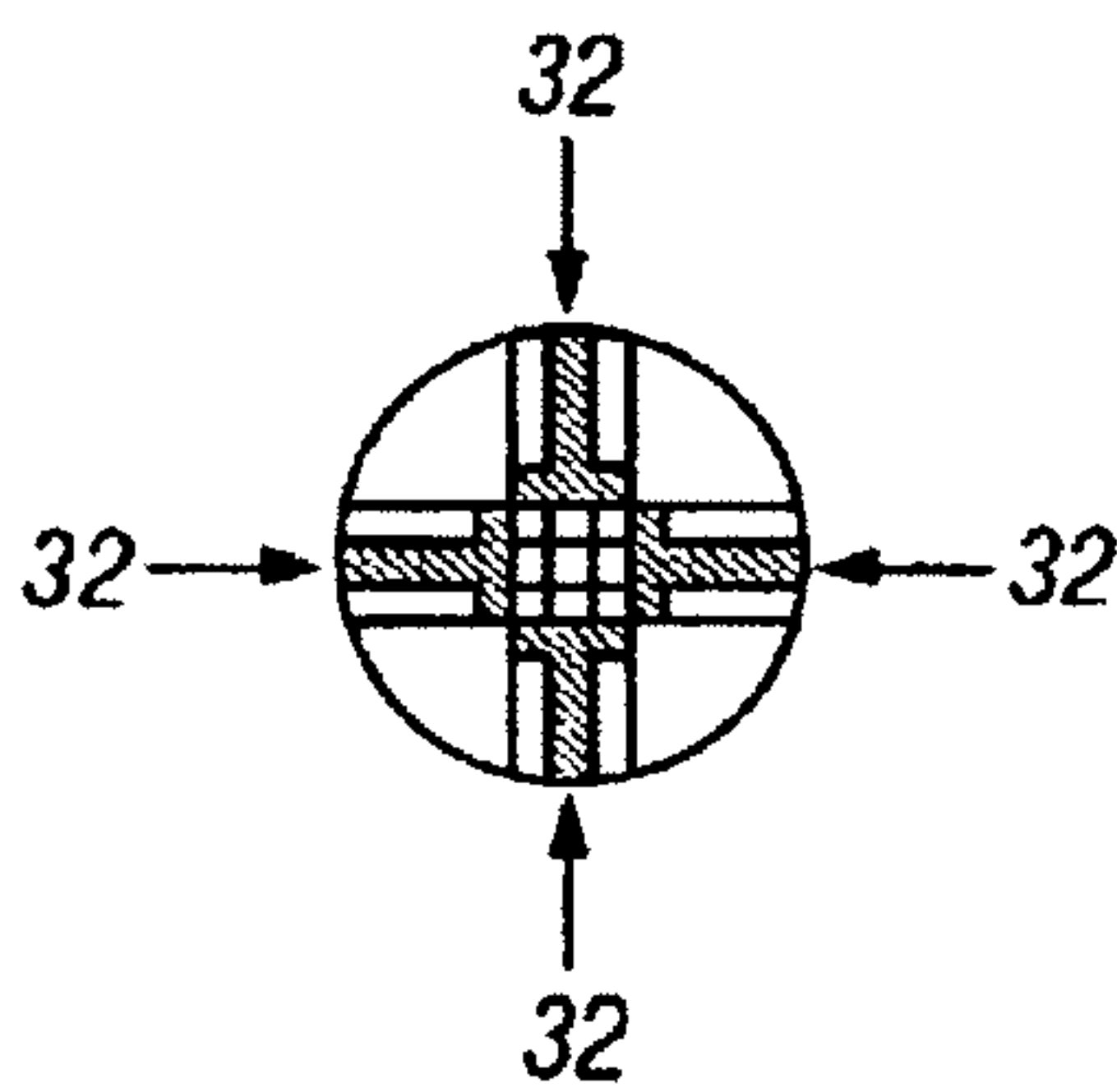


FIG. 8C

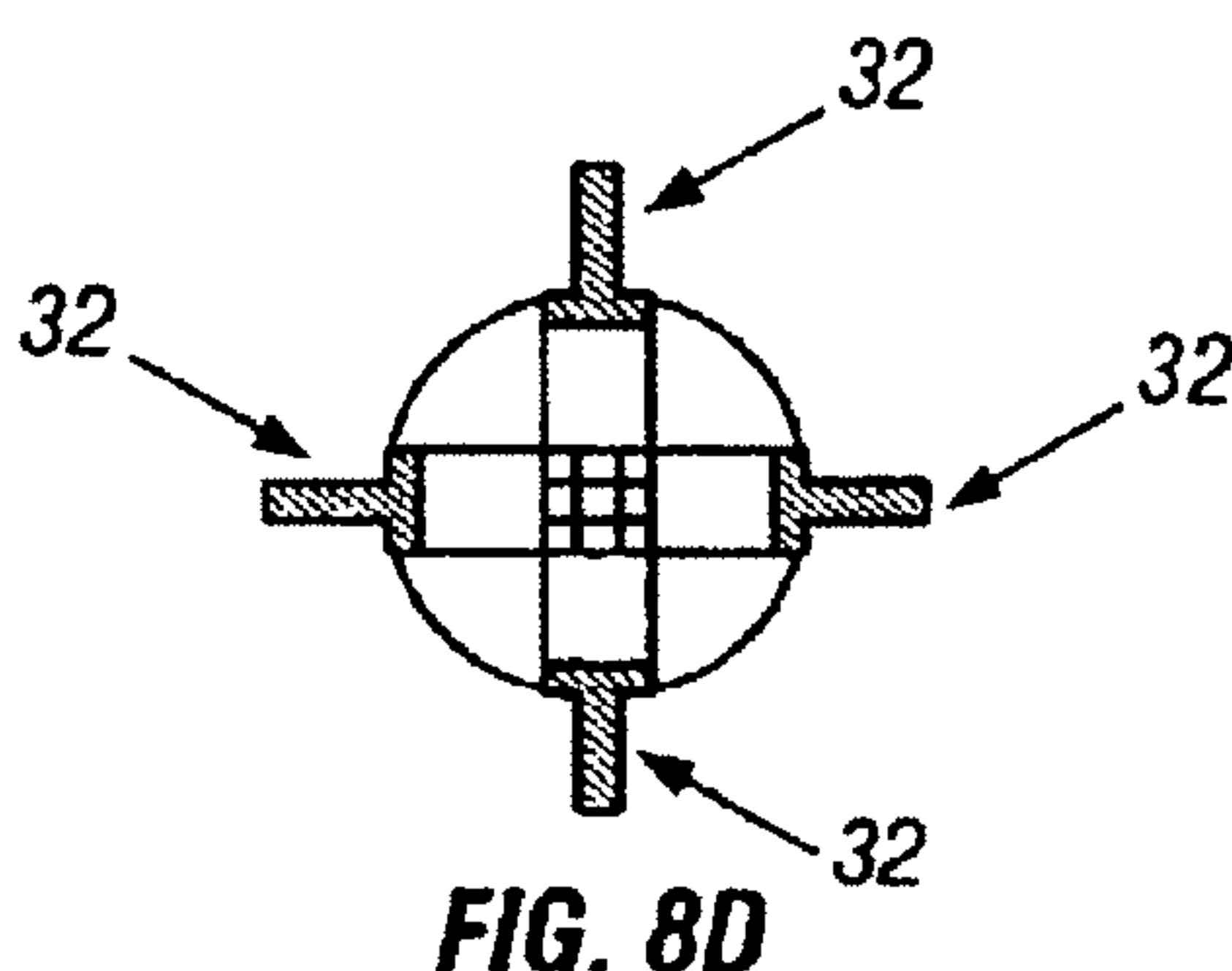


FIG. 8D

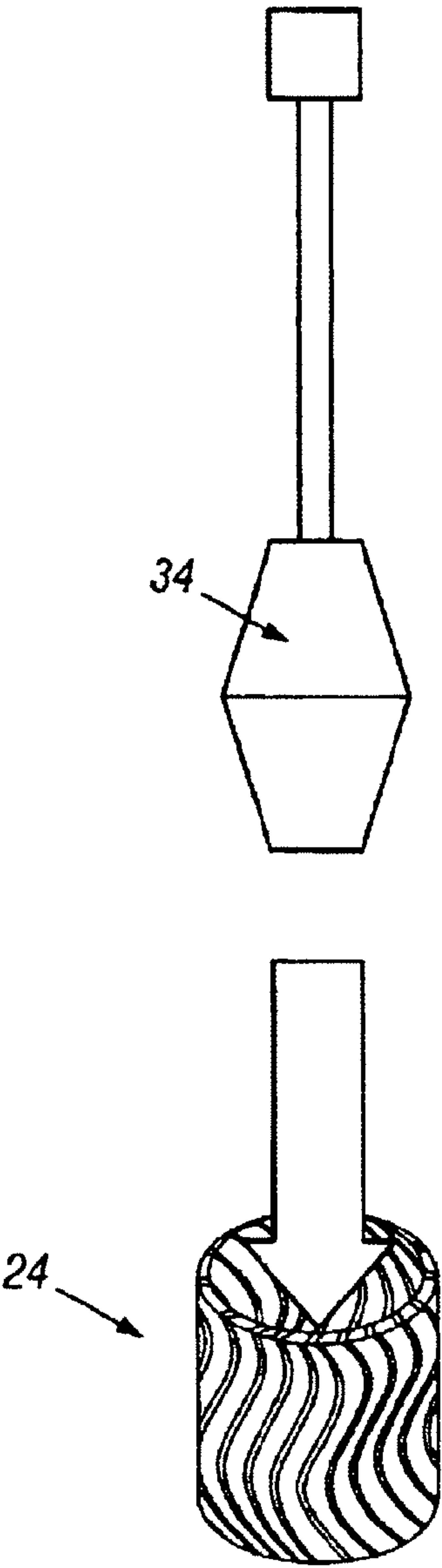


FIG. 9A

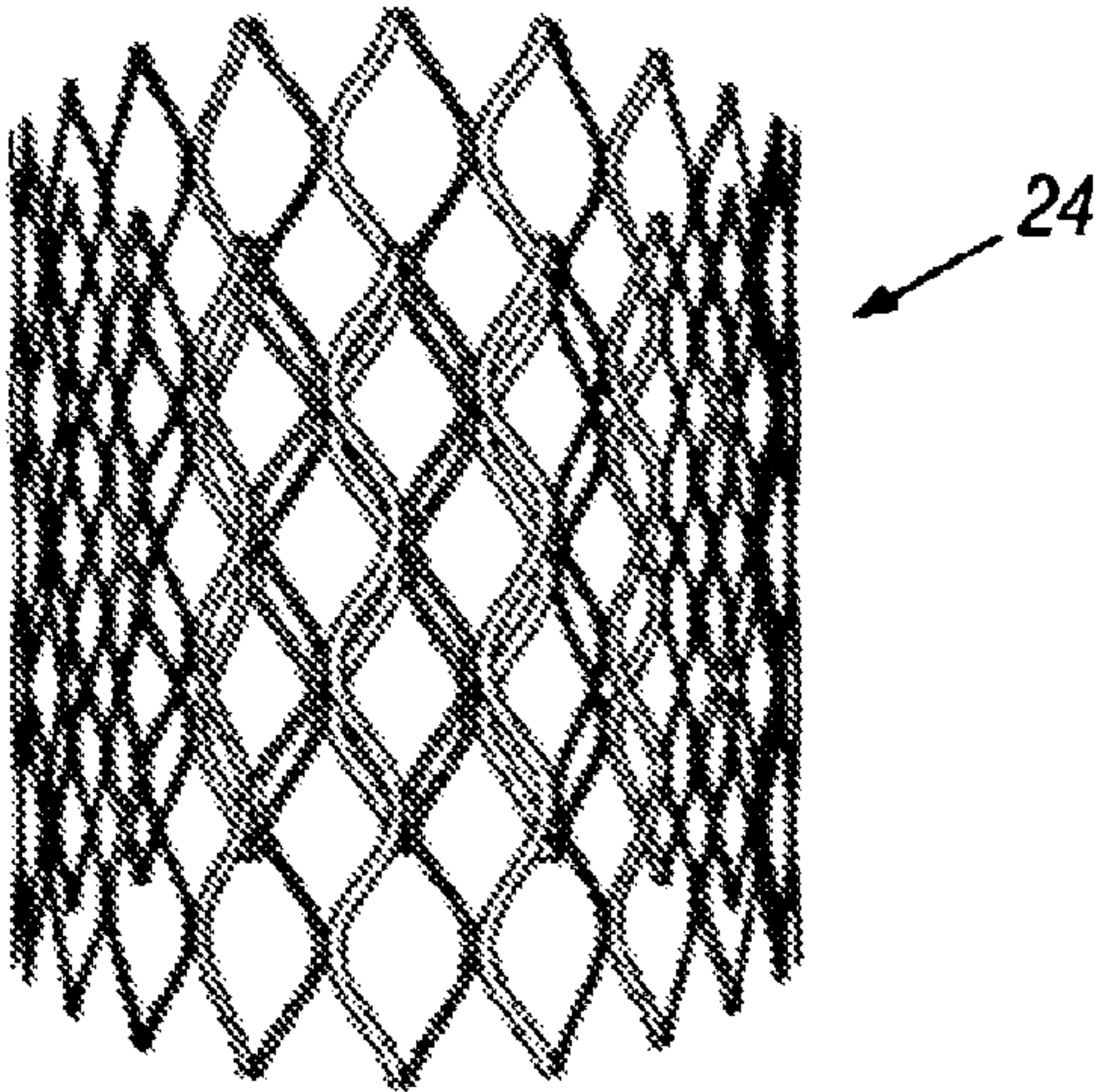


