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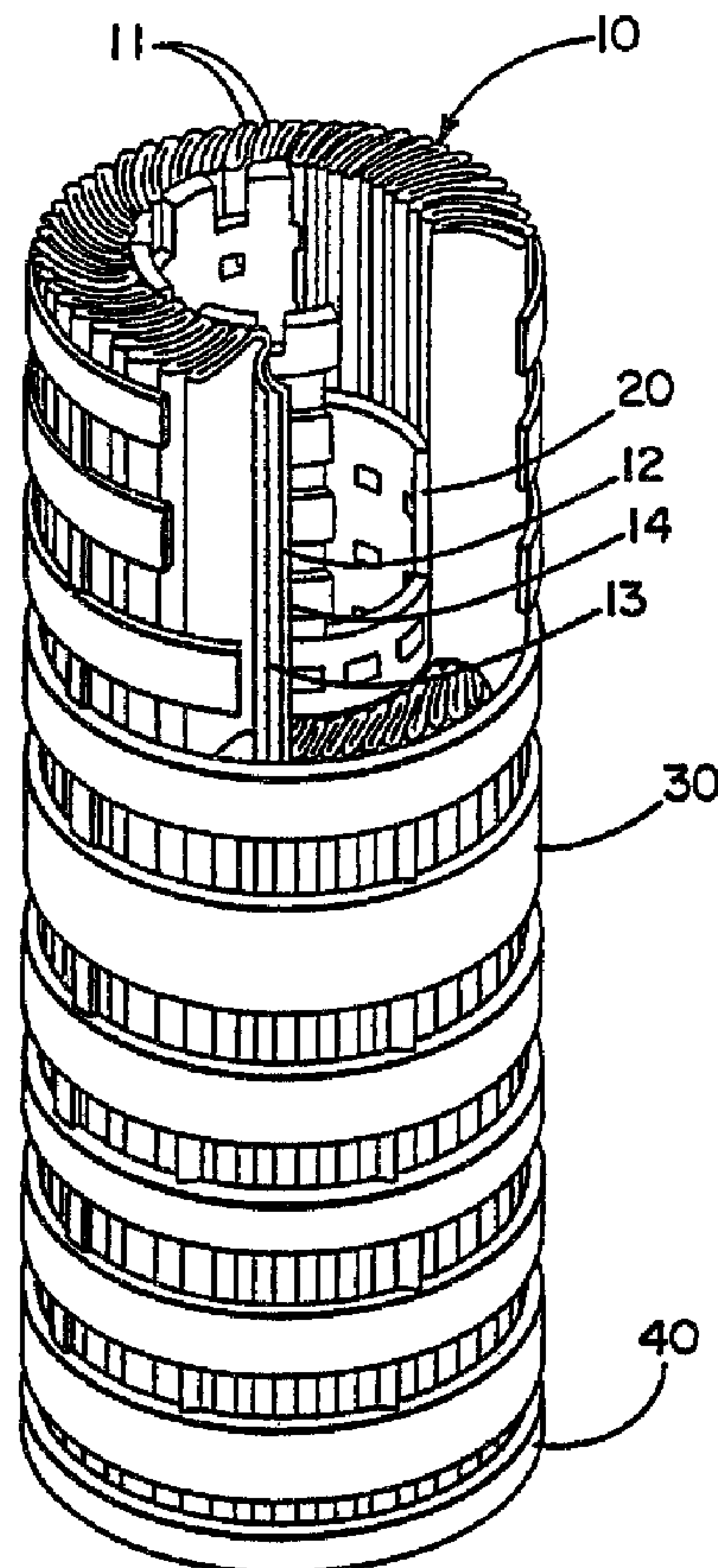
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(57) Abrégé/Abstract:

A filter includes a cylindrical filter element having a longitudinal axis, first and second end surfaces, and a plurality of longitudinal pleats. Each of the pleats has a pair of legs with first and second surfaces. The pleats are in a laid-over state in which the first

**(57) Abrégé(suite)/Abstract(continued):**

surface of each leg is in intimate contact with the first surface of an adjoining leg and the second surface of each leg is in intimate contact with the second surface of an adjoining leg over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element. An impervious end cap is connected to the first end surface of the filter element.

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ABSTRACT OF THE DISCLOSURE

A filter includes a cylindrical filter element having a longitudinal axis, first and second end surfaces, and a plurality of longitudinal pleats. Each of the pleats has a pair of legs with first and second surfaces. The pleats are in a laid-over state in which the first surface of each leg is in intimate contact with the first surface of an adjoining leg and the second surface of each leg is in intimate contact with the second surface of an adjoining leg over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element. An impervious end cap is connected to the first end surface of the filter element.

## Pleated Filter Assembly, and the Method and Apparatus for Making

This invention relates to pleated filter elements, methods and apparatus for manufacturing pleated filter elements and methods for precoating and backwashing filter elements.

Cylindrical filter elements having radially-extending, longitudinal pleats are among the most common types of filter elements and are used to filter innumerable fluids, i.e., liquids or gases. (Throughout this application, "filter" and "filtration" include both the removal of particulates, e.g., by sieving or trapping within a porous medium, and the removal of impurities, e.g., by ion exchange resins or sorbents). In a typical cylindrical pleated filter element, a plurality of pleats are arranged around a tubular core to define a cylinder. As viewed in a transverse cross-section, the individual pleats of such a filter element extend radially outward from the core toward the outer periphery of the filter element. It is good design practice to have enough pleats in a cylindrical filter element so that adjoining pleats contact one another along the circumference of the core. However, because of the radial geometry of the pleats, the spacing between adjacent pleats necessarily increases as the distance from the center of the core increases. Accordingly, in a typical cylindrical pleated filter element, there is a great deal of unused space between adjacent pleats.

Making a filter element larger to compensate for the unused space between adjacent pleats is

frequently not possible. In the filter industry today, the dimensions of filter housings within which the filter elements are enclosed have become fairly standardized. Accordingly, a major challenge  
5 of filter designers is to increase the filtering capacity of a filter element, i.e., the usable surface area, without altering its external dimensions so that it can be employed with existing filter housings.

10 While cylindrical pleated filter elements are very common, they have typically not been used as precoat filters. A precoat filter is a type of filter in which a slurry is applied as a cake, called a precoat, to the exterior of a non-pleated,  
15 porous support structure called a septum. After the precoat is applied to the septum, a fluid to be filtered is then directed through the precoat and the septum where the precoat serves to filter the fluid. Pleated filter elements have not been used  
20 as supports for septa because the pleats tend to collapse as the precoat is applied or as the fluid flows through the precoat.

The present invention provides a filter including a cylindrical filter element having an end  
25 surface and an impervious end cap connected to the end surface. The filter element has a plurality of longitudinal pleats, each of the pleats having a pair of legs. Each of the legs has a first surface and a second surface. The pleats are in a laid-over  
30 state in which the first surface of each leg is in intimate contact with the first surface of an adjoining leg and the second surface of each leg is in intimate contact with the second surface of an adjoining leg over substantially the entire height  
35 of each leg and over a continuous region extending

for at least approximately 50% of the axial length of the filter element.

5 The present invention also provides a filter comprising a cylindrical filter element having an inner radius, outer radius, and a plurality of longitudinal pleats. Each pleat has a height greater than the difference between the outer and inner radii. The filter further comprises a wrap member wrapped around the filter element.

10 Because the pleats are in a laid-over state or because the height of each pleat is greater than the difference between the outer and inner radii, the height of the pleats is much larger than that of a conventional filter of the same dimensions. As a  
15 result, the surface area of a filter according to the present invention usable for filtration, which is proportional to the pleat height, can be greatly increased, resulting in a longer lifespan.

A filter embodying the present invention may  
20 have a hollow center and a cylindrical outer periphery. It can be used for outside-in flow in which a fluid to be filtered flows from the outer periphery through the filter element into the hollow center, or it can be used for inside-out flow in  
25 which fluid flows from the hollow center through the filter element to the outer periphery.

The present invention also provides a pleating apparatus which may form a material into pleats having unequal legs. The pleating apparatus  
30 includes a pleating member and a stripper member having pleating surfaces spaced by a gap. At least one of the pleating surfaces is curved or extends at an acute angle to a support surface for supporting a material to be pleated. The pleating member and the  
35 stripper member are moved relative to each other to

compress the material within the gap and thereby form a pleat, which may have unequal legs. As a result of the pleats having unequal legs, they can readily be formed into a laid-over state. A pleating apparatus according to the present invention can be used to pleat not only single-layer materials, but can also be used to pleat multi-layer composites.

The present invention further provides a precoat filter including a pleated filter element having a longitudinal axis and a plurality of longitudinal pleats. A septum adapted to support a precoat layer is wrapped around and bears against a periphery of the filter element.

In preferred embodiments, the pleated filter element of the precoat filter is cylindrical and has laid-over pleats extending non-radially with respect to the longitudinal axis of the filter element. Alternatively, the pleats may extend radially, with adjoining pleats pressed into intimate contact with one another by wedges or the like. A flow straightener such as a mesh may be disposed around the septum to prevent turbulence from damaging the precoat layer.

The pleated filter element of a precoat filter according to the present invention can have a large surface area, so it can trap fines which pass through the precoat layer and prevent them from flowing to the downstream side of the filter. By having its pleats in a laid-over state

or pressed into intimate contact with one another, the filter element can provide a more stable support for the septum and thereby prevent cracking of the precoat layer in response to fluctuations in the pressure across the filter.

5       Therefore, according to one aspect, the invention provides a filter which removes one or more substances from a fluid flowing through the filter. The filter comprises a pleated filter element including a longitudinal axis, first and second end surfaces, an inner periphery, an outer  
10 periphery and a plurality of longitudinal pleats. Each pleat includes a crown, a root, and a pair of legs, and the legs of each pleat are joined to one another at the crown of the pleat and are joined to legs of adjacent pleats at the root of the pleat. Each pleat leg abuts an adjacent  
15 pleat leg along the inner periphery of the filter element and the pleats extend from the inner periphery in a curved, an arcuate, an angled or a straight-nonradial direction to the outer periphery. The height of each pleat, measured in a direction along the legs and extending from the inner  
20 periphery at the root of the filter element to the outer periphery at the crown of the filter element, is greater than  $(D-d)/2$  and less than  $(D^2 - d^2)/[4(d+2t)]$ , where D and d are the outer diameter and the inner diameter of the filter element at the outer periphery and the inner  
25 periphery, respectively, and t is the thickness of each leg. The pleated filter element comprises a pleated

composite including a filter medium having an upstream side and a downstream side, an upstream drainage medium positioned upstream of the upstream side of the filter medium and a downstream drainage medium positioned

5 downstream from the downstream side of the filter medium.

Fluid to be filtered flows along the upstream drainage medium to the filter medium, the upstream drainage medium distributing fluid to be filtered along the pleats between the roots and the crowns and along the upstream side of the

10 filter medium and allowing the filter medium to be used for filtration. The fluid to be filtered then flows through

the filter medium, the filter medium having a filtering characteristic which removes one or more substances from fluid flowing through the filter medium. Filtered fluid

15 then flows from the filter medium along the downstream drainage medium, the downstream drainage medium draining filtered fluid from the downstream surface of the filter medium along the pleats between the roots and the crowns.

The filter further comprises first and second end elements

20 sealingly arranged with the first and second end surfaces, respectively, of the pleated filter element, wherein at least one of the end elements comprises an open end element.

According to an aspect of the present invention there is provided a method of making a filter comprising  
25 corrugating a composite including an upstream drainage

medium, a filter medium, and a downstream drainage medium to form a plurality of pleats wherein each pleat includes a crown, a root, and a pair of legs and wherein the legs of each pleat are joined to one another at the crown of the pleat and are joined to legs of adjacent pleats at the root of the pleat, arranging the plurality of pleats into a cylindrical filter element including first and second end surfaces and longitudinally extending pleats wherein the height of each pleat, measured in a direction along the legs and extending from the inner periphery at the root to the outer periphery at the crown, is greater than  $(D-d)/2$  and is less than or equal to about  $(D^2 - d^2)/[4(d+2t)]$  where D and d are the outer diameter and the inner diameter of the filter element at the outer periphery and the inner periphery, respectively, and t is the thickness of a pleat leg, sealing first and second end elements to the first and second end surfaces, respectively, of the pleated filter element, wherein at least one of the end elements comprises an open end element, and positioning a retainer around the plurality of pleats.

According to another aspect of the present invention there is provided a filter comprising a cylindrical filter element having a filter medium and a drainage means extending along at least one side of the filter medium, a longitudinal axis, first and second end surfaces, and a

plurality of longitudinal pleats, each of the pleats having a pair of legs, each of the legs having a first and a second surface, the pleats being in a laid-over state in which the heights of the pleats are greater than  $(D-d)/2$ ,  
5 where  $D$  and  $d$  are the outer and inner diameters of the filter element, respectively, and in which the first surface of one leg of one pleat is in intimate contact with the first surface of an adjoining leg of the one pleat and the second surface of the one leg is in intimate contact  
10 with the second surface of an adjoining leg of an adjacent pleat over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element, and a first impervious end cap connected to the  
15 first end surface of the filter element.

According to a further aspect of the invention there is provided a method of making a filter comprising arranging a plurality of pleats into a cylindrical, laid-over state to form a filter element including  
20 longitudinally extending pleats having a height greater than  $(D-d)/2$ , where  $D$  and  $d$  are the outer and inner diameters of the filter element, wherein the pleats of the filter element include a filter medium and a drainage means extending along at least one side of the filter medium and  
25 wherein arranging the pleats includes intimately contacting

a first surface of one leg of one pleat with the first surface of an adjoining leg of the one pleat and a second surface of the one leg with the second surface of an adjoining leg of an adjacent pleat over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element, and sealing at least a first end of the filter element to prevent axial flow through the filter medium at the first end.

10 According to a further aspect of the present invention there is provided a pleating apparatus comprising a support surface for supporting a filter material to be pleated, a first member having a first pleating surface, a second member having a second pleating surface spaced from the first pleating surface by a gap for receiving the filter material to be pleated, at least one of the first and second pleating surfaces being curved or extending at an acute angle to the support surface, and a driver for producing relative movement of the first member and the second member and compressing the filter material within the gap between the first and second pleating surfaces to form a pleat.

According to a further aspect of the present invention there is provided a pleating method comprising disposing a filter material on a support surface, inserting a portion

of the filter material between first and second pleating surfaces, at least one of the first and second pleating surfaces being curved or extending at an acute angle with respect to the support surface, and compressing the portion  
5 of the filter material between the pleating surfaces and forming a pleat.

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Additionally, the present invention provides a method of assembling a filter, a pleating method, and filtering methods, all as defined by the attached claims.

5        Figure 1 is a cut-away perspective view of a filter.

Figure 2 is a transverse cross-sectional view of a portion of the filter of Figure 1.

10       Figure 3 is an enlarged cross-sectional view of one of the pleats of Figure 2.

Figure 4 is a schematic perspective view of a portion of a filter composite having an insert strip at one end.

15       Figure 5 schematically illustrates one method of forming the pleats of a filter element into a laid-over state.

Figures 6-11 are schematic views illustrating a method and apparatus for forming a filter element.

20       Figures 12 and 13 are schematic views illustrating another method and apparatus for forming a filter element.

Figure 14 is an enlarged side view of one of the pleats of Figure 9.

25       Figure 15 is a side view of a pleating apparatus.

Figure 16 is a plan view of the pleating apparatus of Figure 15.

Figure 17 is a side view of another pleating apparatus.

30       Figure 18 is a side view of another pleating apparatus.

Figures 19-21 are schematic views illustrating a method and apparatus for assembling a filter element.

35       Figure 22 is a cut-away perspective view of

another filter.

Figure 23 is a cross-sectional view of a precoat filter.

Figure 24 is a cross-sectional view of another precoat filter.

Figure 1 illustrates a first embodiment of a filter according to the present invention. This embodiment is generally cylindrical in form and includes a pleated filter element 10 having a plurality of longitudinal pleats 11. A cylindrical core 20 may be coaxially disposed along the inner periphery of the filter element 10, and a cylindrical cage or wrap 30 may be disposed along the outer periphery of the filter element 10.

As shown in figures 2 and 3, each pleat 11 has two legs 11a which are joined to one another at the crown 11b of the outer periphery of the filter element 10 and which are joined to a leg 11a of an adjacent pleat 11 at the root 11c of the inner periphery of the filter element 10. Each leg 11a has an internal surface 11d which opposes the internal surface 11d of the other leg 11a in the same pleat 11, and an external surface 11e which opposes the external surface 11e of a leg 11a of an adjacent pleat 11. When the filter element 10 is being used such that fluid flows radially inwardly through the element, the internal surfaces 11d of the legs 11a form the downstream surface of the filter element 10, while the external surfaces 11e form the upstream surface of the filter element 10. Alternatively, when the filter element 10 is being used such that fluid flows radially outwardly through the element, the internal surfaces 11d and the external surfaces 11e respectively form the upstream and downstream surfaces of the filter

element 10.

As shown in the figures, the opposing inner surfaces 11d of the legs 11a of each pleat 11 are in intimate contact with one another over substantially the entire height h of the legs 11a and of the pleat 11 and over a continuous region extending for a significant portion of the axial length of the filter element 10. In addition, the opposing external surfaces 11e of the legs 11a of adjacent pleats 11 are in intimate contact over substantially the entire height h of the adjacent pleats 11 and legs 11a and over a continuous region extending for a significant portion of the axial length of the filter element. Here, the height h (shown in Figure 2) of the pleats 11 and the legs 11a is measured in a direction along the surfaces of the legs 11a and extends from the inner periphery to the outer periphery of the filter element 10. The condition illustrated in Figures 2 and 3 in which the surfaces of the legs 11a of the pleats 11 are in intimate contact and in which the height h of each pleat 11 is greater than the distance between the inner and outer peripheries of the filter element 10 (i.e.,  $[D-d]/2$  in Figure 2) will be referred to as a laid-over state. In the laid-over state, pleats may extend, for example, in an arcuate or angled fashion or in a straight, non-radial direction, and there may be is substantially no empty space between adjacent pleats, and virtually all of the volume between the inner and outer peripheries of the filter element 10 may be occupied by the filter element 10 and can be effectively used for filtration.

Because the filter element 10 is formed from a material having a finite thickness t, at the

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radially inner and outer ends of the pleats 11 where the filter element 10 is folded back upon itself to form the pleats 11, the pleats 11 will be somewhat rounded. As a result, at the radially inner ends of the pleats 11, small triangular gaps 11f are formed between the opposing internal surfaces 11d of adjoining legs 11a, and at the radially outer ends of the pleats 11, small triangular gaps 11g are formed between the opposing external surfaces 11e of adjoining legs 11a. However, in the present invention, the height of these gaps 11f and 11g as measured along the height of the pleats is preferably extremely small. The height of the gaps 11f adjoining the inner diameter of the filter element 10 is preferably no more than approximately  $t$  and more preferably no more than approximately  $\frac{1}{2}t$ , wherein  $t$  is the thickness of the material forming the filter element 10, as shown in Figure 3. The height of the gaps 11g adjoining the outer diameter of the filter element 10 is preferably no more than approximately  $4t$  and more preferably no more than approximately  $2t$ . The sharper the pleats 11, i.e., the less rounded are their radially inner and outer ends, the smaller can be the heights of the gaps 11f and 11g and the greater can be the percent of the volume between the inner and outer peripheries of the filter element 10 which is available for filtration.

The opposing surfaces of adjoining legs 11a of the pleats need not be in intimate contact over the entire axial length of the filter element 10, but the greater is the length in the axial direction of the region of intimate contact, the more effectively used is the space between the inner and outer periphery of the filter element 10. Therefore,

adjoining legs 11a are in intimate contact over a continuous region which preferably extends for at least approximately 50%, more preferably at least approximately 75%, and most preferably approximately 95 - 100% of the axial length of the filter element 10.