FIG. 9B



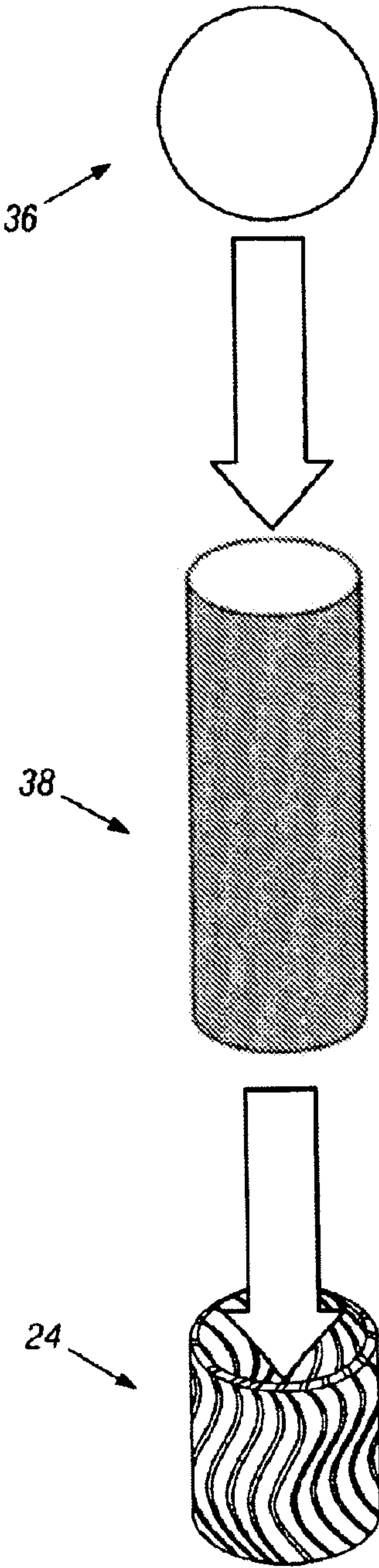


FIG. 10A

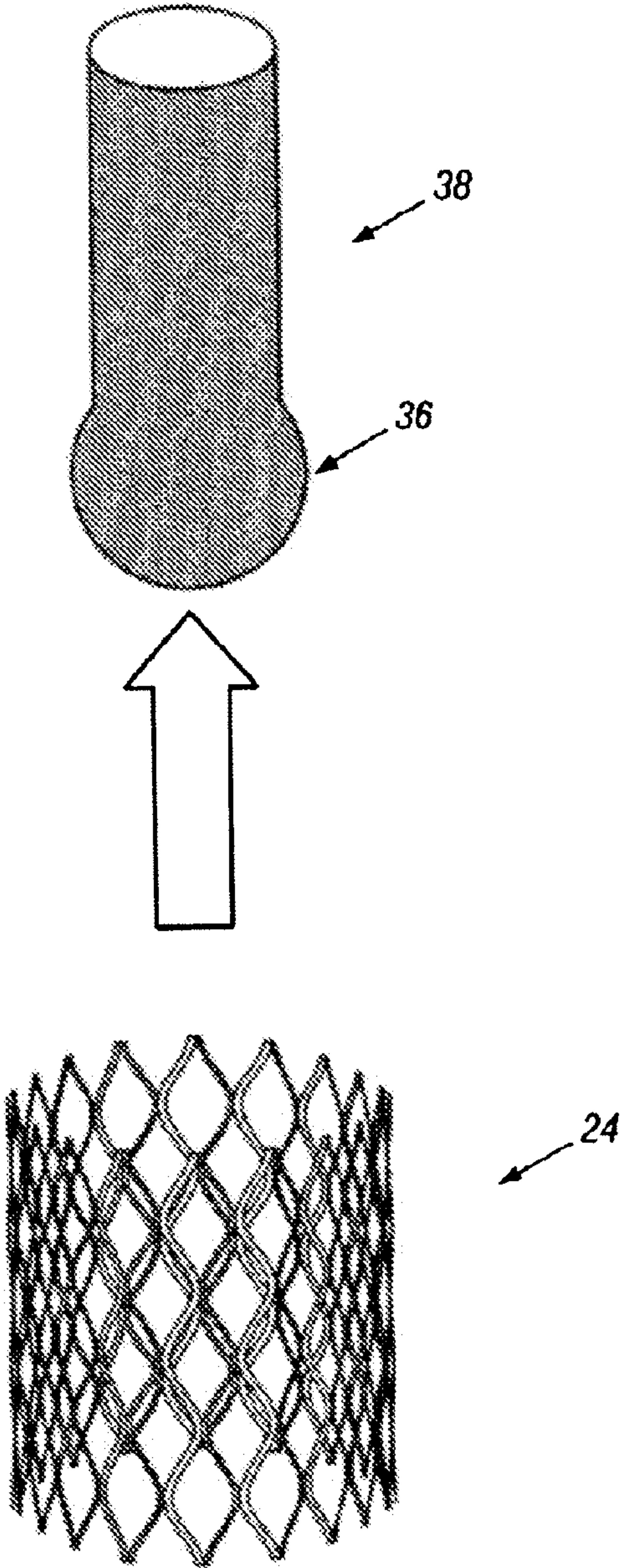


FIG. 10B

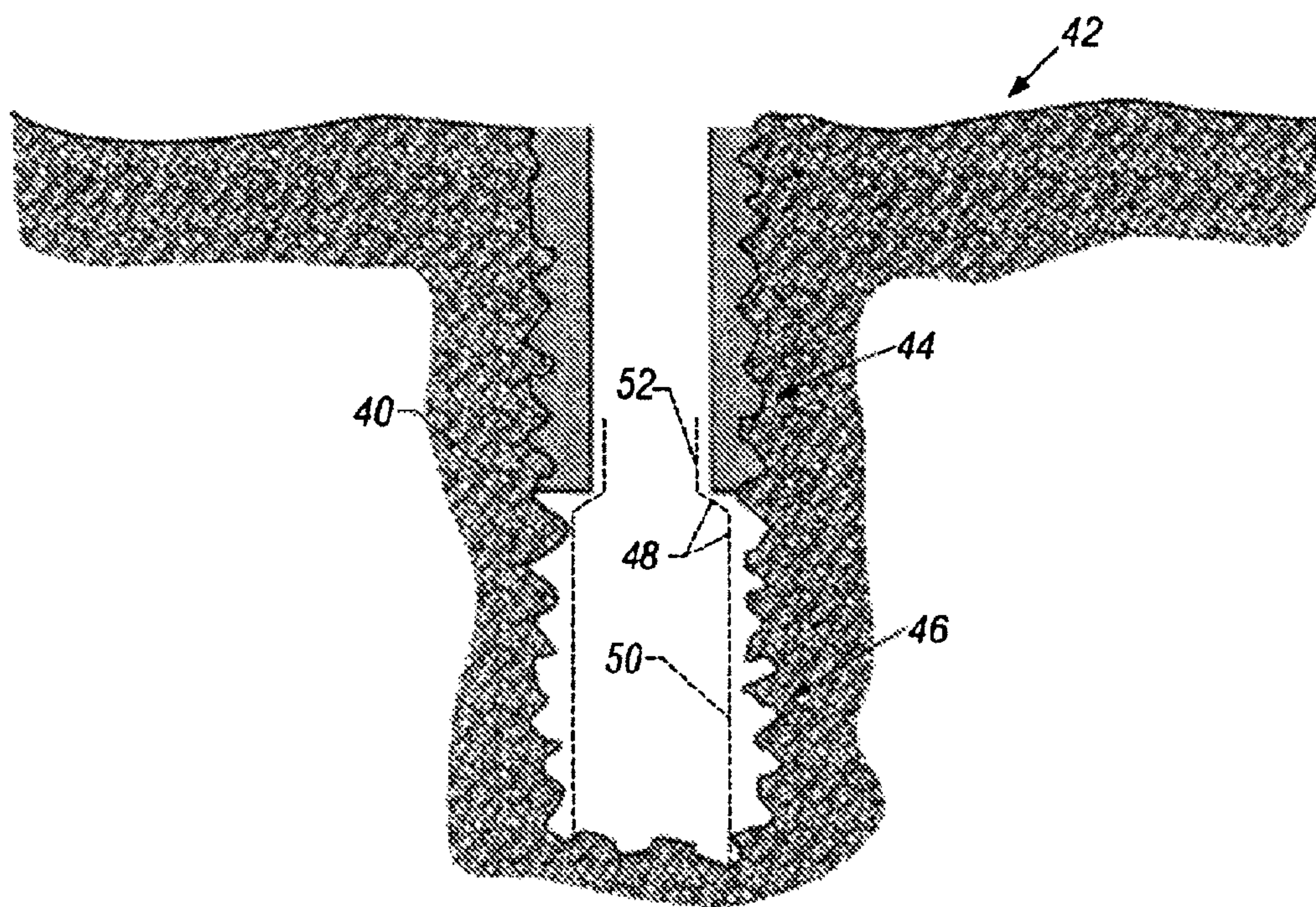


FIG. 11