The filter element 10 includes a filter medium and drainage means disposed on at least one side, preferably the upstream side, and more preferably on both the upstream and downstream sides of the filter medium. The drainage means prevents opposing surfaces of the filter medium from coming into contact with one another and enables fluid to evenly flow to or from substantially all portions of the surface of the filter medium when the pleats are in the laid-over state. Thus, virtually the entire surface area of the filter medium may be effectively used for filtration.

In the embodiment of Figure 1, the filter element 10 comprises a three-layer composite of a filter medium 12, upstream drainage means in the form of an upstream drainage layer 13 disposed on the upstream surface of the filter medium 12, and downstream drainage means in the form of a downstream drainage layer 14 disposed on the downstream surface of the filter medium 12. Here, upstream and downstream surfaces may refer to the exterior and interior surfaces when the filter is being subjected to radially inward fluid flow or to interior and exterior surfaces when the filter is being subjected to radially outward fluid flow.

There are no particular restrictions on the type of filter medium which can be employed in the present invention, and it can be selected in accordance with the fluid which is to be filtered

and the desired filtering characteristics. The filter medium 12 can be used to filter fluids such as liquids, gases, or mixtures thereof. The filter may comprise a porous film or a fibrous sheet or mass; it may have a uniform or graded pore structure and any appropriate effective pore size; it may be formed from any suitable material, such as a natural or synthetic polymer, glass, or metal.

The filter medium 12 may comprise a single layer, or a plurality of layers of the same medium may be disposed atop one another to a desired thickness. Furthermore, it is possible for the filter medium to include two or more layers having different filtering characteristics, e.g., with one layer acting as a prefilter for the second layer.

The upstream and/or downstream drainage layers may be regions of a single, unitary porous sheet having a finely-pored center region, which serves as a filter medium, and coarsely-pored upstream and/or downstream regions which serve as the drainage layers. However, the drainage layers are preferably distinct layers separate from the filter medium.

The upstream and downstream drainage layers 13 and 14 can be made of any materials having suitable edgewise flow characteristics, i.e., suitable resistance to fluid flow through the layer in a direction parallel to its surface. The edgewise flow resistance of the drainage layer is preferably low enough that the pressure drop in the drainage layer is less than the pressure drop across the filter medium, thereby providing an even distribution of fluid along the surface of the filter medium. The drainage layers can be in the form of a mesh or screen or a porous woven or non-woven sheet.

Meshes and screens (also called netting) come in various forms. For high temperature applications, a metallic mesh or screen may be employed, while for lower temperature applications, a polymeric mesh may be particularly suitable. Polymeric meshes come in the form of woven meshes and extruded meshes. Either type may be employed, but extruded meshes are generally preferable because they are smoother and therefore produce less abrasion of adjoining layers of the filter composite. An extruded mesh may have a first set of parallel strands and a second set of parallel strands intersecting the first set of strands at an angle. Extruded meshes may be classified as either symmetrical or non-symmetrical. In a symmetrical mesh, neither of the first or second sets of strands extends in the so-called "machine direction" of the mesh, which is the direction in which the mesh emerges from a mesh manufacturing machine. In a non-symmetrical mesh, one of the sets of strands extends parallel to the machine direction. In the present invention, it is possible to use either symmetrical or non-symmetrical meshes. Non-symmetrical meshes have a somewhat lower resistance to edgewise flow per thickness than do symmetrical meshes. Therefore, for a given edgewise flow resistance, a non-symmetrical mesh can be thinner than a symmetrical mesh, so the number of pleats in a filter element 10 using a non-symmetrical mesh can be larger than for a filter element of the same size using a symmetrical mesh. On the other hand, symmetrical meshes have the advantage that they are easier to work with when manufacturing a pleated filter element 10.

Meshes may be characterized by their thickness

and by the number of strands per inch. These dimensions are not limited to any particular values and can be chosen in accordance with the desired edgewise flow characteristics of the mesh and the  
5 desired strength. Typically, the mesh will have a mesh count of at least 10 strands per inch.

In embodiments of the present invention, the opposing surfaces of the pleats are in intimate contact. Consequently, the strands of the drainage  
10 mesh of each leg of the pleats are pressed against the strands of the drainage mesh of an adjacent leg of the pleats. If the strands of the mesh on two opposing surfaces are parallel to one another, the strands may have a tendency to "nest", i.e., to fit  
15 between one another rather than to lie atop one another. This degrades the drainage properties of the mesh and decreases its ability to provide drainage for the filter medium. With a non-symmetric mesh, care must be taken that the machine  
20 direction strands are on the side of the mesh facing toward the filter medium rather than away from it so as to prevent nesting of the strands when the filter element 10 is corrugated. With a symmetric mesh, however, there are no machine direction strands, so  
25 it does not matter which surface of the mesh faces the filter medium, and less care is required in assembly of the filter element 10.

Regardless of whether a mesh is symmetric or non-symmetric, the strands of the meshes can be  
30 prevented from nesting if the meshes are oriented as follows. Assuming that the first set of strands is on the side of a mesh facing toward the filter medium and the second set of strands is separated from the filter medium by the first set of strands,  
35 the second set of strands can be prevented from

nesting when the pleats are in a laid-over state if the second set of strands extends along lines intersecting the longitudinal axis of the filter element at an angle between 0 and 90 degrees. If  
5 the second set of strands extends along lines intersecting the axis at an angle of either 0 or 90 degrees, i.e., if the second set of strands is either parallel or perpendicular to the axis of the filter element, it is possible for the second set of  
10 strands to nest. However, at any angle between these limits, the second set of strands will lie atop each other without nesting.

If the mesh is so oriented, when the pleats 11 assume a laid-over state, a surface which is tangent  
15 to the second strands of the mesh on each leg of a pleat will be in intimate contact with a surface which is tangent to the second strands of the mesh of an adjoining leg.

Specific examples of suitable extruded  
20 polymeric meshes are those available from Nalle Plastics (Austin, Texas) under the trade names Naltex, Zicot, and Ultraflo.

Meshes are particularly suitable as drainage layers when the filter medium is a fibrous laid-down  
25 medium. On the other hand, when the filter medium is a membrane, a woven or non-woven fabric is more suitable for use as the drainage layer because a fabric is usually smoother than a mesh and produces less abrasion of adjoining layers of the filter  
30 composite. An example of a suitable non-woven fabric for use as a drainage layer is a polyester non-woven fabric sold under the trade designation Reemay 2011 by Reemay, Inc.

The upstream and downstream drainage layers 13  
35 and 14 can be of the same or different construction.

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It has been found that the pressure drop across the filter medium 12 may be lowest and filter life may be longest when both drainage layers 13 and 14 have substantially the same edgewise flow resistance.

5 Therefore, regardless of whether the drainage layers 13 and 14 are made of the same material, they are preferably selected so as to have substantially the same resistance to edgewise flow. For ease of  
10 materials for both drainage layers 13 and 14, thereby assuring the same edgewise flow resistance through both drainage layers.

Alternatively, the upstream and downstream drainage layers 13 and 14 may have different  
15 characteristics and these characteristics may be varied to provide a desired effect. For example, where the thickness of the filter composite is fixed, e.g. in order to fix the surface area of the filter medium within an envelope, the thickness of  
20 the upstream drainage layer may be greater than the thickness of the downstream drainage layer. This may provide greater cake space on the upstream side of the filter medium, but it may sacrifice even flow distribution on the downstream side of the filter  
25 medium.

The filter composite forming the filter element  
10 may include other layers in addition to the filter medium 12 and the drainage layers 13 and 14. For example, in order to prevent abrasion of the  
30 filter medium due to rubbing contact with the drainage layers when the pleats expand and contract during pressure fluctuations of the fluid system in which the filter is installed, a cushioning layer can be disposed between the filter medium and one or  
35 both of the drainage layers. The cushioning layer

is preferably made of a material smoother than the drainage layers and having a higher resistance to abrasion than the filter medium 12. For example, when the drainage layers are made of an extruded  
5 nylon mesh, an example of a suitable cushioning layer is a polyester non-woven fabric such as that sold under the trade designation Reemay 2250 by Reemay Corporation.

10 The layers forming the filter element 10 can be formed into a composite by conventional filter manufacturing techniques, either prior to or simultaneous with corrugation.

In the prior art, in order to ensure adequate drainage in a filter element with closely spaced  
15 pleats, it was necessary to form large surface irregularities, such as grooves, in the surfaces of the pleats in order to create drainage passageways. These grooves, typically formed by a method such as embossing, greatly reduced the volume of a filter  
20 element which was available for filtration. In the present invention, the drainage layers can provide adequate drainage even when in intimate contact with one another, so large surface irregularities in the pleats are not necessary. Therefore, each of the  
25 layers in the filter composite forming the filter element 10 may have a substantially flat surface.

The core 20 supports the inner periphery of the filter element 10 against forces in the radial direction and also helps to give the filter axial  
30 strength and rigidity against bending. The core 20 may be of conventional design and may be made of any material having sufficient strength and which is compatible with the fluid being filtered. Openings are formed through the wall of the core 20 to permit  
35 the passage of fluid between the outside and the

center of the core 20.

When the filter element 10 is being subjected to outside-to-inside fluid flow, the presence of a core 20 is usually desirable. However, depending upon the forces acting on the filter element 10 during filtration, it may be possible to omit the core 20. For example, when fluid flow through the filter element 10 is primarily from the inside to the outside thereof, radially inward forces on the filter element 10 may be absent or so low that a core 20 becomes unnecessary, enabling a reduction in the weight of the filter.

A filter according to the present invention preferably includes means for retaining the pleats of the filter element 10 in a laid-over state. In the present embodiment, this means comprises the outer cage 30 which surrounds the filter element 10. The cage 30 may be of conventional design with openings formed therein for the passage of fluid. The material of which the cage 30 is made can be selected based on the fluid being filtered and the filtering conditions.

Usually, a filter according to the present invention will be equipped with end caps 40 (only one of which is shown in Figure 1) at one or both ends of the filter element 10. The end caps 40 can be either blind or open end caps, and the material of which they are formed and their shape can be selected in accordance with the filtering conditions and the materials of the members to which the end caps are to be joined. Preferably, the end caps 40 are attached to the filter element 10, but they may also be attached to the core 20 or the cage 30. Conventional techniques can be used to attach the end caps to the filter element 10, such as by use of

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an epoxy, by polycapping (as taught, for example, in U.S. Patent No. 4,154,688), or by spin welding.

5 In order to prevent leakage of fluid at the ends of the filter element 10, it is desirable to obtain a good seal between the end caps 40 and the end surfaces of the filter element 10 so that fluid is prevented from passing through the end surfaces of the filter element 10. However, it may be difficult to obtain a good seal when the filter  
10 element 10 and the end caps 40 are made of materials having poor affinity for one another. In such cases, an insert in the form of a strip of material having a good affinity for the end cap material can be corrugated into the ends of the filter element  
15 10. Figure 4 schematically illustrates a portion of a filter element having an insert 15 corrugated between two of the layers of the filter composite. When the end caps 40 are attached, the insert 15 enables the creation of a good seal between both  
20 ends of the filter element 10 and the end caps 40. For example, when the end caps are made of a fluoropolymer, a strip of another fluoropolymer, such as a fluorinated ethylene-propylene (FEP) resin, can be corrugated into the ends of the filter  
25 element 10 as the insert 15. The insert 15 need only be wide enough to bond the filter medium to the end cap, and therefore, as shown in Figure 4, it normally extends for only a portion of the axial length of the filter element 10. A typical width  
30 for the insert 15 is approximately 0.5 inches.

The filter element 10 illustrated in Figure 1 can be manufactured by a variety of techniques. In one technique, the filter composite is first corrugated to form a corrugated sheet, cut to a  
35 suitable length or suitable number of pleats, and

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then formed into a cylindrical shape. The lengthwise edges of the corrugated sheet are then sealed to each other by conventional means to form a cylindrical filter element 10. The pleats of the filter element 10 are then laid over as the filter element 10 is inserted into a cage 30. After the filter element 10 has been fit into the cage 30, a core 20 is inserted into the hollow center of the filter element 10, and then end caps 40 are attached to the ends of the filter element 10 to form a completed filter.

Figure 5 illustrates one method of laying over the pleats. In this method, the filter element 10 is inserted lengthwise into the mouth of a funnel-shaped tool 60 having an exit (the left end in Figure 5) adjoining a cage. As the filter element 10 is pushed into the tool 60, it is simultaneously twisted, either by hand or by machine, thereby causing the pleats to lay over against one another. The dimensions of the tool 60 are selected so that at the exit, the filter element 10 has an outside diameter small enough for the filter element 10 to slide into the cage 30.

It is also possible to form the pleats of a corrugated sheet 10 into a laid-over state before forming the pleats into a cylindrical form. For example, after the filter composite is passed through a corrugator to form a substantially planar corrugated sheet, the sheet can be pressed between two flat surfaces to flatten the sheet and cause the pleats to lay over against one another. The thus flattened corrugated sheet can then be bent into cylindrical form and the ends of the sheet sealed to one another to form a cylindrical filter element 10.

It may be easier to lay over the pleats of the

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filter element 10 if there is a smooth radius on the outside pleat crest as opposed to a sharp crease. One method of creating a smooth radius is to place a disposable layer of paper, referred to as a strip-out paper, on the downstream side of the filter corrugated composite during corrugation. The strip out paper becomes part of the pleats and produces a desired smooth radius. The strip-out paper is then stripped off the composite after the completion of corrugation and before the composite is formed into a cylinder. The material used for the strip-out paper is not critical. An example of a suitable material is a smooth paper. The thickness of the strip-out paper can be selected based on the desired bending radius of the corrugated composite, taking into consideration the thickness of the other layers of the composite.

Another technique for manufacturing the filter element 10 allows the formation of pleats in which the adjoining legs have slightly different lengths. For many filter elements, especially those formed from a multilayer composite, it is easier and more reliable to form the filter element into a laid-over state if the adjoining legs of each pleat have slightly different lengths. Such pleats will be referred to as pleats with unequal legs.

Preferred embodiments of a pleating method and apparatus according to this aspect of the present invention will now be described with reference to Figures 6-11, which schematically illustrate one cycle in a pleating method of the present invention. As shown in these figures, pleats are formed atop a support, such as a planar pleating table 100, by a pleater member and a stripper member. In accordance with one aspect of the invention, the pleats are

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formed between surfaces of the pleater member and the stripper member which are curved or extend at an acute angle from the pleating table 100, preferably substantially less than 90°, more preferably within the range from about 15° to about 75°, and most preferably within the range from about 30° to about 60°, e.g., 45°. For example, the pleater member may be a wedge-shaped member referred to as a pleating wedge 101 and the stripper member may be a thin plate referred to as a stripper knife 102. The pleating wedge 101 can be raised and lowered with respect to, and moved back and forth parallel to, the top surface of the pleating table 100, while the stripper knife 102 can be raised and lowered with respect to the pleating table 100. For convenience, the surface of the pleating table 100 is usually level, but a level surface is not necessary for the method of the present invention.

The material 103 to be pleated may be dispensed onto the pleating table 100 by any suitable means, such as a reel 104. The material 103 may be a single sheet or layer, or it may be a composite of a plurality of layers, such as a filter medium and one or more drainage layers. The layers may be formed into a composite prior to being stored on the reel 104, or the individual layers may be stored on separate reels and simultaneously fed to the pleating table 100 so that the composite is formed as the layers are pleated.

As shown in the figures, the front surface 101a of the pleating wedge 101 and the rear surface 102a of the stripper knife 102 (the surface which opposes the pleating wedge 101) are both sloped with respect to the pleating table 10 by similar but not necessarily equal acute angles. It is because these

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surfaces extend at acute angles, or because they are curved, that the method of the present invention is able to form pleats having adjoining legs of unequal lengths.

5           Figure 6 illustrates the start of the pleating cycle, in which the pleating wedge 101 is located at a point A in the figure. At this position, the front surface 101a of the pleating wedge 101 is spaced from the rear surface 102a of the stripper  
10 knife 102 by a predetermined distance which depends upon the height of the pleats which are to be formed. The lower surface of the pleating wedge 101 is in frictional contact with the material 103 to be pleated, and the lower edge of the stripper knife 102  
15 is pressed against the material 103 to be pleated so as to restrain it.

          The pleating wedge 101 is then moved from point A towards the stripper knife 102 in the direction of the arrow in Figure 7 while the lower surface of the  
20 pleating wedge 101 remains in frictional contact with the material 103 to be pleated. At the same time, the stripper knife 102 is maintained stationary. Due to the frictional contact between the pleating wedge 101 and the material 103 to be  
25 pleated, the movement of the pleating wedge 101 towards the stripper knife 104 causes the portion of the material 103 disposed between the pleating wedge 101 and the stripper knife 102 to bend upwards from the surface of the pleating table 100 in the form of  
30 a bulge 105.

          As the pleating wedge 101 is moved still closer to the stripper knife 102, the bulge 105 in the material 103 to be pleated begins to fold into the shape of a pleat 11, as shown in Figure 8. The  
35 pleating wedge 101 is advanced further to a point B

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in Figure 9, in which the material 103 is compressed between the front surface 101a of the pleating wedge 101 and the rear surface 102a of the stripper knife 102, thereby forming a single pleat 11.

5           The stripper knife 102 is then raised from the pleating table 100 and simultaneously pivoted in the clockwise direction in the figures. As the stripper knife 102 rises, its rear surface 102a slides along the pleat 11 which was just formed, further pressing  
10 the pleat 11 against the front surface 101a of the pleating wedge 101. When the rear surface 102a of the stripper knife 102 clears the upper end of the pleat 11, the rear surface 102a of the stripper knife 102 may then contact the front surface 101a of  
15 the pleating wedge 101, as shown in Figure 10. The stripper knife 102 is then lowered, and its rear surface 102a slides along the front surface 101a of the pleating wedge 101 between the pleating wedge 101 and the pleat 11 just formed until the lower  
20 edge contacts the material 103 to be pleated, as shown in Figure 11. During the raising and lowering of the stripper knife 102, the pleating wedge 101 may be maintained substantially stationary.

          Next, while the stripper knife 102 is  
25 maintained stationary, which in turn holds the material 103 stationary, the pleating wedge 101 is returned to point A to complete the pleating cycle. The path of the pleating wedge 101 as it travels from point B back to point A is such that the lower  
30 surface of the pleating wedge 101 is raised above the surface of the material 103 to be pleated so that the material 103 will not be pulled backwards. For example, the pleating wedge 101 can be moved along a path with straight sides indicated as B-C-D-  
35 A in Figure 6. Alternatively, the pleating wedge

101 can move along an arcuate path in going from point B to point A. Upon the wedge 101 returning to point A, the above process is repeated.

Each time the cycle illustrated in Figures 6-11 is performed, a new pleat 11 is formed, and it is moved by the stripper knife 102 to the right to join the pleats 11 which have already been formed and which accumulate on the right side of the stripper knife 102 in the figures. The entire group of completed pleats 11 is incrementally pushed to the right by the movement of the stripper knife 102. Any desired number of pleats can be formed by repeating the above-described cycle a corresponding number of times. The group of completed pleats may be conveniently rolled off the end of the pleating table 100.

Figures 12 and 13 are schematic illustrations showing the operation of a creaser bar 109. These figures are analogous to Figures 6-11 except the pleating apparatus further includes a creaser bar 109 which moves up and down through a gap 110 in the pleating table 100. In these figures, as the pleating wedge 101 begins to move toward point B from point A, the creaser bar 109 is made to protrude through the gap 110 in the pleating table 100 and above the surface of the pleating table 100. When the creaser bar 109 protrudes above the surface of the pleating table 100, it contacts the material 103 and forces the material 103 to bulge upwards properly, e.g., without any wrinkles. The upper edge of the creaser bar may also form a crease in the material which may become the crest or root of the pleat. As the pleating wedge 101 moves closer to point B, the creaser bar 109 is retracted beneath the surface of the pleating table 100 so that the

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pleating wedge 101 can pass over the gap 110 in the pleating table 100. The pleating process is otherwise the same as described with respect to Figures 6-11.