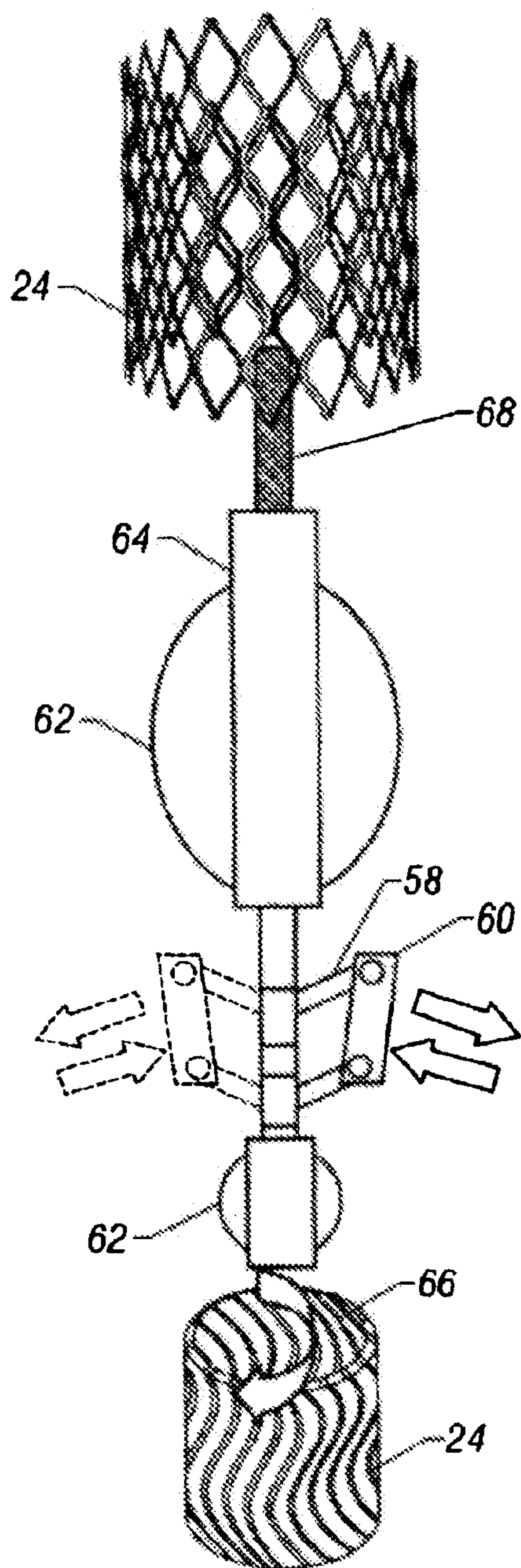


FIG. 12

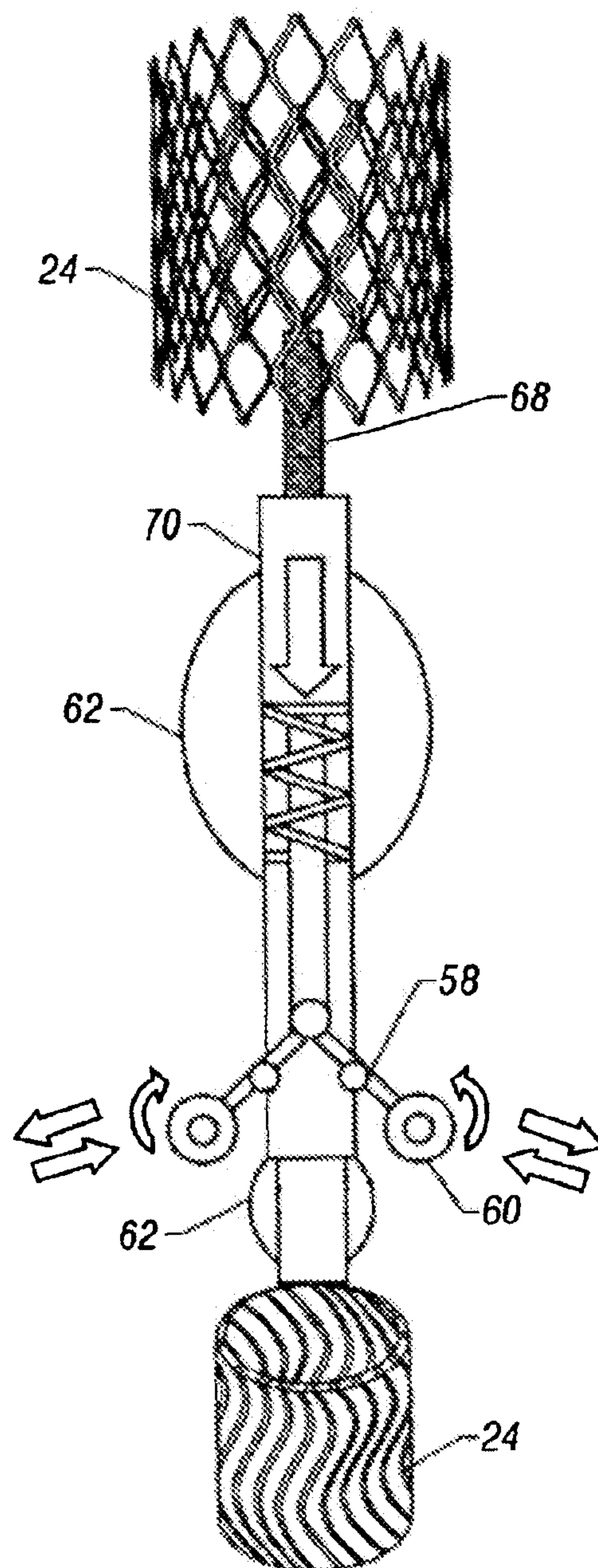


FIG. 13

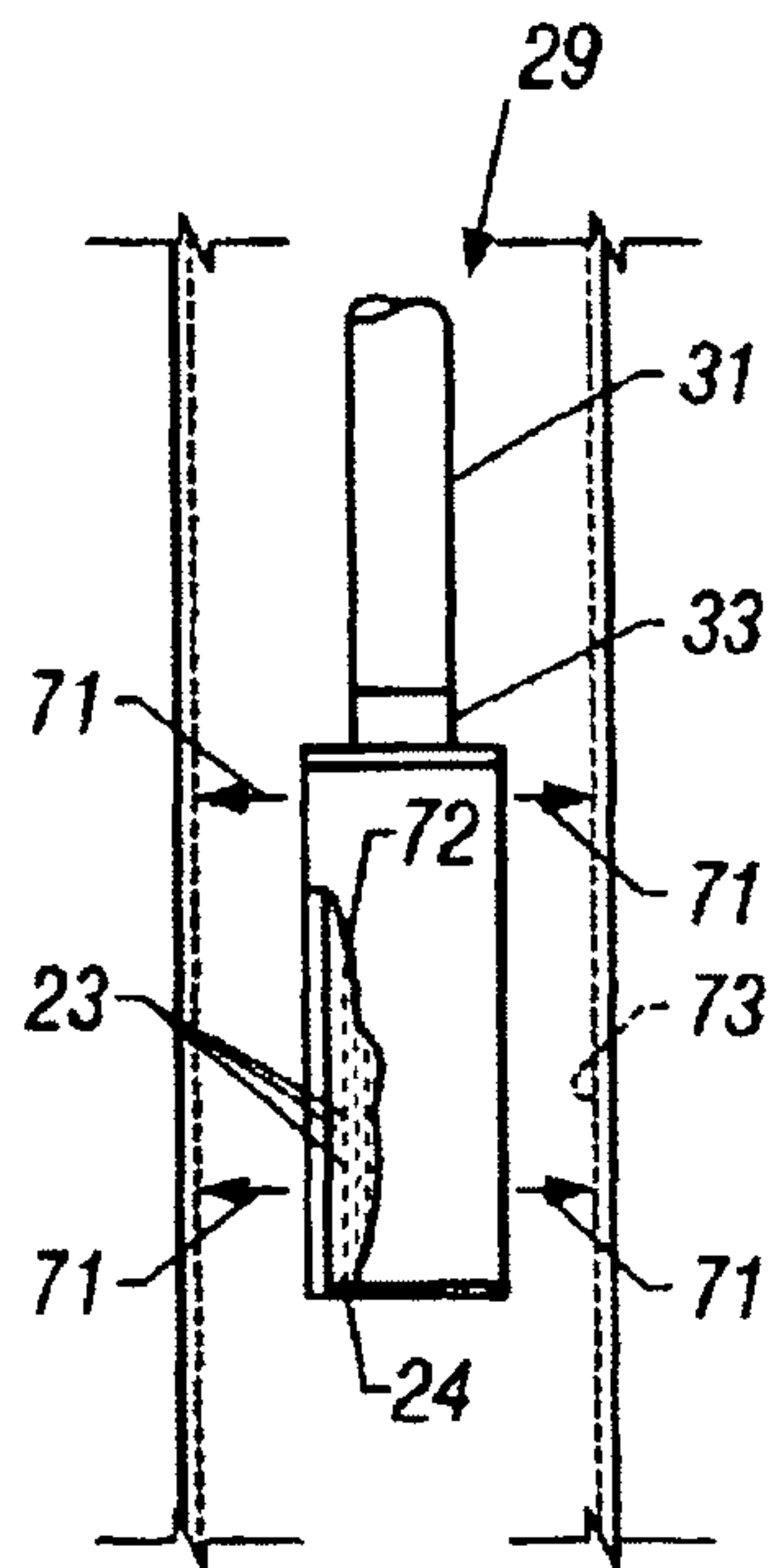


FIG. 14

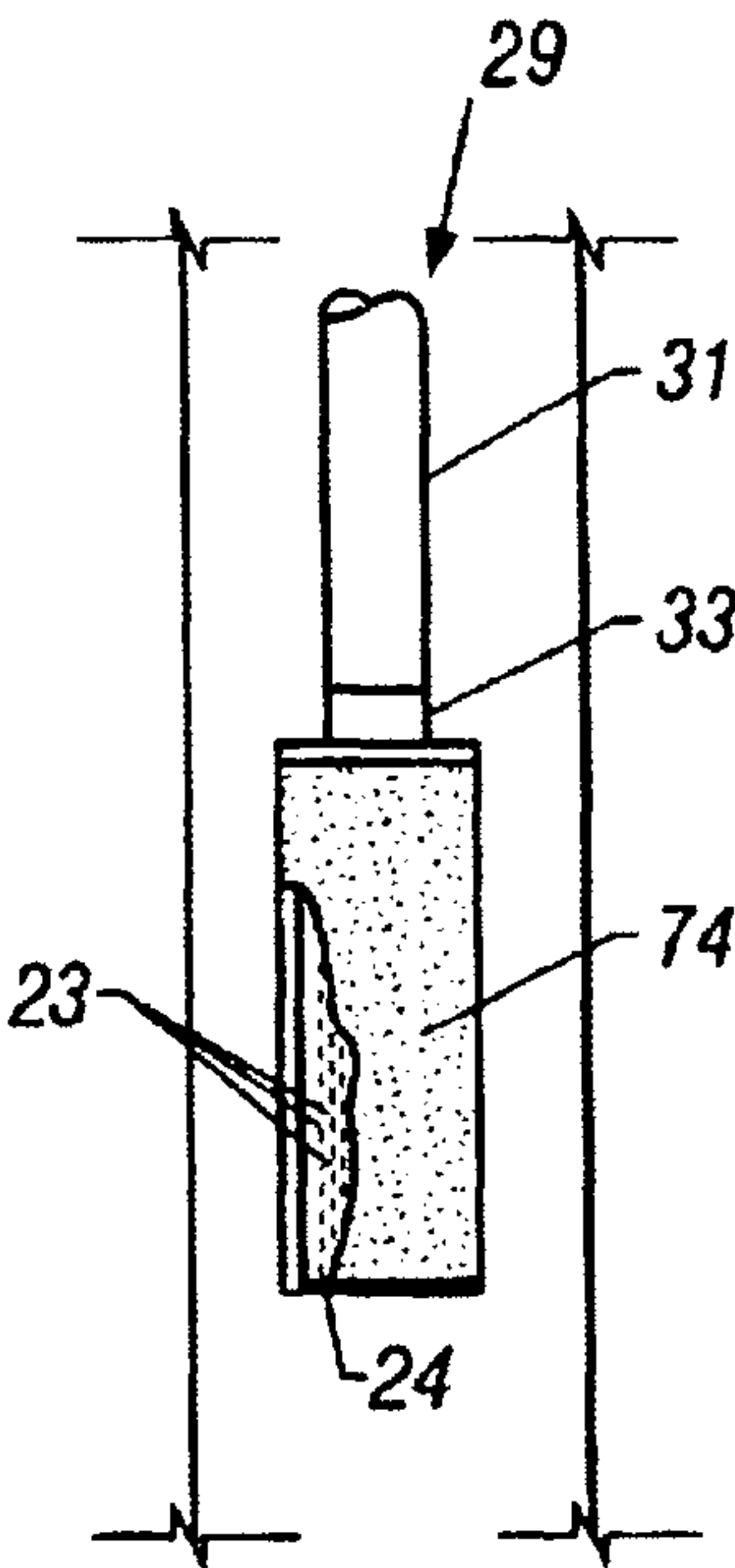