5           Figure 14 is an enlarged view of a pleat 11 which can be formed by the processes illustrated in Figures 6-13. The pleat has two legs 11a', 11a", one of which contacts the front surface 101a of the pleating wedge 101 and the other of which contacts  
10           the rear surface 102a of the stripper knife 102. Because the front surface 101a of the pleating wedge 101 is sloped with respect to the pleating table 100 by an acute angle, the length L1 of the leg 11a' contacting the front surface 101a of the pleating  
15           wedge 101 may be shorter than the length L2 of the adjoining leg 11a" of the same pleat 11, wherein the lengths may be measured between the points where the material 103 being pleated is folded back upon itself. If the front surface 101a of the pleating  
20           wedge 101 is sloped with respect to the surface of the pleating table 100 by an angle  $\theta_1$  and the thickness of the material 103 to be pleated is t, then the difference between the lengths L1 and L2 of adjoining legs 11a', 11a" is approximately  $L2 - L1 =$   
25            $2t/\tan\theta_1$ . The difference in length can be set to a desired value by suitably selecting the angle of the pleating wedge 101. Due to the difference in length, pleats formed by the method of the present invention can be easily formed into a laid-over  
30           state.

          Many of the components of a pleating apparatus according to the present invention are similar to those of commercially available push bar type pleating machines, such as a Model No. 10148  
35           pleating machine manufactured by Chandler Machine

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Company of Ayer, Massachusetts. Pleating is performed atop a pleating table 100, as shown in Figures 15 and 16. In a typical pleating machine, the pleating table 100 has two sections 100a and 100b which can be moved with respect to each other in the horizontal direction to form a gap of a desired size between the two sections. When the movable sections 100a and 100b are separated by a gap, the creaser bar 109 can be moved up and down in the gap by an unillustrated drive mechanism to assist in the pleating process. If the creaser bar 109 is not employed, the two sections 100a and 100b of the pleating table 100 are made to abut, or the pleating table 100 can be made in one piece and the creaser bar can be omitted.

In the embodiment of Figure 15, the material being pleated is a filter composite 103 of three different layers 103a, 103b, 103c dispensed onto the pleating table 100 from three different reels 104a, 104b, 104c, respectively. The layers 103a, 103b, 103c can be made of the same or different materials. In this example, the material 103b on the middle reel 104b is a filter medium, while the materials 103a and 103c on the top and bottom reels 104a and 104c are extruded meshes which serve as drainage layers for the upstream and downstream surfaces of the filter medium 103b.

The pleating apparatus is equipped with a bar which has a generally L-shaped cross section and which is referred to as a pusher bar 111. The pusher bar 111 is movably disposed atop the pleating table 100 so as to move along a closed path, at least one portion of which extends parallel to the surface of the pleating table 100. In this embodiment, the pusher bar 111 is driven along a

four-sided closed path, indicated by points A'-B'-C'-D' in Figure 15, by a drive mechanism 112. While a pusher bar 111 need not be employed in a pleating apparatus according to the present invention, the  
5 pusher bar 111 and its associated drive mechanism 112 serve as a convenient means of driving a pleating wedge 101.

The pleating wedge 101 is rigidly secured to the front end of the pusher bar 111 by bolts or  
10 other suitable means so that the two move together as a single unit. In accordance with one aspect of the present invention, the pleating wedge 101 has a front surface 101a having a constant acute angle of slope  $\theta_1$  with respect to the surface of the pleating  
15 table 100. Preferably, at least the front surface 101a of the pleating wedge 101 has a width which is substantially the same as or greater than the width of the filter composite 103.

As the pusher bar 111 moves along the path A'-  
20 B'-C'-D', the pleating wedge 101 moves along the path A-B-C-D. The pleating wedge 101 has a lower surface which preferably extends parallel to the pleating table 100. As the pusher bar 111 travels along leg D'-A' of the path, the lower surface of  
25 the pleating wedge 101 is lowered into frictional contact with the filter composite 103 being pleated. As long as the pleating wedge 101 is in frictional contact with the filter composite 103, it is possible for the lower surface of the pusher bar 111  
30 to be spaced from the filter composite 103 as the pusher bar 111 moves along leg A'-B'. In other words, the lower surface of the pusher bar 111 need not be flush with the lower surface of the pleating wedge 101. The horizontal stroke of the pusher bar  
35 111, i.e., the distance along leg A'-B', may be

readily adjustable, so the height of the pleats, which depends upon the stroke length, can be set at a desired value. As the pusher bar 111 rises along leg B'-C' and travels backwards along leg C'-D', the pleating wedge 101 travels along leg B-C and leg C-D, and the lower surface of the pleating wedge 101 is raised above the filter composite 103 by the drive mechanism 112 and the pusher bar 111 so that the filter composite 103 will not be pulled backwards by the pleating wedge 101.

A stripper knife 102 is pivotably mounted on reciprocating members commonly referred to as sliders 113. The sliders 113 are disposed on opposite widthwise sides of the pleating wedge 101 and are raised and lowered along a vertical path by a drive mechanism 114. The timing of the movement of the sliders 113 and the pusher bar 111, as well as the creaser bar 109 during the operation of this embodiment can be controlled by a conventional mechanical or electrical controller which is coupled to the respective drive mechanisms 112, 114. The stripper knife 102 preferably comprises a thin blade having a width which is substantially the same as or greater than the width of the filter composite 103. The upper end of the stripper knife 102 is secured to a bar, referred to as a stripper bar 115, which is pivotably supported on the sliders 113 by a pins 116 attached to between the two sliders 113. The lower end of the stripper knife 102 extends to close proximity of the pleating table 100 so as to be able to restrain the composite 103 from movement and the lower end of the stripper knife 102 may be tapered to assist in separating completed pleats from the front surface 101a of the pleating wedge 101. The stripper bar 115 is biased in the clockwise

direction in the figure by an unillustrated biasing member, such as a spring, so that the stripper knife 102 is biased towards the front surface 101a of the pleating wedge 101. Alternatively, the pivot axis  
5 of the stripper bar can be chosen so that the weight of the stripper knife will exert a clockwise torque on the stripper knife about the rod and thereby bias the stripper knife towards the pleating wedge. The  
10 stripper bar 115 is prevented from rotating in the counterclockwise direction past the position shown in Figure 15 by an unillustrated stopping member, such as a pin.

In the illustrated embodiment, the rear surface 102a of the stripper knife 102, which opposes the  
15 front surface 101a of the pleating wedge 101, is planar. In accordance with another aspect of the present invention, when the stripper knife 102 is in the position shown in Figure 15, the rear surface 102a has a constant acute angle of slope  $\theta_2$  with  
20 respect to the surface of the pleating table 100 which is close to the angle of slope  $\theta_1$  of the front surface 101a of the pleating wedge 101. The slope of the rear surface 102a of the stripper knife 102 may be slightly smaller than or equal to, but is  
25 preferably slightly larger than, e.g., about 5° larger than, the slope of the front surface 101a of the pleating wedge 101, so that a wedge-shaped space is formed between the pleating wedge 101 and the  
30 stripper knife 102. This wedge-shaped space assists in forming pleats with unequal legs.

Figure 17 illustrates a portion of another pleating apparatus embodying the present invention, which is analogous to the pleating apparatus shown  
in Figures 15 and 16. As in the previous  
35 embodiment, a stripper knife 102 is secured to a

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stripper bar 115, which is pivotably supported through a rod 116 by two sliders 113 disposed on opposite widthwise sides of a pleating wedge 101. Each slider 113 in this embodiment has generally the shape of an L with a first leg 113a extending upwards from the surface of the pleating table 100 and a second leg 113b extending generally parallel to the pleating table 100. The stripper bar 115 is pivotably mounted on the second legs 113b so as to be in the same location with respect to the pleating wedge 101 as the stripper bar 115 of the embodiment of Figure 15. The first leg 113a of each slider 113 is spaced from the location of the sliders 113 of Figure 15 so as not interfere with the movement of the creaser bar 109. The two sections 100a, 100b of the pleating table 100 are separated from one another to provide a gap 110 therebetween large enough for the creaser bar 109 to pass through. The creaser bar 109 can be raised and lowered by an unillustrated drive mechanism, as previously described. The creaser bar 109 has a width which is substantially the same as or greater than the width of the filter composite 103 being pleated. The structure and operation of this embodiment are otherwise analogous to those of the embodiment of Figures 15 and 16.

In the preceding embodiments, the opposing surfaces of the pleating wedge and the stripper knife are both generally planar, so the legs of each pleat formed between the opposing surfaces are substantially straight. However, when a pleated filter element is formed into a laid-over state in a cylindrical configuration, the individual pleats generally take on a curved shape as viewed in a transverse cross section, with each leg of a pleat

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extending along an arc from the inner to the outer periphery of the filter element. It is therefore easier to lay over the pleats of a filter element if the pleats are formed with a curved profile at the  
5 time of pleating.

Figure 18 illustrates another embodiment of the present invention capable of manufacturing curved pleats, including curved pleats having unequal legs. In this embodiment, the opposing surfaces 101a, 102a  
10 of the pleating member 101 and the stripper knife 102 are both curved in at least the portions which contact the filter composite during pleating. While a variety of curves, regular or irregular, are suitable for the opposing surfaces, in the  
15 illustrated embodiments the surfaces have an arcuate shape. The pleating member 101 has a front surface 101a with a radius of curvature which is preferably smaller than that along the rear surface 102a of the  
20 stripper knife 102 so that the two surfaces 101a, 102a are separated by a space that increases in size with increasing distance from the surface of the pleating table 100. This space assists in forming pleats with unequal legs. In the illustrated  
embodiment, the stripper knife 102 is pivotably  
25 mounted on a slider 113 which is analogous to the slider 113 of Figure 15, the two sections 100a, 100b of the pleating table 100 abut, and the creaser bar 109 is maintained in an inoperative position beneath the pleating table 100. Pleating is performed using  
30 the embodiment of Figure 18 in essentially the manner illustrated in Figures 6-13, e.g., a filter composite is pressed between the curved surfaces 101a, 102a of the pleating member 101 and the  
stripper knife 102 to form pleats having curved  
35 legs, preferably of unequal length, which can be

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easily formed into a cylindrical laid-over state.