FIG. 14A

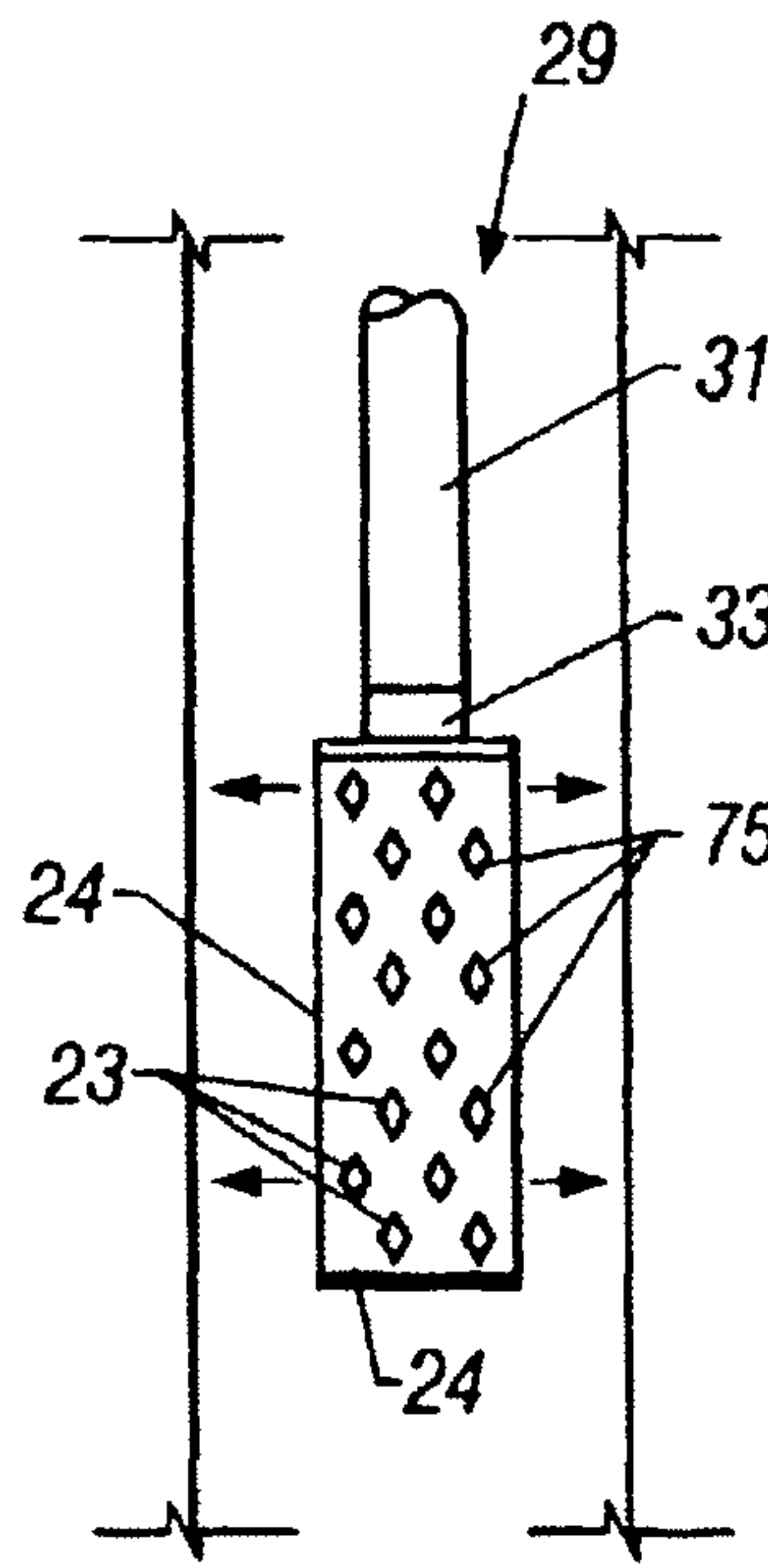


FIG. 14B

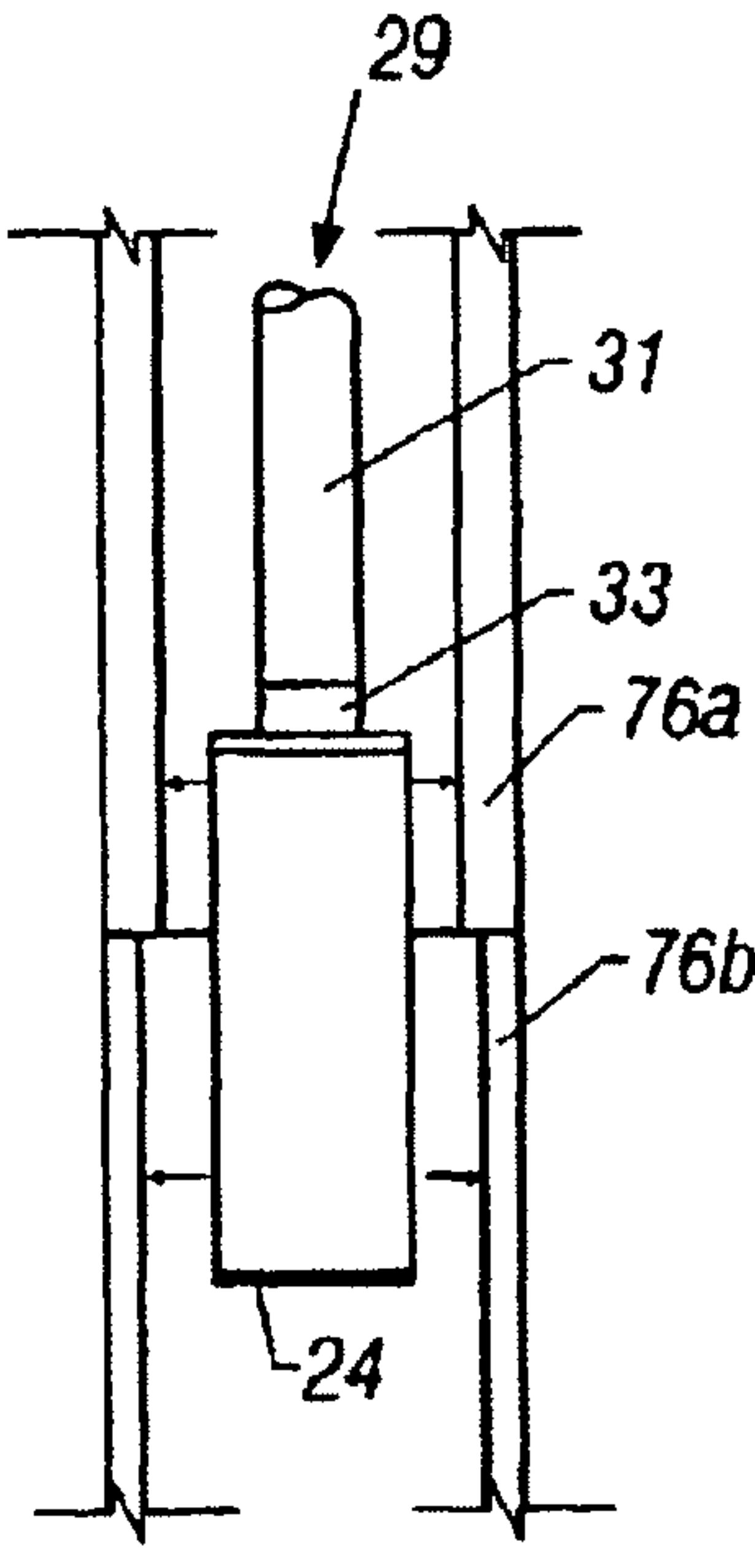
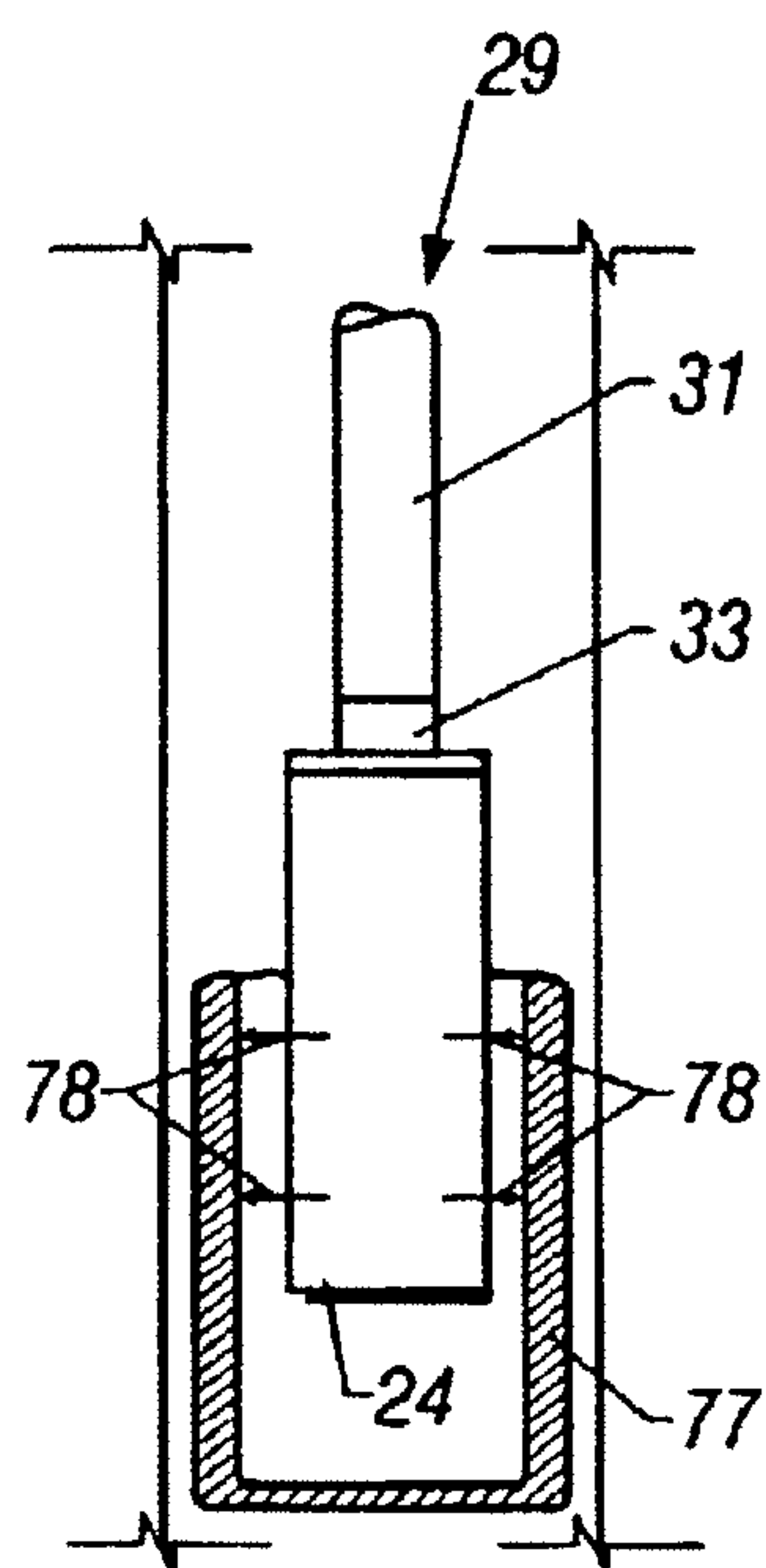
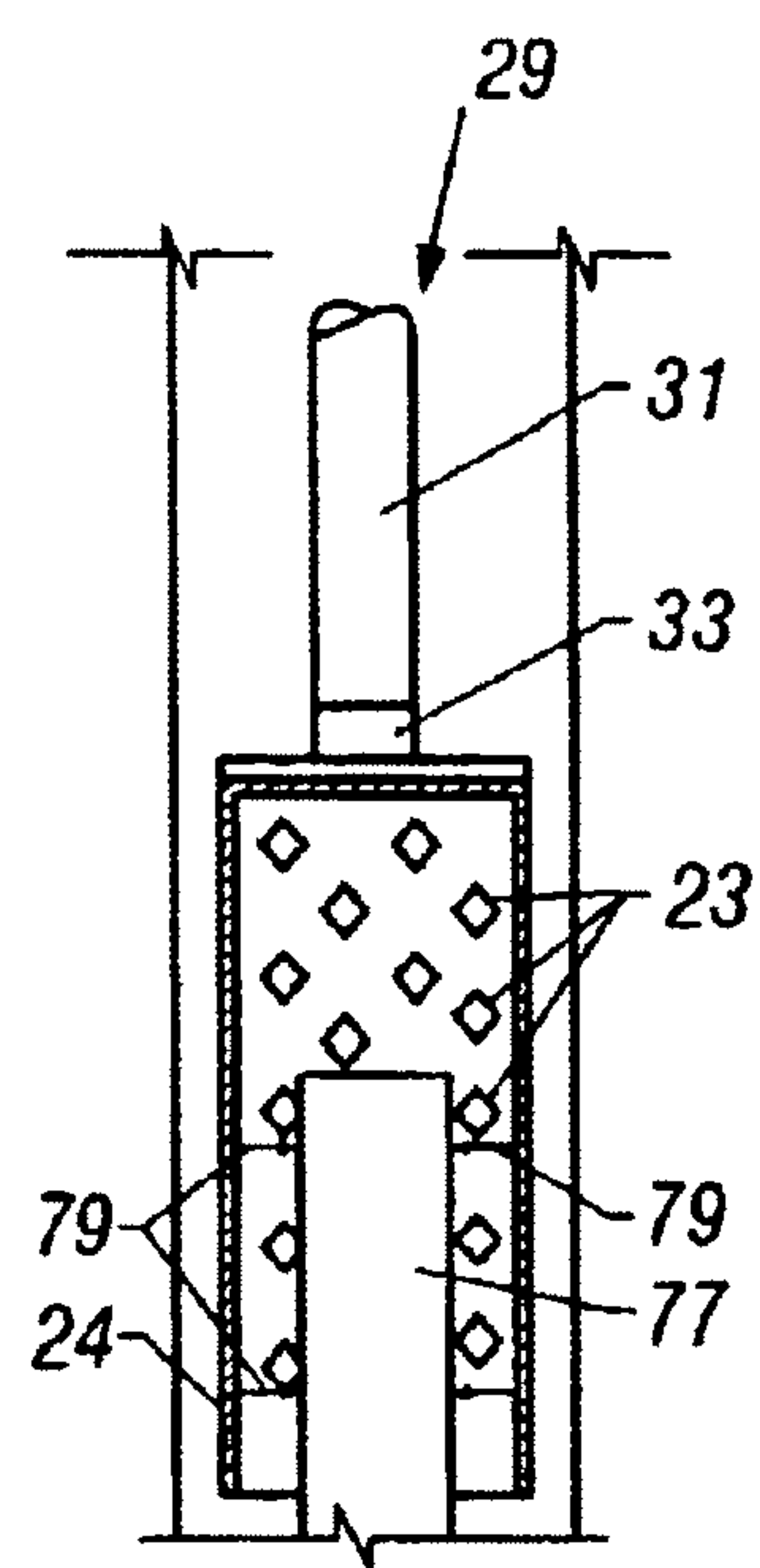


FIG. 14C





**FIG. 14D**



**FIG. 14E**

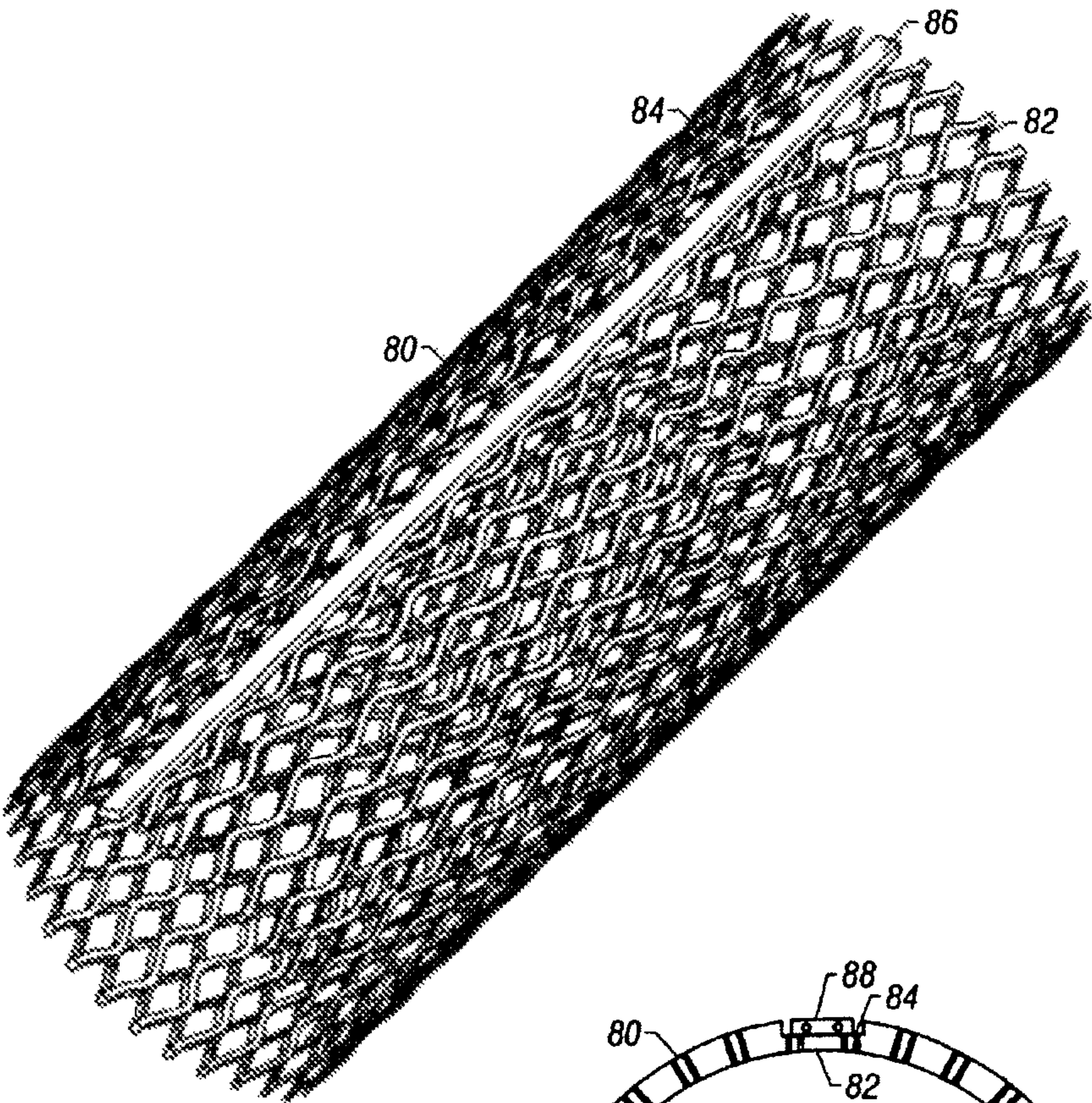


FIG. 15

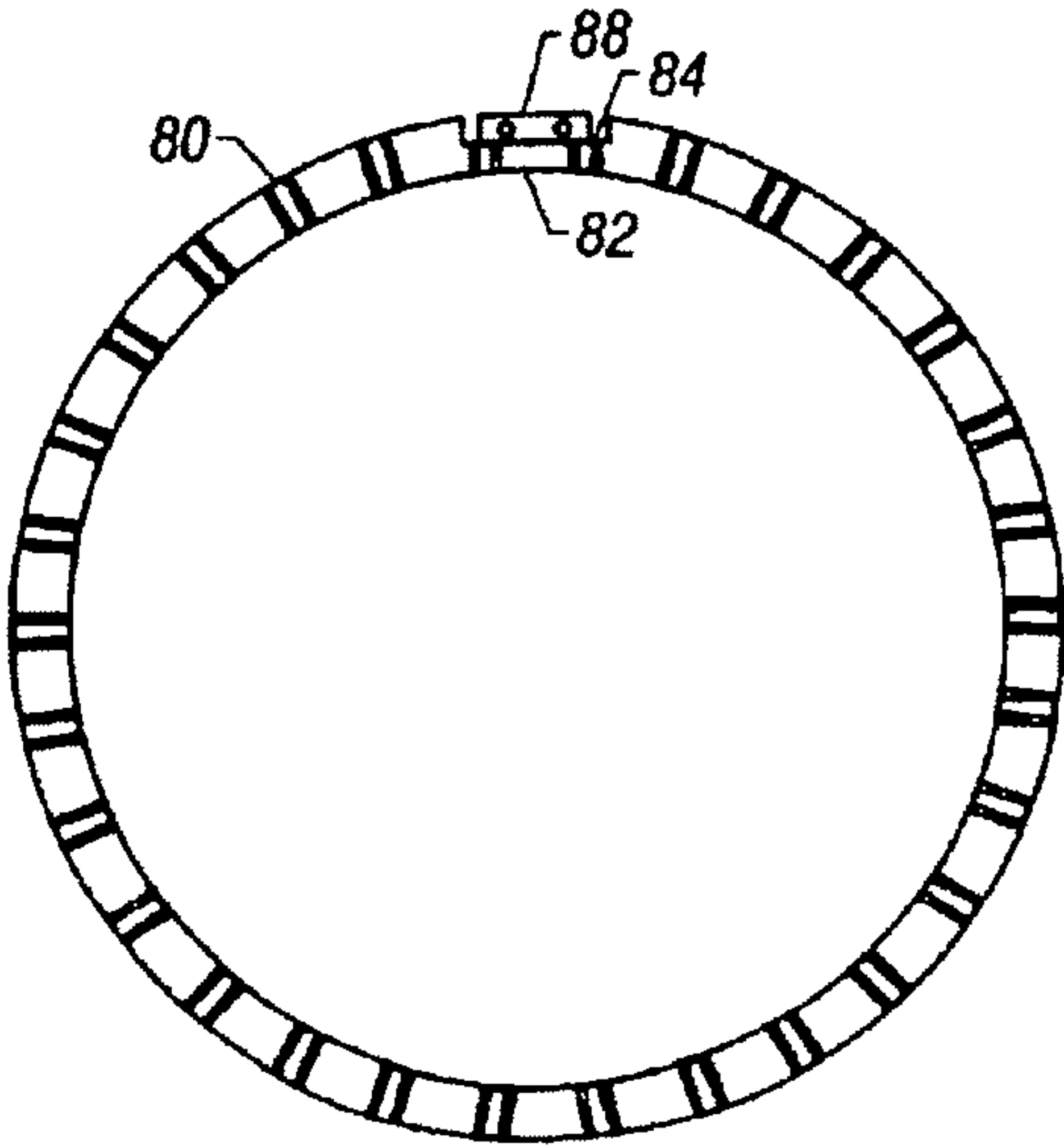
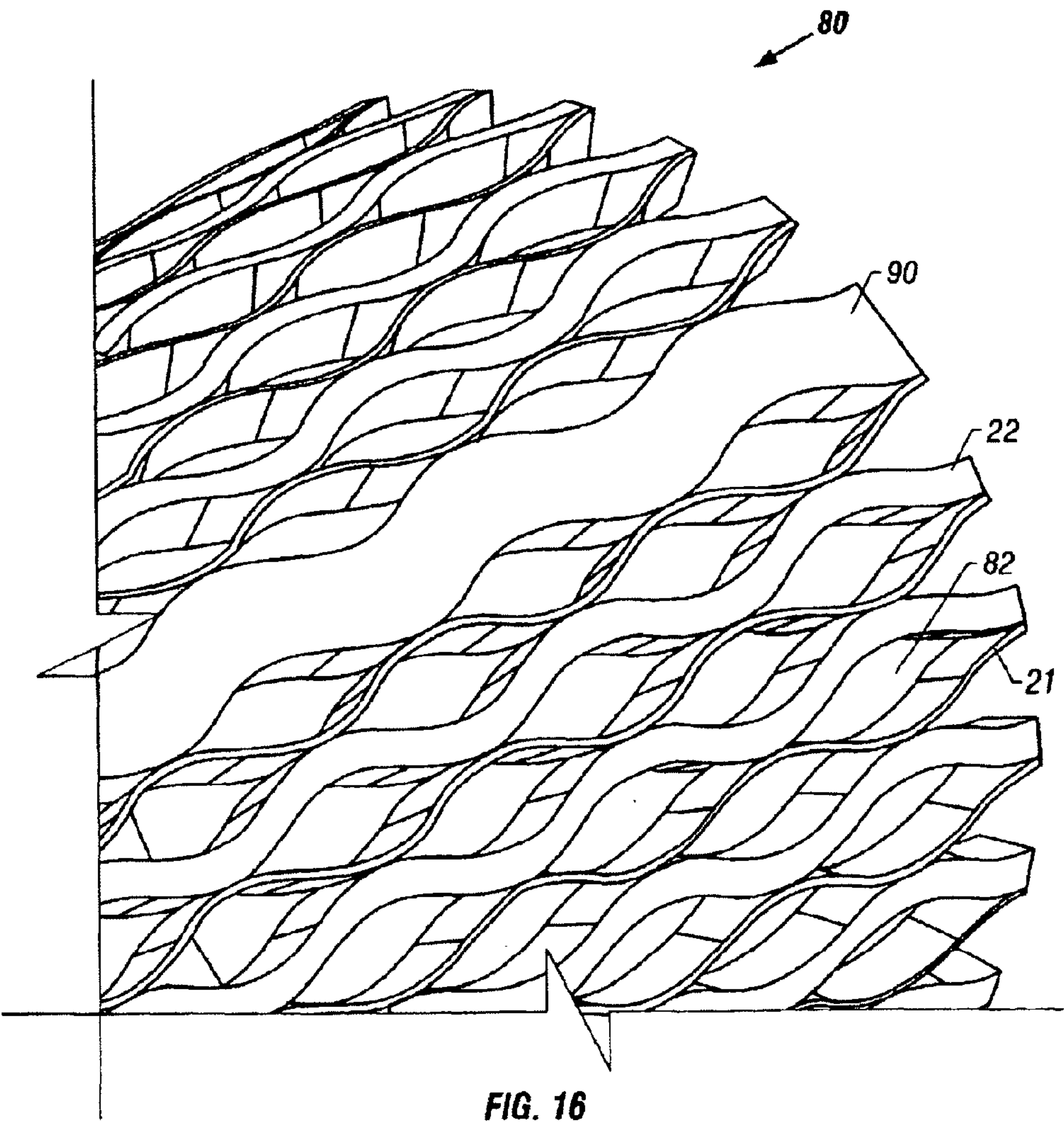