After the filter composite has been pleated by the method of the present invention, the pleated filter composite which emerges from the pleating apparatus is cut to a prescribed length or  
5 prescribed number of pleats determined by the intended dimensions of the filter element. The pleated filter composite is then formed into a cylindrical shape, and the lengthwise edges of the  
10 pleated filter composite are sealed to each other by conventional means to form a cylindrical pleated filter pack. The pleats of the filter pack are then formed into a laid-over state in which the opposing  
15 surfaces of adjoining legs of the pleats contact each other over a substantial portion of the height of the pleats. Because the pleats have curved legs and/or unequal legs, the formation of the cylindrical, pleated filter pack into a laid-over state is greatly facilitated.

20 Figures 19-21 illustrate one suitable method of forming the cylindrical pleated filter element into a laid-over state. A conventional perforated cylindrical core 20 is disposed on a chuck 120, and a cylindrical pleated filter element 10 having  
25 pleats formed by the method of the present invention is disposed loosely over the core 20 as shown in Figure 19. A tubular member 122 having an inner diameter which corresponds to the desired outer diameter of the laid-over filter element 10 is  
30 placed on the upper end of the filter element 10 and pressed downwards as shown by the arrow in Figure 19. The pleats of the filter element 10 are loosely packed prior to being laid over, and the pleats at the upper end of the filter element 10 can usually  
35 be easily compressed so as to fit into the lower end

of the tubular member 122. As the tubular member 122 is pressed downwards over the filter element 10, the pleats of the filter element 10 are laid over against each other until the outer diameter of the filter element 10 matches the inner diameter of the tubular member 122.

When the entire length of the tubular member 122 has been fit over the filter element 10, the tubular member 122, the laid-over filter element 10, and the core 20 are removed from the chuck 120 as a single unit and disposed on another chuck 123, as shown in Figure 20. This chuck 123 has a lower base 124 supporting an upper base 125 by means of a connecting rod 126. The upper base 125 may be disk shaped and preferably has a diameter smaller than the inner diameter of the tubular member 122 but larger than the inner diameter of the laid-over filter element 10. A conventional perforated cylindrical cage 30 having an inner diameter corresponding to the desired outer diameter of the laid-over filter element 10 is then placed atop the tubular member 122 and pressed downwards in the direction of the arrow in Figure 19. The filter pack 121 is prevented from moving downwards by the upper base 125 of the chuck 123, but the tubular member 122 is free to move, so the downwards force exerted on the cage 30 causes it to slide over the laid-over filter element 10 and in the process displace the tubular member 122. The cage 30 is pushed downwards until its lower end reaches the upper base 125 and the tubular member 122 is completely separated from the filter element 10, as shown in Figure 20. The assembly comprising the core 20, the laid-over filter element 10, and the cage 30 can then be removed from the chuck 123 and

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subjected to further processing, such as the installation of end caps on one or both ends by conventional end capping techniques.

Filter elements according to the present invention have a far greater surface area usable for filtration than conventional pleated filter elements for the same inner and outer diameter. For example, for a filter element having longitudinal pleats as shown in Figures 2 and 3, the total surface area A of the filter element is given by the formula

$$A = 2hNL \quad \dots \quad (1)$$

wherein

h is the height of the pleats,

N is the number of pleats in the filter element, and

L is the length of the pleats measured in the axial direction of the filter element.

In a pleated filter element in which adjacent pleats contact one another along the inner diameter of the filter element, the number of pleats N is approximately given by

$$N = \frac{\pi(d+2t)}{2t} \quad \dots \quad (2)$$

wherein t is the thickness of the composite (filter medium + drainage layers + other layers).

In a conventional filter element without laid-over pleats, the pleat height is given by the formula

$$h = \frac{(D - d)}{2} \quad \dots \quad (3)$$

wherein

D is the outer diameter of the filter element, and

d is the inner diameter of the filter element.

In contrast, in a filter element with laid-over pleats such as shown in Figure 2 in which the opposing surfaces of adjoining legs of the pleats are in intimate contact over substantially the entire pleat height, the maximum pleat height  $h_{\max}$  which can be achieved is approximated by the formula

$$h_{\max} = \frac{D^2 - d^2}{4(d + 2t)} \dots \quad (4)$$

In an actual filter with laid-over pleats, the height of the pleats will be less than the maximum pleat height  $h_{\max}$  because, for example, of the difficulty of forming the pleats into perfectly knife-edged pleats. However, the actual pleat height is preferably at least 80% and more preferably at least 90% of  $h_{\max}$  so as to make optimal use of the volume between the inner and outer diameters of the filter element.

Using these formulas, it is possible to calculate the increase in filtering area provided by the filter of the present invention. For a filter element having a length L of 10 inches, a composite thickness t of 0.175 inches, an inner diameter d of 1.2 inches, and an outer diameter D of 2.75 inches, the number N of pleats is given by Equation (2) as

$$N = \frac{\pi \cdot (1.2 + 0.35)}{0.35} = 13$$

The pleat height for a conventional filter and the maximum pleat height for a filter according to the present invention are given by Equations (3) and (4), respectively as

$$h(\text{conventional filter}) = \frac{(2.75 - 1.2)}{2}$$

$$= 0.775 \text{ inches}$$

$$h_{\max}(\text{laid-over pleats}) = \frac{(2.75^2 - 1.2^2)}{4(1.2 + 0.35)}$$

$$= 1.239 \text{ inches}$$

Plugging these values into Equation (1) gives the following surface areas, wherein  $A_{\max}$  is the maximum possible surface area corresponding to a pleat height of  $h_{\max}$ :

$$A(\text{conventional filter}) = 2 \times .775 \times 13 \times 10$$

$$= 201.5 \text{ in}^2$$

$$A_{\max}(\text{laid-over pleats}) = 2 \times 1.239 \times 13 \times 10$$

$$= 322.14 \text{ in}^2.$$

Thus, in this example, the maximum possible filter surface area of a filter according to the present invention having laid-over pleats is approximately 60% greater filter surface area than a conventional pleated filter with the same inner and outer dimensions. Even if the actual height of the laid-over pleats is only 80% of  $h_{\max}$ , the actual filter surface area will still be  $322.14 \times .80 = 257.71 \text{ in}^2$ , which is 28% higher.

The increased surface area of a filter element with laid-over pleats according to the present invention increases the useful life of the filter element compared with a conventional filter element having the same inner and outer dimensions.

Furthermore, having the pleats in a laid-over state results in the pleats being uniformly supported and acts to distribute concentrated loads evenly across the filter element. This minimizes pleat movement and increases the ability of the

pleats to retain particles in pulsating flow system. In addition, when the pleats are in a laid-over state, the end surfaces of the filter element are extremely compact and provide greater resistance to damage of the filter medium during the installation of end caps on the filter element.

The pressure drop  $\Delta P$  across a pleated filter element having upstream and downstream support and drainage layers is given by the following equation:

10            $\Delta P = (K_e h + K_m / 2h) \cdot (\mu Q / Nl)$        ....       (5)  
wherein

$\mu$  = absolute viscosity of fluid being filtered

$Q$  = volumetric flow rate of fluid

$K_e$  = edgewise flow resistance factor of support

15       and

drainage material

$K_m$  = flow resistance factor of filter medium

$h$  = pleat height

$l$  = pleat length in axial direction of filter

20        $N$  = number of pleats.

If all of the factors in Equation (5) are constant except for the pleat height  $h$ , then the pressure drop  $\Delta P$  will be a minimum when the pleat height  $h$  is expressed by the following equation:

25            $h = (K_m / 2K_e)^{1/2}$        ...       (6)

Thus, in situations in which the outer diameter of the filter element can be chosen at will, the pressure drop  $\Delta P$  across a filter according to the present invention can be minimized and the efficiency of the filter can be maximized by choosing the outer diameter so that the pleat height  $h$  satisfies Equation (6).

Means other than a cage can be used to retain the pleats in a laid-over state. For example, the cage could be replaced by a plurality of unconnected

35

rings fitting over the filter element 10 so as to prevent the pleats from unfolding. Another suitable means of retaining the pleats is a sheet of material wrapped around the filter element with sufficient tension to prevent the pleats from unbending from a laid-over state. Figure 22 is a cutaway view of a second embodiment of the present invention in which the cage of Figure 1 is replaced by a helical wrap member 50 comprising a parallel-sided strip of a flexible material which is helically wrapped about the filter element 10 in a plurality of turns. The wrap member 50 can be made of any material which is compatible with the fluid being filtered. If the wrap member 50 completely envelops the outer periphery of the filter element 10, the wrap member 50 is preferable porous. For many application, a porous, polymeric, non-woven material available from Reemay Corporation under the trade designation Reemay is suitable. Laminates of the Reemay material can also be employed. Examples of other suitable materials are oil board paper and mylar film.

The wrap member 50 may be a relatively thin material not intended to resist large stresses, so it would be primarily suitable for use when the filter element 10 is being subjected to outside-to-inside flow. In this case, the wrap member 50 only need be strong enough to maintain the pleats in a laid-over state and to resist radially outward forces occurring during momentary reversals of flow direction of fluid through the filter element 10. Alternatively, the wrap may be formed from a stronger material which resists the relatively larger stresses associated with inside-to-outside flow. The tension of the wrap member 50 can be

selected in accordance with the expected filtering conditions.