FIG. 15A





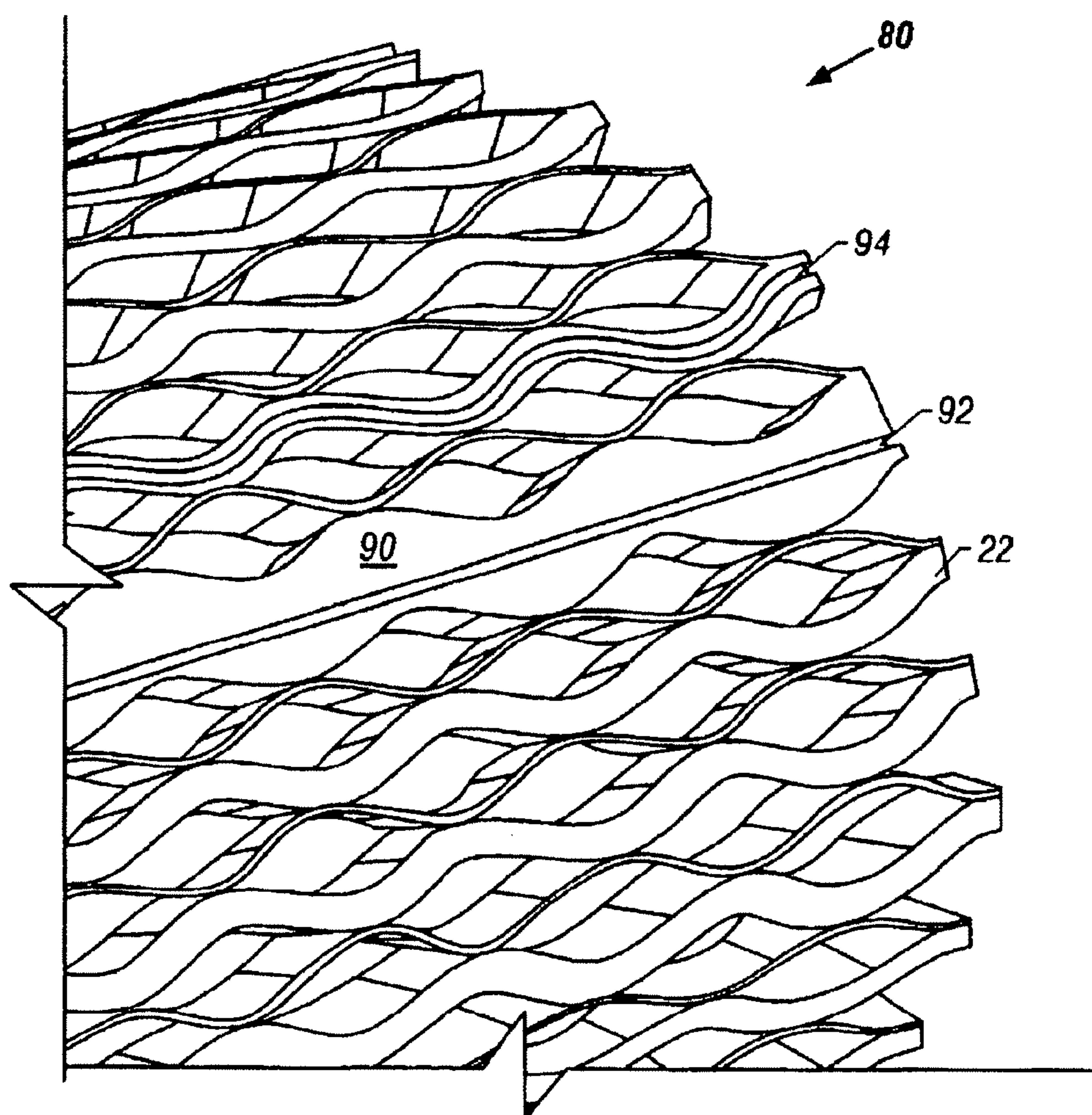
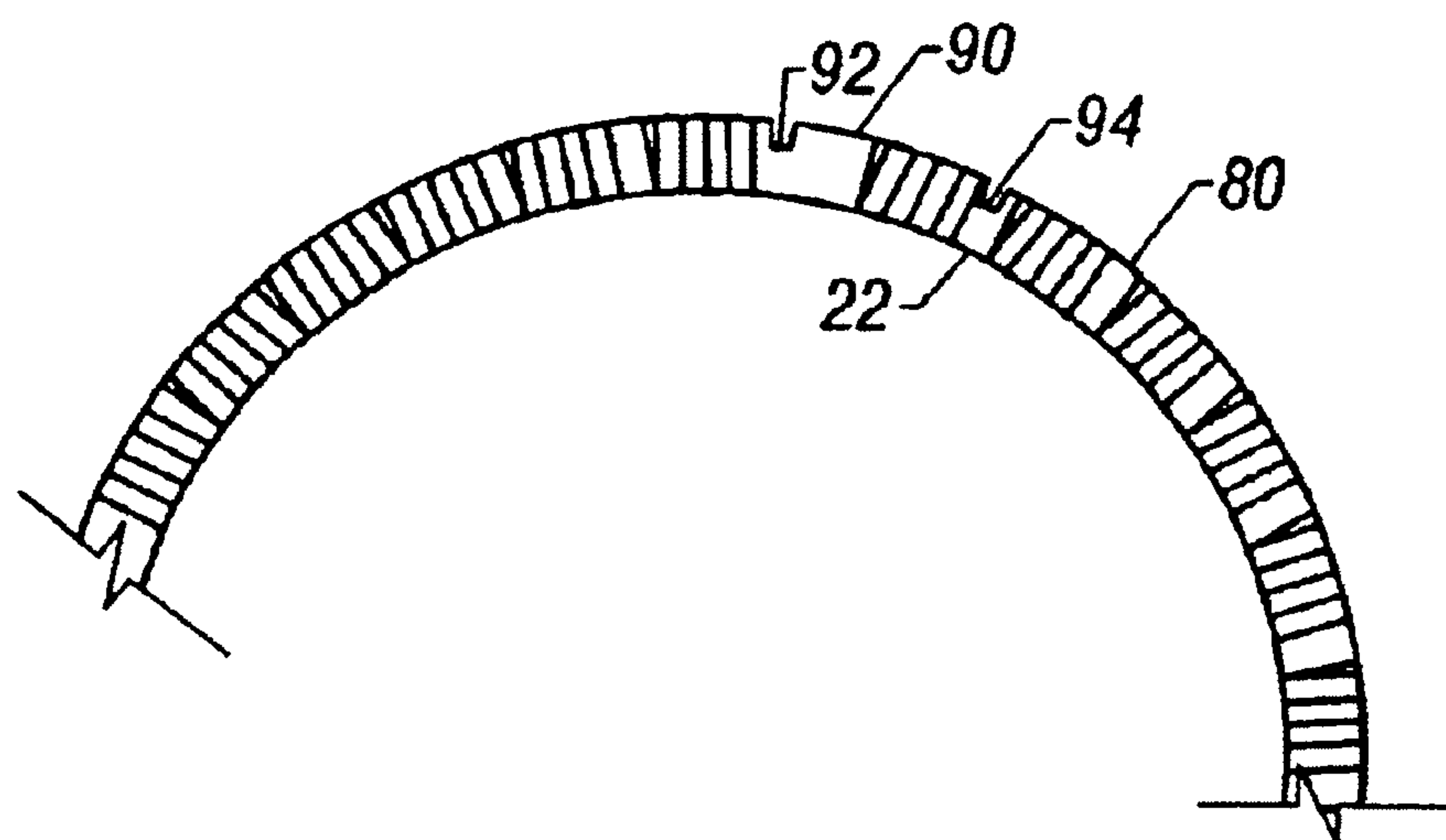
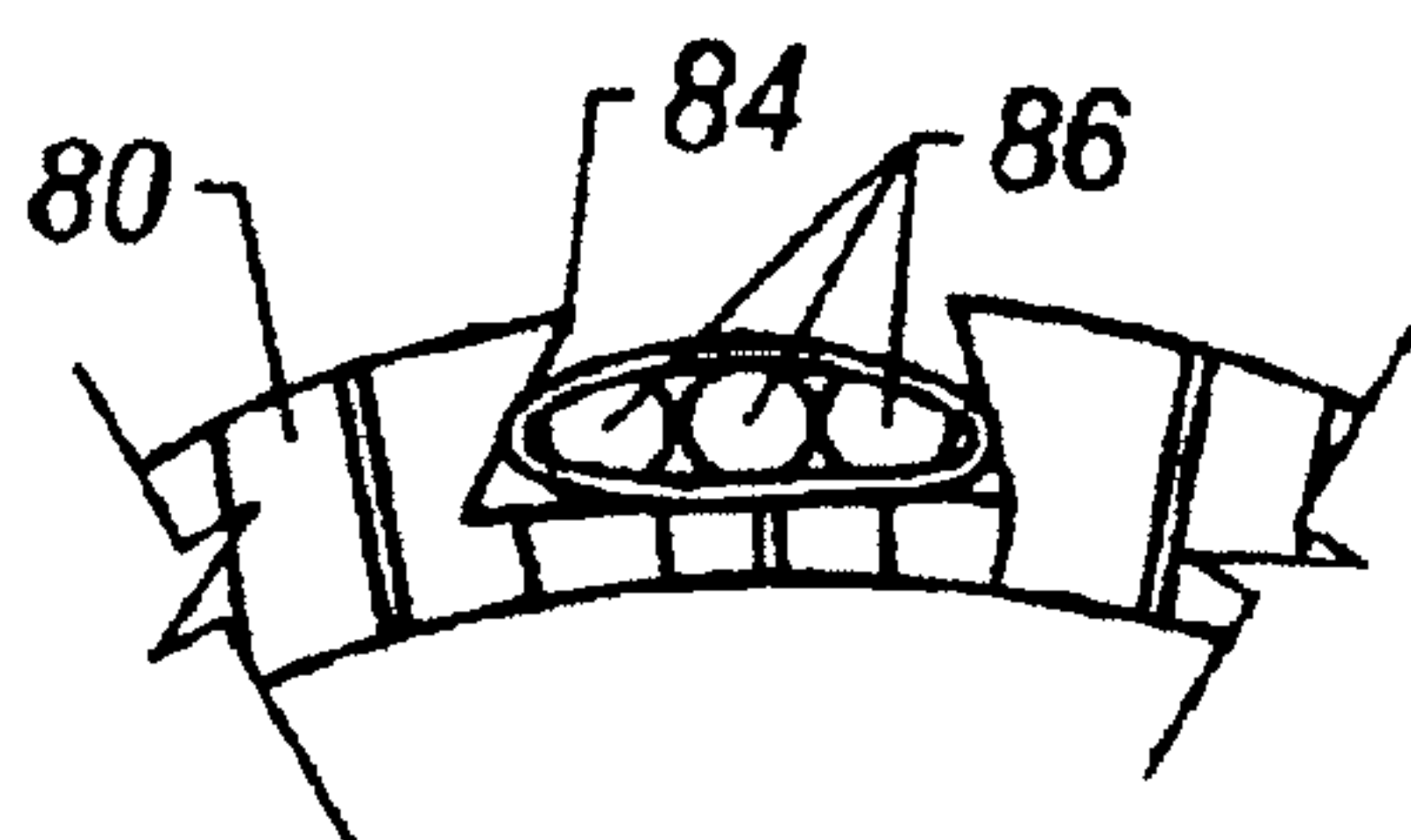


FIG. 17A





**FIG. 17B**



**FIG. 18**

## EXPANDABLE TUBING AND METHOD

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

## CROSS REFERENCE TO RELATED APPLICATIONS

The following is based on and claims the priority of provisional application No. 60/242,276 filed Oct. 20, 2000 and provisional application No. 60/263,941 filed Jan. 24, 2001.

## FIELD OF THE INVENTION

This invention relates to equipment that can be used in the drilling and completion of wellbores in an underground formation and in the production of fluids from such wells.

## BACKGROUND OF THE INVENTION

Fluids such as oil, natural gas and water are obtained from a subterranean geologic formation (a "reservoir") by drilling a well that penetrates the fluid-bearing formation. Once the well has been drilled to a certain depth the borehole wall must be supported to prevent collapse. Conventional well drilling methods involve the installation of a casing string and cementing between the casing and the borehole to provide support for the borehole structure. After cementing a casing string in place, the drilling to greater depths can commence. After each subsequent casing string is installed, the next drill bit must pass through the inner diameter of the casing. In this manner each change in casing requires a reduction in the borehole diameter. This repeated reduction in the borehole diameter creates a need for very large initial borehole diameters to permit a reasonable pipe diameter at the depth where the wellbore penetrates the producing formation. The need for larger boreholes and multiple casing strings results in more time, material and expense being used than if a uniform size borehole could be drilled from the surface to the producing formation.

Various methods have been developed to stabilize or complete uncased boreholes. U.S. Pat. No. 5,348,095 to Worrall et al. discloses a method involving the radial expansion of a casing string to a configuration with a larger diameter. Very large forces are needed to impart the radial deformation desired in this method. In an effort to decrease the forces needed to expand the casing string, methods that involve expanding a liner that has longitudinal slots cut into it have been proposed (U.S. Pat. Nos. 5,366,012 and 5,667,011). These methods involve the radial deformation of the slotted liner into a configuration with an increased diameter by running an expansion mandrel through the slotted liner. These methods still require significant amounts of force to be applied throughout the entire length of the slotted liner.

A problem sometimes encountered while drilling a well is the loss of drilling fluids into subterranean zones. The loss of drilling fluids usually leads to increased expenses but can result in a borehole collapse and a costly "fishing" job to recover the drill string or other tools that were in the well. Various additives are commonly used within the drilling fluids to help seal off loss circulation zones, such as cottonseed hulls or synthetic fibers.

Once a well is put in production an influx of sand from the producing formation can lead to undesired fill within the

wellbore and can damage valves and other production related equipment. Many methods have been attempted for sand control.

The present invention is directed to overcoming, or at least reducing the effects of one or more of the problems set forth above, and can be useful in other applications as well.

## SUMMARY OF THE INVENTION

According to the present invention, a technique is provided for use of an expandable bistable device in a borehole. The bistable device is stable in a first contracted configuration and a second expanded configuration. An exemplary device is generally tubular, having a larger diameter in the expanded configuration than in the contracted configuration. The technique also may utilize a conveyance mechanism able to transport the bistable device to a location in a subterranean borehole. Furthermore, the bistable device can be constructed in various configurations for a variety of applications.

## BRIEF DESCRIPTION OF THE DRAWINGS

The invention will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

FIGS. 1A and 1B are illustrations of the forces imposed to make a bistable structure;

FIGS. 2A and 2B show force-deflection curves of two bistable structures;

FIGS. 3A-3F illustrate expanded and collapsed states of three bistable cells with various thickness ratios;

FIGS. 4A and 4B illustrate a bistable expandable tubular in its expanded and collapsed states;

FIGS. 4C and 4D illustrate a bistable expandable tubular in collapsed and expanded states within a wellbore;

FIGS. 5A and 5B illustrate an expandable packer type of deployment device;

FIGS. 6A and 6B illustrate a mechanical packer type of deployment device;

FIGS. 7A-7D illustrate an expandable swage type of deployment device;

FIGS. 8A-8D illustrate a piston type of deployment device;

FIGS. 9A and 9B illustrate a plug type of deployment device;

FIGS. 10A and 10B illustrate a ball type of deployment device;

FIG. 11 is a schematic of a wellbore utilizing an expandable bistable tubular;

FIG. 12 illustrates a motor driven radial roller deployment device; and

FIG. 13 illustrates a hydraulically driven radial roller deployment device.

FIG. 14 illustrates a bistable expandable tubular having a wrapping;

FIG. 14A is a view similar to FIG. 14 in which the wrapping comprises a screen;

FIG. 14B is a view similar to FIG. 14 showing another alternate embodiment;

FIG. 14C is a view similar to FIG. 14 showing another alternate embodiment;

FIG. 14D is a view similar to FIG. 14 showing another alternate embodiment;

FIG. 14E is a view similar to FIG. 14 showing another alternate embodiment;

FIG. 15 is a perspective view of an alternative embodiment of the present invention.



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FIG. 15A is a cross-sectional view of an alternative embodiment of the present invention.

FIG. 16 is a partial perspective view of an alternative embodiment of the present invention.

FIGS. 17A-B are a partial perspective view and a partial cross-sectional end view respectively of an alternative embodiment of the present invention.

FIG. 18 is a partial cross-sectional end view of an alternative embodiment of the present invention.

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the invention to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

#### DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Bistable devices used in the present invention can take advantage of a principle illustrated in FIGS. 1A and 1B. FIG. 1A shows a rod 10 fixed at each end to rigid supports 12. If the rod 10 is subjected to an axial force it begins to deform as shown in FIG. 1B. As the axial force is increased rod 10 ultimately reaches its Euler buckling limit and deflects to one of the two stable positions shown as 14 and 15. If the buckled rod is now clamped in the buckled position, a force at right angles to the long axis can cause the rod to move to either of the stable positions but to no other position. When the rod is subjected to a lateral force it must move through an angle  $\beta$  before deflecting to its new stable position.

Bistable systems are characterized by a force deflection curve such as those shown in FIGS. 2A and 2B. The externally applied force 16 causes the rod 10 of FIG. 1B to move in the direction X and reaches a maximum 18 at the onset of shifting from one stable configuration to the other. Further deflection requires less force because the system now has a negative spring rate and when the force becomes zero the deflection to the second stable position is spontaneous.

The force deflection curve for this example is symmetrical and is illustrated in FIG. 2A. By introducing either a precurvature to the rod or an asymmetric cross section the force deflection curve can be made asymmetric as shown in FIG. 2B. In this system the force 19 required to cause the rod to assume one stable position is greater than the force 20 required to cause the reverse deflection. The force 20 must be greater than zero for the system to have bistable characteristics.

Bistable structures, sometimes referred to as toggle devices, have been used in industry for such devices as flexible discs, over center clamps, hold-down devices and quick release systems for tension cables (such as in sailboat rigging backstays).

Instead of using the rigid supports as shown in FIGS. 1A and 1B, a cell can be constructed where the restraint is provided by curved struts connected at each end as shown in FIGS. 3A-3F. If both struts 21 and 22 have the same thickness as shown in FIGS. 3A and 3B, the force deflection curve is linear and the cell lengthens when compressed from its open position FIG. 3B to its closed position FIG. 3A. If the cell struts have different thicknesses, as shown in FIGS. 3C-3F, the cell has the force deflection characteristics shown in FIG. 2B, and does not change in length when it moves between its two stable positions. An expandable bistable tubular can thus

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be designed so that as the radial dimension expands, the axial length remains constant. In one example, if the thickness ratio is over approximately 2:1, the heavier strut resists longitudinal changes. By changing the ratio of thick-to-thin strut dimensions, the opening and closing forces can be changed. For example, FIGS. 3C and 3D illustrated a thickness ratio of approximately 3:1, and FIGS. 3E and 3F illustrate a thickness ratio of approximately 6:1.