The wrap member 50 can be wrapped around the filter element 10 with or without overlap between adjacent turns of the wrap member 50. For example, adjacent turns of the wrap member 50 can abut each other with substantially no overlap, or by employing an overlap, it is possible to wrap multiple layers of the wrap member 50 around the filter element 10. However, it has been found that if the wrap member 50 includes unobstructed openings, the dirt capacity of the filter element 10 can be greatly increased compared to that of an unwrapped pleated filter element or compared to a pleated filter element completely enveloped in a wrap member. The openings may be holes formed in the material of the wrap member 50 itself, or they may be gaps left between adjacent turns of the wrap member 50. In the embodiment of Figure 22, the wrap member 50 is wrapped around the filter element 10 so as to leave openings in the form of a helical gap 51 between adjacent turns.

To prevent the wrap member 50 from becoming loaded, the size of the openings of the wrap member 50 should be large enough to allow the passage of virtually all of the particles contained in the fluid being filtered. Furthermore, the total area of the openings is generally less than 50% of the total surface area of the cylindrical surface defined by the peaks of the pleats 11 of the filter element 10. More preferably, the total area of the openings is in the range from about 6% to about 30% of the total area of the surface defined by the peaks of the pleats 11.

The wrap member 50 is preferably secured in a

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manner which prevents it from becoming unwound from the filter element 10. One method of securing the wrap member 50 is to attach it to the filter element 10 by a bonding agent, such as a hot melt adhesive, which is applied to the wrap member 50 as it is wound around the filter element 10. The bonding agent can be applied to the wrap member 50 in the form of a continuous or intermittent bead which spirals around the filter element 10 parallel to the edges of the wrap member 50. Alternatively, if the wrap member 50 is made of a polymeric material, it may be fusion bonded to the filter element 10 by a hot wheel which travels down the length of the filter element 10 as the filter element 10 is rotated. The wrap member 50 can be attached directly to the filter element 10, or if there is overlap between adjacent turns of the wrap member 50, the adjacent turns can be attached directly to one another. It is also possible to wrap the wrap member 50 around the filter element 10 without directly attaching the two together, and to secure only the portions of the wrap member 50 adjoining the end caps 40 by means of the end caps 40 or by other mechanical means such as crimping.

A wrap member 50 is usually wrapped around a cylindrical filter element by disposing the filter element on a mandrel and rotating the mandrel and the filter element while applying the wrap member to the filter element. The pleats of the filter element can be deformed into the laid-over state at the time of wrapping by use of a funnel-shaped tool 60 like that illustrated in Figure 5. As the mandrel is rotated, the tool 60 can be advanced in the lengthwise direction of the filter element. As the pleats emerge from the exit of the tool 60, they

will be in a laid-over state, and the wrap member 50 can be wrapped around the pleats in this state.

5 The wrap member 50 is not limited to a single strip of material. For example, the wrap member 50 may comprise two strips of material wrapped around the filter element 10 in a double helix.

Alternatively, the wrap member 50 could be wrapped around the filter element 10 in the circumferential direction rather than the helical direction.

10 A number of examples of pleated filter elements according to the present invention are listed below. The components of each filter element are listed from the upstream to the downstream side of the element.

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Element A - Cylindrical element inside an external cage

|    |                                                                                                 |                                                                                           |
|----|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 5  | Upstream drainage layer                                                                         | Nalle extruded polypropylene mesh (NIF.013D 26 x 31)                                      |
| 10 | Filter medium                                                                                   | melt-blown tapered-pore polypropylene medium with a 10-micrometer absolute removal rating |
|    | Downstream drainage layer                                                                       | Nalle extruded polypropylene mesh (NIF.013D 26 x 31)                                      |
| 15 | Number of pleats = 63    Pleat height = .600 in.<br>Cage I.D. = 2.60 in.    Core O.D. = 1.8 in. |                                                                                           |

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Element B - Cylindrical element inside an external cage

|    |                                                                                                    |                                                                                           |
|----|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| 20 | Upstream drainage layer                                                                            | Nalle extruded polypropylene mesh (NIF.013D 26 x 31)                                      |
| 25 | Prefilter                                                                                          | melt-blown tapered-pore polypropylene medium with a 10-micrometer absolute removal rating |
| 30 | Filter medium                                                                                      | melt-blown polypropylene medium with a 6-micrometer absolute removal rating               |
| 35 | Downstream drainage layer                                                                          | Nalle extruded polypropylene mesh (NIF.013D 26 x 31)                                      |
|    | Number of pleats = 58    Pleat height = .650 in.<br>Cage I.D. = 2.60 inches    Core O.D. = 1.8 in. |                                                                                           |

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Element C - Cylindrical element inside an external cage

|    |                                                                                                 |                                                                                                                         |
|----|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------|
| 5  | Upstream drainage layer                                                                         | Nalle extruded polypropylene mesh (NIF.020S 16 x 16)                                                                    |
| 10 | Prefilter                                                                                       | fibrous depth filter made of thick polypropylene fibers and a 90-micrometer absolute removal rating                     |
| 15 | Filter medium                                                                                   | fibrous depth filter made of thick polypropylene fibers. About .080 inches thick. 20-micrometer absolute removal rating |
| 20 |                                                                                                 |                                                                                                                         |
|    | Downstream drainage layer                                                                       | Nalle extruded polypropylene mesh (NIF.020S 16 x 16)                                                                    |
| 25 | Number of pleats = 24    Pleat height = .830 in.<br>Cage I.D. = 2.45 in.    Core O.D. = 1.3 in. |                                                                                                                         |

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Element D - Cylindrical element with a helical wrap

|    |                           |                                                                                                   |
|----|---------------------------|---------------------------------------------------------------------------------------------------|
| 30 | Upstream drainage layer   | Nalle extruded nylon mesh (NIF.020S 15 x 15)                                                      |
|    | Cushioning layer          | Reemay 2250 non-woven polyester                                                                   |
| 35 | Filter medium             | glass fiber medium with a 6-micrometer absolute removal rating on a non-woven polyester substrate |
| 40 | Downstream drainage layer | Nalle extruded nylon mesh (NIF.020S 15 x 15)                                                      |

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|                                                                                                      |                                                     |                                                                                                    |
|------------------------------------------------------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------------------------------------------------|
| 5                                                                                                    | Helical wrap                                        | Reemay 2024 non-woven polyester attached to filter element with polyamide hot melt beads           |
| Number of pleats = 63    Pleat height = .750 in.<br>Core O.D. = 1.875 in.    Element O.D. = 3.02 in. |                                                     |                                                                                                    |
| 10                                                                                                   | Element E - Cylindrical element with a helical wrap |                                                                                                    |
| 15                                                                                                   | Upstream drainage layer                             | Nalle extruded nylon mesh<br>(NIF.020S 15 x 15)                                                    |
| 15                                                                                                   | Cushioning layer                                    | Reemay 2250 non-woven polyester                                                                    |
| 20                                                                                                   | Filter medium                                       | glass fiber medium with a 12-micrometer absolute removal rating on a non-woven polyester substrate |
| 25                                                                                                   | Downstream drainage layer                           | Nalle extruded nylon mesh<br>(NIF.020S 15 x 15)                                                    |
| 30                                                                                                   | Helical wrap                                        | Reemay 2024 non-woven polyester attached to filter element with polyamide hot melt beads           |
| Number of pleats = 40    Pleat height = .530 in.<br>Core O.D. = 1.123 in.    Element O.D. = 1.93 in. |                                                     |                                                                                                    |

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Element F - Cylindrical element inside an external cage

|    |                                                                                           |                                                              |
|----|-------------------------------------------------------------------------------------------|--------------------------------------------------------------|
| 5  | Upstream drainage layer                                                                   | Reemay 2011 non-woven polyester                              |
|    | Upstream filter medium                                                                    | nylon membrane with a 0.2-micrometer absolute removal rating |
| 10 | Downstream filter medium                                                                  | same as upstream medium                                      |
|    | Downstream drainage layer                                                                 | Reemay 2011 non-woven polyester                              |
| 15 | Number of pleats = 127 Pleat height = .86 in.<br>Cage I.D. = 2.65 in. Core O.D. = 1.4 in. |                                                              |

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Element G - Cylindrical element inside an external cage

|    |                                                                                            |                                                                                                                     |
|----|--------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| 20 | Upstream drainage layer                                                                    | PTFE non-woven with an FEP binder                                                                                   |
| 25 | Filter medium                                                                              | UP00 series membrane (PTFE membrane available from Sumitomo Electric under the trade name Poreflon. Suitable grade) |
| 30 | Downstream drainage layer                                                                  | PTFE non-woven with an FEP binder                                                                                   |
|    | Number of pleats = 140 Pleat height = .49 in.<br>Cage I.D. = 2.46 in. Core O.D. = 1.68 in. |                                                                                                                     |

35 An FEP strip was corrugated into each end of the filter element to aid in attaching the end caps to the filter element.

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In each of the above examples, the opposing surfaces of adjoining legs of the pleats were in intimate contact over the entire axial length of the filter element.

5       The illustrated embodiments of the present invention are intended for use with outside-in radial fluid flow through the filter element. However, it is also possible to use a filter according to the present invention for inside-out  
10 radial flow. A fluid to be filtered, i.e., a liquid or a gas, is directed through the laid-over pleats 11 of the filter element 10 of the filter. The fluid is distributed by the upstream drainage layer 13 along the entire upstream surface of the filter  
15 medium 12, even those regions of the filter medium 12 deep within the filter element 10 near the core 20. The fluid then passes through the filter medium 12, filtering the fluid and depositing particulates on or within the filter medium 12. From the  
20 downstream side of the filter medium 12, the filtered fluid drains along the downstream drainage layer 14, enters the interior of the perforated core 20, and then exits the filter.

      The filter may be cleaned by directing a  
25 cleaning fluid in the opposite direction through the filter. The cleaning fluid may be a gas which is blown back through the filter or it may be a liquid which is backwashed through the filter. For  
example, a backwash liquid, such as water, may be  
30 directed from the interior of the perforated core 20 through the laid-over pleats 11 of the filter element 10. The backwash liquid is distributed by the downstream drainage layer 14 along the entire downstream surface of the filter medium 12, even  
35 those regions of the filter medium 12 distant from

the core 20 near the cage 30 or the wrap 50. The backwash liquid then passes through the filter medium 12, driving the particulates from within the filter medium 12 and/or from the upstream surface of the filter medium 12. The particulates are then flushed through the upstream drainage layer 13 and expelled from the filter with the backwash liquid. The ratio of the amount of backwash liquid flushed through the filter element to the amount of fluid filtered through the filter element may be as much as about 10 and more preferably in the range of about 2 to about 4.