An expandable bore bistable tubular, such as casing, a tube, a patch, or pipe, can be constructed with a series of circumferential bistable connected cells 23 as shown in FIGS. 4A and 4B, where each thin strut 21 is connected to a thick strut 22. The longitudinal flexibility of such a tubular can be modified by changing the length of the cells and by connecting each row of cells with a compliant link. Further, the force deflection characteristics and the longitudinal flexibility can also be altered by the design of the cell shape. FIG. 4A illustrates an expandable bistable tubular 24 in its expanded configuration while FIG. 4B illustrates the expandable bistable tubular 24 in its contracted or collapsed configuration. Within this application the term "collapsed" is used to identify the configuration of the bistable element or device in the stable state with the smallest diameter, it is not meant to imply that the element or device is damaged in any way. In the collapsed state, bistable tubular 24 is readily introduced into a wellbore 29, as illustrated in FIG. 4C. Upon placement of the bistable tubular 24 at a desired wellbore location, it is expanded, as illustrated in FIG. 4D.

The geometry of the bistable cells is such that the tubular cross-section can be expanded in the radial direction to increase the overall diameter of the tubular. As the tubular expands radially, the bistable cells deform elastically until a specific geometry is reached. At this point the bistable cells move, e.g. snap, to a final expanded geometry. With some materials and/or bistable cell designs, enough energy can be released in the elastic deformation of the cell (as each bistable cell snaps past the specific geometry) that the expanding cells are able to initiate the expansion of adjoining bistable cells past the critical bistable cell geometry. Depending on the deflection curves, a portion or even an entire length of bistable expandable tubular can be expanded from a single point.

In like manner if radial compressive forces are exerted on an expanded bistable tubular, it contracts radially and the bistable cells deform elastically until a critical geometry is reached. At this point the bistable cells snap to a final collapsed structure. In this way the expansion of the bistable tubular is reversible and repeatable. Therefore the bistable tubular can be a reusable tool that is selectively changed between the expanded state as shown in FIG. 4A and the collapsed state as shown in FIG. 4B.

In the collapsed state, as in FIG. 4B, the bistable expandable tubular is easily inserted into the wellbore and placed into position. A deployment device is then used to change the configuration from the collapsed state to the expanded state.

In the expanded state, as in FIG. 4A, design control of the elastic material properties of each bistable cell can be such that a constant radial force can be applied by the tubular wall to the constraining wellbore surface. The material properties and the geometric shape of the bistable cells can be designed to give certain desired results.

One example of designing for certain desired results is an expandable bistable tubular string with more than one diameter throughout the length of the string. This can be useful in boreholes with varying diameters, whether designed that way or as a result of unplanned occurrences such as formation washouts or keyseats within the borehole. This also can be beneficial when it is desired to have a portion of the bistable



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expandable device located inside a cased section of the well while another portion is located in an uncased section of the well. FIG. 11 illustrates one example of this condition. A wellbore 40 is drilled from the surface 42 and comprises a cased section 44 and an openhole section 46. An expandable

bistable device 48 having segments 50, 52 with various diameters is placed in the well. The segment with a larger diameter 50 is used to stabilize the openhole section 46 of the well, while the segment having a reduced diameter 52 is located inside the cased section 44 of the well.

Bistable collars or connectors 24A (see FIG. 4C) can be designed to allow sections of the bistable expandable tubular to be joined together into a string of useful lengths using the same principle as illustrated in FIG. 4A and 4B. This bistable connector 24A also incorporates a bistable cell design that allows it to expand radially using the same mechanism as for the bistable expandable tubular component. Exemplary bistable connectors have a diameter slightly larger than the expandable tubular sections that are being joined. The bistable connector is then placed over the ends of the two sections and mechanically attached to the expandable tubular sections. Mechanical fasteners such as screws, rivets or bands can be used to connect the connector to the tubular sections. The bistable connector typically is designed to have an expansion rate that is compatible with the expandable tubular sections, so that it continues to connect the two sections after the expansion of the two segments and the connector.

Alternatively, the bistable connector can have a diameter smaller than the two expandable tubular sections joined. Then, the connector is inserted inside of the ends of the tubulars and mechanically fastened as discussed above. Another embodiment would involve the machining of the ends of the tubular sections on either their inner or outer surfaces to form an annular recess in which the connector is located. A connector designed to fit into the recess is placed in the recess. The connector would then be mechanically attached to the ends as described above. In this way the connector forms a relatively flush-type connection with the tubular sections.

A conveyance device 31 transports the bistable expandable tubular lengths and bistable connectors into the wellbore and to the correct position. (See FIGS. 4C and 4D). The conveyance device may utilize one or more mechanisms such as wireline cable, coiled tubing, coiled tubing with wireline conductor, drill pipe, tubing or casing.

A deployment device 33 can be incorporated into the bottom hole assembly to expand the bistable expandable tubular and connectors. (See FIGS. 4C and 4D). Deployment devices can be of numerous types such as an inflatable packer element, a mechanical packer element, an expandable swage, a piston apparatus, a mechanical actuator, an electrical solenoid, a plug type apparatus, e.g. a conically shaped device pulled or pushed through the tubing, a ball type apparatus or a rotary type expander as further discussed below.

An inflatable packer element is shown in FIGS. 5A and 5B and is a device with an inflatable bladder, element, or bellows incorporated into the bistable expandable tubular system bottom hole assembly. In the illustration of FIG. 5A, the inflatable packer element 25 is located inside the entire length, or a portion, of the initial collapsed state bistable tubular 24 and any bistable expandable connectors (not shown). Once the bistable expandable tubular system is at the correct deployment depth, the inflatable packer element 25 is expanded radially by pumping fluid into the device as shown in FIG. 5B. The inflation fluid can be pumped from the surface through tubing or drill pipe, a mechanical pump, or via a downhole electrical pump which is powered via wireline cable. As the

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inflatable packer element 25 expands, it forces the bistable expandable tubular 24 to also expand radially. At a certain expansion diameter, the inflatable packer element causes the bistable cells in the tubular to reach a critical geometry where the bistable "snap" effect is initiated, and the bistable expandable tubular system expands to its final diameter. Finally the inflatable packer element 25 is deflated and removed from the deployed bistable expandable tubular 24.

A mechanical packer element is shown in FIGS. 6A and 6B and is a device with a deformable plastic element 26 that expands radially when compressed in the axial direction. The force to compress the element can be provided through a compression mechanism 27, such as a screw mechanism, cam, or a hydraulic piston. The mechanical packer element deploys the bistable expandable tubulars and connectors in the same way as the inflatable packer element. The deformable plastic element 26 applies an outward radial force to the inner circumference of the bistable expandable tubulars and connectors, allowing them in turn to expand from a contracted position (see FIG. 6A) to a final deployment diameter (see FIG. 6B).

An expandable swage is shown in FIGS. 7A-7D and comprises a series of fingers 28 that are arranged radially around a conical mandrel 30. FIGS. 7A and 7C show side and top views respectively. When the mandrel 30 is pushed or pulled through the fingers 28 they expand radially outwards, as illustrated in FIGS. 7B and 7D. An expandable swage is used in the same manner as a mechanical packer element to deploy a bistable expandable tubular and connector.

A piston type apparatus is shown in FIGS. 8A-8D and comprises a series of pistons 32 facing radially outwardly and used as a mechanism to expand the bistable expandable tubulars and connectors. When energized, the pistons 32 apply a radially directed force to deploy the bistable expandable tubular assembly as per the inflatable packer element. FIGS. 8A and 8C illustrate the pistons retracted while FIGS. 8B and 8D show the pistons extended. The piston type apparatus can be actuated hydraulically, mechanically or electrically.

A plug type actuator is illustrated in FIGS. 9A and 9B and comprises a plug 34 that is pushed or pulled through the bistable expandable tubulars 24 or connectors as shown in FIG. 9A. The plug is sized to expand the bistable cells past their critical point where they will snap to a final expanded diameter as shown in FIG. 9B.

A ball type actuator is shown in FIGS. 10A and 10B and operates when an oversized ball 36 is pumped through the middle of the bistable expandable tubulars 24 and connectors. To prevent fluid losses through the cell slots, an expandable elastomer based liner 38 is run inside the bistable expandable tubular system. The liner 38 acts as a seal and allows the ball 36 to be hydraulically pumped through the bistable tubular 24 and connectors. The effect of pumping the ball 36 through the bistable expandable tubulars 24 and connectors is to expand the cell geometry beyond the critical bistable point, allowing full expansion to take place as shown in FIG. 10B. Once the bistable expandable tubulars and connectors are expanded, the elastomer sleeve 38 and ball 36 are withdrawn.

Radial roller type actuators also can be used to expand the bistable tubular sections. FIG. 12 illustrates a motor driven expandable radial roller tool. The tool comprises one or more sets of arms 58 that are expanded to a set diameter by means of a mechanism and pivot. On the end of each set of arms is a roller 60. Centralizers 62 can be attached to the tool to locate it correctly inside the wellbore and the bistable tubular 24. A motor 64 provides the force to rotate the whole assembly, thus turning the roller(s) circumferentially inside the wellbore. The axis of the roller(s) is such as to allow the roller(s) to



rotate freely when brought into contact with the inner surface of the tubular. Each roller can be conically-shaped in section to increase the contact area of roller surface to the inner wall of the tubular. The rollers are initially retracted and the tool is run inside the collapsed bistable tubular. The tool is then rotated by the motor **64**, and rollers **60** are moved outwardly to contact the inner surface of the bistable tubular. Once in contact with the tubular, the rollers are pivoted outwardly a greater distance to apply an outwardly radial force to the bistable tubular. The outward movement of the rollers can be accomplished via centrifugal force or an appropriate actuator mechanism coupled between the motor **64** and the rollers **60**.

The final pivot position is adjusted to a point where the bistable tubular can be expanded to the final diameter. The tool is then longitudinally moved through the collapsed bistable tubular, while the motor continues to rotate the pivot arms and rollers. The rollers follow a shallow helical path **66** inside the bistable tubular, expanding the bistable cells in their path. Once the bistable tubular is deployed, the tool rotation is stopped and the roller retracted. The tool is then withdrawn from the bistable tubular by a conveyance device **68** that also can be used to insert the tool.

FIG. **13** illustrates a hydraulically driven radial roller deployment device. The tool comprises one or more rollers **60** that are brought into contact with the inner surface of the bistable tubular by means of a hydraulic piston **70**. The outward radial force applied by the rollers can be increased to a point where the bistable tubular expands to its final diameter. Centralizers **62** can be attached to the tool to locate it correctly inside the wellbore and bistable tubular **24**. The rollers **60** are initially retracted and the tool is run into the collapsed bistable tubular **24**. The rollers **60** are then deployed and push against the inside wall of the bistable tubular **24** to expand a portion of the tubular to its final diameter. The entire tool is then pushed or pulled longitudinally through the bistable tubular **24** expanding the entire length of bistable cells **23**. Once the bistable tubular **24** is deployed in its expanded state, the rollers **60** are retracted and the tool is withdrawn from the wellbore by the conveyance device **68** used to insert it. By altering the axis of the rollers **60**, the tool can be rotated via a motor as it travels longitudinally through the bistable tubular **24**.

Power to operate the deployment device can be drawn from one or a combination of sources such as: electrical power supplied either from the surface or stored in a battery arrangement along with the deployment device, hydraulic power provided by surface or downhole pumps, turbines or a fluid accumulator, and mechanical power supplied through an appropriate linkage actuated by movement applied at the surface or stored downhole such as in a spring mechanism.

The bistable expandable tubular system is designed so the internal diameter of the deployed tubular is expanded to maintain a maximum cross-sectional area along the expandable tubular. This feature enables mono-bore wells to be constructed and facilitates elimination of problems associated with traditional wellbore casing systems where the casing outside diameter must be stepped down many times, restricting access, in long wellbores.

The bistable expandable tubular system can be applied in numerous applications such as an expandable open hole liner (see FIG. **14**) where the bistable expandable tubular **24** is used to support an open hole formation by exerting an external radial force on the wellbore surface. As bistable tubular **24** is radially expanded in the direction of arrows **71**, the tubular moves into contact with the surface forming wellbore **29**. These radial forces help stabilize the formations and allow the drilling of wells with fewer conventional casing strings. The

open hole liner also can comprise a material, e.g. a wrapping **72**, that reduces the rate of fluid loss from the wellbore into the formations. The wrapping **72** can be made from a variety of materials including expandable metallic and/or elastomeric materials. By reducing fluid loss into the formations, the expense of drilling fluids can be reduced and the risk of losing circulation and/or borehole collapse can be minimized.

Liners also can be used within wellbore tubulars for purposes such as corrosion protection. One example of a corrosive environment is the environment that results when carbon dioxide is used to enhance oil recovery from a producing formation. Carbon dioxide ( $\text{CO}_2$ ) readily reacts with any water ( $\text{H}_2\text{O}$ ) that is present to form carbonic acid ( $\text{H}_2\text{CO}_3$ ). Other acids can also be generated, especially if sulfur compounds are present. Tubulars used to inject the carbon dioxide as well as those used in producing wells are subject to greatly elevated corrosion rates. The present invention can be used for placing protective liners, a bistable tubular **24**, within an existing tubular (e.g. tubular **73** illustrated with dashed lines in FIG. **14**) to minimize the corrosive effects and to extend the useful life of the wellbore tubulars.

Another application involves use of the bistable tubular **24** illustrated in FIG. **14** as an expandable perforated liner. The open bistable cells in the bistable expandable tubular allow unrestricted flow from the formation while providing a structure to stabilize the borehole.

Still another application of the bistable tubular **24** is as an expandable sand screen where the bistable cells are sized to act as a sand control screen or an expandable screen element **74** can be affixed to the bistable expandable tubular as illustrated in FIG. **14A** in its collapsed state. The expandable screen element **74** can be formed as a wrapping around bistable tubular **24**. It has been found that the imposition of hoop stress forces onto the wall of a borehole will in itself help stabilize the formation and reduce or eliminate the influx of sand from the producing zones, even if no additional screen element is used.

Another application of the bistable tubular **24** is as a reinforced expandable liner where the bistable expandable tubular cell structure is reinforced with a cement or resin **75**, as illustrated in FIG. **14B**. The cement or resin **75** provides increased structural support or hydraulic isolation from the formation.

The bistable expandable tubular **24** also can be used as an expandable connection system to join traditional lengths of casing **76a** or **76b** of different diameters as illustrated in FIG. **14C**. The tubular **24** also can be used as a structural repair joint to provide increased strength for existing sections of casing.

Another application includes using the bistable expandable tubular **24** as an anchor within the wellbore from which other tools or casings can be attached, or as a "fishing" tool in which the bistable characteristics are utilized to retrieve items lost or stuck in a wellbore. The bistable expandable tubular **24** in its collapsed configuration is inserted into a lost item **77** and then expanded as indicated by arrows **78** in FIG. **14D**. In the expanded configuration the bistable tubular exerts radial forces that assist in retrieving the lost item. The bistable tubular also can be run into the well in its expanded configuration, placed over and collapsed in the direction of arrows **79** around lost item **77** in an attempt to attach and retrieve it as illustrated in FIG. **14E**. Once lost item **77** is gripped by bistable tubular **24**, it can be retrieved through wellbore **29**.

The above described bistable expandable tubulars can be made in a variety of manners such as: cutting appropriately shaped paths through the wall of a tubular pipe thereby creating an expandable bistable device in its collapsed state;



cutting patterns into a tubular pipe thereby creating an expandable bistable device in its expanded state and then compressing the device into its collapsed state; cutting appropriate paths through a sheet of material, rolling the material into a tubular shape and joining the ends to form an expandable bistable device in its collapsed state; or cutting patterns into a sheet of material, rolling the material into a tubular shape, joining the adjoining ends to form an expandable bistable device in its expanded state and then compressing the device into its collapsed state.

The materials of construction for the bistable expandable tubulars can include those typically used within the oil and gas industry such as carbon steel. They can also be made of specialty alloys (such as a monel, inconel, hastelloy or tungsten-based alloys) if the application requires.

The configurations shown for the bistable tubular **24** are illustrative of the operation of a basic bistable cell. Other configurations may be suitable, but the concept presented is also valid for these other geometries.

FIG. **15** illustrates an expandable tubing **80** formed of bi-stable cells **82**. The tubing **80** defines a thinned portion **84** (best seen in FIG. **15**) which may be in the form of a slot, as shown, a flattening, or other thinning of a portion of the tubing **80**. The thinned portion **84** extends generally longitudinally and may be linear, helical, or follow some other circuitous path. In one embodiment, the thinned portion extends from one end of the tubing to the other to provide a communication line path **84** for the tubing **80**. In such an embodiment, a communication line **86** may pass through the communication line path **84** along the tubing **80**. In this way, the communication line **86** stays within the general outside diameter of the tubing **80** or extends only slightly outside this diameter. Although the tubing is shown with one thinned portion **84**, it may include a plurality that are spaced about the circumference of the tubing **80**. The thinned portion **84** may be used to house a conduit (not shown) through which communication lines **86** pass or which is used for the transport of fluids or other materials, such as mixtures of fluids and solids.

As used herein, the term "communication line" refers to any type of communication line such as electric, hydraulic, fiber optic, combinations of these, and the like.

FIG. **15A** illustrates an exemplary thinned portion **84** designed to receive a device **88**. As with the cable **60** placement, device **88** is at least partially housed in the thinned portion of the tubing **80** so that the extent to which it extends beyond the outer diameter of the tubing **80** is lessened. Examples of certain alternative embodiments of devices **88** are electrical devices, measuring devices, meters, gauges, sensors. More specific examples comprise valves, sampling devices, a device used in intelligent or smart well completion, temperature sensors, pressure sensors, flow-control devices, flow rate measurement devices, oil/water/gas ratio measurement devices, scale detectors, equipment sensors (e.g., vibration sensors), sand detection sensors, water detection sensors, data recorders, viscosity sensors, density sensors, bubble point sensors, composition sensors, resistivity array devices and sensors, acoustic devices and sensors, other telemetry devices, near infrared sensors, gamma ray detectors, H<sub>2</sub>S detectors, CO<sub>2</sub> detectors, downhole memory units, downhole controllers. Examples of measurements that the devices might make are flow rate, pressure, temperature, differential pressure, density, relative amounts of liquid, gas, and solids, water cut, oil-water ratio, and other measurements.

As shown in the figure, the device **88** may be exposed to fluid inside and outside of tubing **80** via openings formed by the cells **82**. Thus, the thinned portion **84** may bridge openings as well as linkages **21**, **22** of the cells **82**. Also note that

the communication line **86** and associated communication line path **84** may extend a portion of the length of the tubing **80** in certain alternative designs. For example, if a device **88** is placed intermediate the ends of the tubing **80**, the communication line passageway **84** may only need to extend from an end of the tubing to the position of the device **80**.

FIG. **16** illustrates an expandable tubing **80** formed of bi-stable cells **82** having thin struts **21** and thick struts **22**. At least one of the thick struts (labeled as **90**) is relatively wider than other struts of the tubing **80**. The wider strut **90** may be used for various purposes such as routing of communication lines, including cables, or devices, such as sensor arrays.

FIGS. **17A** and **17B** illustrate tubing **80** having a strut **90** that is relatively wider than the other thick struts **22**. A passageway **92** formed in the strut **90** facilitates placement of a communication line in the well and through the tubing **80** and may be used for other purposes. FIG. **17B** is a cross sectional view showing the passageway **92**. Passageway **92** is an alternative embodiment of a communication line path **84**. A passageway **94** may be configured to generally follow the curvature of a strut, e.g. one of the thick struts **22**, as further illustrated in FIGS. **17A** and **17B**.

FIG. **18** illustrates a thinned portion **84** having a dovetail design with a relatively narrower opening. The communication line **86** is formed so that it fits through the relatively narrow opening into the wider, lower portion, e.g. by inserting one side edge and then the other. Communication line **86** is held in place due to the dovetail design as is apparent from the figures. The width of the communication line **86** is greater than the width of the opening. Note that the communication line **86** may comprise a bundle of lines which may be of the same or different forms (e.g., a hydraulic, an electric, and a fiber optic line bundled together). Also, connectors for connecting adjacent tubings may incorporate a connection for the communication lines.

Note that the communication line passageway **84** may be used in conjunction with other types of expandable tubings, such as those of the expandable slotted liner type disclosed in U.S. Pat. No. 5,366,012, issued Nov. 22, 1994 to Lohbeck, the folded tubing types of U.S. Pat. No. 3,489,220, issued Jan. 13, 1970 to Kinley, U.S. Pat. No. 5,337,823, issued Aug. 16, 1994 to Nobileau, U.S. Pat. No. 3,203,451, issued Aug. 31, 1965 to Vincent.

The particular embodiments disclosed herein are illustrative only, as the invention may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the invention. Accordingly, the protection sought herein is as set forth in the claims below.

What is claimed is:

- [1. An apparatus for use in a wellbore, comprising: an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration, wherein each cell comprises a first member and a second member, the first member and the second member each comprising a mid-point and two ends, and further wherein the first member is more flexible than the second member.]



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[2. The apparatus as recited in claim 2, wherein the first and second members are mechanically connected such that the second member hinders deformation of the first member.]

[3. The apparatus as recited in claim 1, wherein the first member has two stable positions, the first stable position being where the first member mid-point is adjacent to the second member mid-point, the second stable position being where the first member mid-point is displaced from the second member mid-point to form a gap between the first member mid-point and the second member mid-point.]

[4. The apparatus as recited in claim 1, wherein the second member has a greater thickness than the first member.]

[5. The apparatus as recited in claim 1, wherein the thickness ratio of the second member to the first member is greater than approximately 3:1.]

6. [The] An apparatus [as recited in claim 1,] for use in a wellbore, comprising:

*an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration,*

*wherein each cell comprises a first member and a second member, the first member and the second member each comprising a mid-point and two ends,*

*wherein the thickness ratio of the second member to the first member is greater than approximately 6:1[,] and further wherein the first member is more flexible than the second member.*

[7. An apparatus for use in a wellborn, comprising:

*an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration,*

*wherein the bistable device further comprises a wrapping attached to the outer surface of the bistable device.]*

8. [A The] An apparatus [as recited in claim 7,] for use in a wellbore, comprising:

*an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration,*

*wherein the bistable device further comprises a wrapping attached to the other surface of the bistable device, and wherein the wrapping comprises an expandable screen.*

[9. The apparatus as recited in claim 7, wherein the wrapping comprises a deformable material.]

[10. The apparatus as recited in claim 9, wherein the deformable material comprises an elastomer.]

11. [The] An apparatus [as recited in claim 10, wherein the] for use in a wellbore, comprising:

*an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration,*

*wherein the bistable device further comprises a wrapping attached to the outer surface of the bistable device, and*

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*wherein the wrapping comprises a deformable material that comprises an elastomer [is] selected to be resistant to crude oils, brines, and acids encountered in oil and gas wells.*

[12. An apparatus for use in a wellbore, comprising:

*an expandable bistable device configured for deployment proximate a wellbore wall, the expandable bistable device having a plurality of bistable cells arranged in a generally tubular shape, the plurality of bistable cells being stable in a collapsed configuration and in an expanded configuration,*

*wherein the bistable device in its second generally tubular configuration comprises a plurality of diameters.]*

[13. A method of stabilizing an uncased section of a wellbore in an underground formation, comprising:

*providing an expandable bistable device having a generally tubular shape that comprises a plurality of bistable cells; placing the bistable device at a position in the wellbore while in a first stable state;*

*radially expanding the bistable device to a second stable state having a generally tubular configuration without substantially reducing axial length; and*

*attaching a wrapping to the outer surface of the bistable device.]*

14. [The] A method [as recited in claim 13,] of stabilizing an uncased section of a wellbore in an underground formation, comprising:

*providing an expandable bistable device having a generally tubular shape that comprises a plurality of bistable cells;*

*placing the bistable device at a position in the wellbore while in a first stable state;*

*radially expanding the bistable device to a second stable state having a generally tubular configuration without substantially reducing axial length; and*

*attaching a wrapping to the outer surface of the bistable device, wherein [attaching comprises attaching] the wrapping comprises an expandable screen.*

15. [The] A method [as recited in claim 13, further comprising] of stabilizing an uncased section of a wellbore in an underground formation, comprising:

*providing an expandable bistable device having a generally tubular shape that comprises a plurality of bistable cells;*

*placing the bistable device at a position in the wellbore while in a first stable state;*

*radially expanding the bistable device to a second stable state having a generally tubular configuration without substantially reducing axial length; and*

*applying a deformable material that comprises an elastomer selected to be resistant to crude oils, brines, and acids encountered in oil and gas wells to the outer surface of the bistable device.*

[16. The method as recited in claim 15, wherein applying comprises applying an elastomeric material.]

[17. The method as recited in claim 13, wherein radially expanding comprises expanding the bistable device to a plurality of final diameters.]

[18. A method for installing liners within a tubular located in a wellbore, comprising:

*forming an expandable bistable device with a plurality of bistable cells, the expandable bistable device having a generally tubular shape;*

*surrounding the expandable bistable device with an expandable liner element attached to an outer surface of the bistable device;*



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placing the expandable bistable device at a position within a tubular while in a first stable state; and  
expanding the expandable bistable device into a second stable state to hold the liner element against an inner diameter of the tubular.]

[19. The method as recited in claim 18, further comprising locating multiple bistable devices in the wellbore such that the ends of the adjacent bistable devices overlap and form a continuation of the liner element against the inner diameter of the tubular.]

[20. The method as recited in claim 18, further comprising creating each bistable cell with a thin strut connected to a thick strut.]

21. A method for facilitating use of a wellbore, comprising: inhibiting sand influx into a wellbore, wherein inhibiting comprises:

placing a bistable device at a desired position in a wellbore; and

expanding the bistable device at least partially through a nonstable range towards a stable state until the bistable device is able to exert hoop stress forces against the wellbore.

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22. The method as recited in claim 21, further comprising attaching a wrapping to an outer surface of the bistable member.

23. The method as recited in claim 22, wherein attaching comprises attaching an expandable screen.

24. A system for facilitating communication along a wellbore, comprising:

an expandable tubing formed of a plurality of bi-stable cells, the expandable tubing having a communication line passageway,

wherein the communication line passageway is defined by a thinned portion along the expandable tubing.

25. A method of routing a communication line in a well, comprising:

deploying an expandable tubing in a well, wherein deploying comprises running an expandable tubing formed of bistable cells into a well;

routing at least a portion of a communication line adjacent at least a portion of the expandable tubing;

expanding the expandable tubing; and

forming the communication line along a thick strut formed between a plurality of bistable cells.

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