While filters embodying the present invention are useful in a wide variety of applications, one particularly advantageous use is as a precoat filter. One example of a precoat filter 130 is shown in Figure 23 and generally comprises a perforated core 20 and a laid-over filter element 10 which may be similar to those of the filter shown in Figure 1. In addition, the precoat filter 130 comprises a wrap 50 which serves as a septum for holding a precoat layer 131 and a protection member 132 for protecting the precoat layer 131 from erosion.

To support the filter element 10 and the septum 50 against radially directed forces, the core 20 may comprise any sufficiently strong, rigid material which is compatible with the fluid being purified, as previously described. However, while the precoat filter preferably includes a perforated core, the core may be omitted, for example, where the filter element has sufficient structural integrity to withstand the radially directed forces without the core.

The filter element 10 may be a single layer or

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a multi-layer composite and may comprise any suitable filter medium as well as a drainage means and a cushioning layer, as previously described. For example, where the precoat filter is to be used for nuclear condensate polishing in which the fluid to be purified is water, the filter element 10 may comprise a filter medium sandwiched between an upstream drainage layer and a downstream drainage layer. Each drainage layer may comprise a polypropylene extruded mesh. The filter medium preferably includes a fibrous medium comprising aromatic polyamide fibers, such as those available under the trade designation Kevlar from Du Pont de Nemours E.I. Co., which are fibrillated and resin-bonded to a cellulose or non-woven polymeric substrate forming the downstream side of the medium. The pore size of the filter medium is preferably sufficiently small for the filter medium to be able to capture substantially all of the particulates in the precoat material, so that any fine particles in the precoat material which pass through the septum will be trapped by the filter medium. The pore size of the filter medium may also be small enough to capture additional fines in the fluid to be filtered, fines which may be too small to be intercepted by the precoat layer 131.

The septum 50 preferably comprises a flexible, porous wrap wrapped around and completely covering the outer periphery of the filter element 10, as previously described. Preferably, the septum 50 is sufficiently strong so that it can serve not only as a support for the precoat layer 131 but also as a means for keeping the filter element 10 in a laid-over state, both during filtration (when the precoat filter is subjected to radially inward flow) and

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during backwashing (when the precoat filter element is subjected to radially outward flow). The septum 50 is also preferably strong enough to resist the radial outward pressures acting on the precoat filter during backwashing. Commonly, these pressures are in the range of approximately 10 psi to approximately 100 psi.

The septum 50 is preferably selected to have a pore size such that it can prevent passage of most of the particles in the precoat material, allowing a cake of precoat material to build up on the upstream surface of the septum. If the smallest particles in the precoat material pass through the septum 50, they can be captured by the filter element 10 which has a very high dirt capacity and therefore does not become clogged by the fine particles. Since the septum 50 does not need to hold all the particles in the precoat material, it can have a porosity which enables it to be used for long periods of time before needing to be cleaned or replaced.

The material of which the septum 50 is made will depend upon the characteristics of the fluid being filtered and of the precoat material. For example, a suitable septum material is a woven mesh of a corrosion resistant metal, such as stainless steel. A variety of weaves are suitable, including a square weave and a Dutch twill weave, with the square weave being the preferable of the two because it is thinner and therefore easier to handle. In other applications, the septum can be a polymeric mesh or a non-woven polymeric fabric. For nuclear condensate polishing, a preferred material for the septum is a 120 x 180 x 0.004 (inch) x 0.0035 (inch) square weave stainless steel mesh.

The septum can be applied to the filter element

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in any manner such that all fluid flowing inward through the filter element must first pass through the septum. Preferably, the septum bears against the filter element and more preferably directly contacts the filter element. In the present embodiment, the septum 50 is in the form of a strip with parallel sides which is helically wound around the filter element 10 a plurality of turns over the entire length of the filter element. In order to prevent the precoat material from bypassing the septum 50, adjacent turns of the septum 50 preferably overlap one another. The amount of overlap can be selected based on the desired thickness of the septum 50. For example, by wrapping the septum 50 with an overlap of 50%, a double thickness of the septum 50 can be provided around the filter element 10. The septum 50 need not be in the form of a helical wrap and could instead be wrapped in the circumferential direction of the filter element 10, for example. However, a helical wrap is advantageous in that a septum 50 with a narrow width can be used to wrap a filter element 10 any length. A suitable cutting method such as laser cutting may be used to ensure there are no sharp edges on the septum strip.

The septum 50 is preferably restrained from movement in a manner which prevents it from unwinding from the filter element during normal handling and operation. One method of securing the septum 50 is to attach it to the outer periphery of the filter element 10 a bonding agent, such as a hot melt adhesive, applied to the inner surface of the septum 50 as it is wound around the filter element 10. The bonding agent can be applied to the septum 50 in the form of a continuous or intermittent bead

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which spirals around the filter element 10 parallel to the edges of the septum 50. Alternatively, if the septum 50 is made of a polymeric material, it may be fusion bonded to the filter element 10 by a hot wheel which travels down the length of the filter element 10 as the filter element 10 is rotated. Instead of or in addition to the septum 50 being attached directly to the filter element 10, if there is overlap between adjacent turns of the septum 50, the adjacent turns can be attached directly to one another by welding or bonding, for example. However, in many cases, it is sufficient to wrap the septum 50 around the filter element 10 without directly attaching the two together and without securing adjacent turns of the septum 50 to one another, and to secure only the end portions of the septum 50 adjoining the axial ends of the filter element 10 by bonding, by fixing the septum 50 to the end caps, or by other mechanical means such as adhesive tape or a metal band such as a stainless steel band.

When the precoat is applied to the precoat filter and when the fluid to be filtered is passed through the precoat filter, fluid flows radially inward through the precoat filter and undergoes a pressure drop as it does so. Due to the pressure drop, a radially inward force acts on the filter element. A conventional pleated element with radially-extending pleats may compress or collapse due to this inwardly directed force. This compression would cause the septum to wrinkle or buckle, and this would cause the precoat layer to crack and break, which is undesirable. However, because the pleats of a precoat filter 130 embodying this aspect of the present invention are laid over

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on one another the septum 50 may be initially wrapped around the filter element 10 very tightly without damaging the pleats. The denser is the filter element 10 prior to the start of filtration; the smaller is the amount of compression of the filter element 10, the septum 50, and the precoat layer 131 during filtration. Therefore, the septum 50 is preferably wrapped around the filter element 10 with sufficient initial tension that the precoat layer 131 will not crack under the expected operating pressures of the precoat filter. For example, the septum 50 may be wound around the filter element 10 using a tension of up to about 30 pounds or more per inch of width. The initial tension of the septum 50 will depend upon the factors such as the nature of the precoat filter 130 and the operating pressures during filtration. Preferably, the septum 50 is wrapped with an initial tension such that the compression of the diameter of the precoat filter 130 due to the pressure drop across the precoat filter 130 during filtration will be no greater than approximately 5%. Tightly winding the filter element 10 with the septum 50 not only compresses the filter element 10 prior to filtration, but it also prevents movement of the pleats during fluctuations in the pressure across the precoat element, movement which could cause cracking of the precoat layer 131.

Even though adjoining legs of the pleats of the filter element 10 are pressed into intimate contact with one another when the pleats are in a laid-over state, due to the provision of the drainage layers, fluid can easily flow along the upstream and downstream surfaces of the filter medium. Therefore, tightly winding the filter element 10

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with the septum 50 does not impair the filtering capability of the precoat filter 130.

The septum 50 may be surrounded by a protective member 132 which acts as a flow straightener to prevent turbulence in the fluid surrounding the precoat filter from eroding the precoat layer 131. The protective member 132 also supports the precoat layer 131 during brief periods during which radially inward flow through the precoat filter 130 is decreased or stopped. The protective member 132 can be made of a variety of materials which are sufficiently porous that the precoat material can readily pass through it. One example of a suitable material for the protective member 132 is a polymeric knit mesh, as disclosed in U.S. Patent No. 4,904,380, which can be disposed around the septum 50 by various techniques. For example, it can be in the form of a mesh strip wrapped around the septum 50 as a helical wrap, or it can be in the form of a sleeve, either of which may extend completely or only partially along the precoat element.

The precoat filter also comprises end caps which may be fixed to one or more of the core, the laid-over filter element, and the septum in any suitable manner, as previously described. The end caps can be used to secure the ends of the septum 50 and prevent it from unwinding. If the ends of the septum 50 are restrained prior to the installation of the end caps by mechanical restraining members such as tape or bands, the end caps can be installed over the restraining members. Although not shown, the end caps can be equipped with conventional sealing members such as gaskets or O-rings for sealingly connecting the precoat filter to a filtration system in which it is to be employed.

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The precoat filter may further include a perforated cage or similar member surrounding the protective member 132 to keep the protective member 132 in place and to give the precoat filter added strength. The cage has openings formed therein which are preferably sufficiently large so as not to obstruct the flow of fluid and produce no significant pressure drop. The cage can have a conventional construction and can be made of any material compatible with the fluid being filtered.

A precoat filter with laid-over pleats is preferable to a conventional pleated filter because it has a much larger surface area than a conventional pleated filter having the same inner and outer dimensions. This means that the precoat filter with laid-over pleats has a longer useful life and can capture fine particles of the precoat layer 131 which pass through the septum 50 for extended periods without fouling.

In addition, because the pleats are laid over, they better resist damage due to the compressive forces generated when the septum 50 is wrapped around the filter element 10 and when the fluid flows through the precoat layer 131 and the precoat filter 130. These forces are spread out along the leg of each laid-over pleat rather than concentrated at the crest of a conventional radially-extending pleat. Consequently, the septum 50 may be wrapped more tightly around a laid-over filter element 10 and the laid-over filter element 10 can withstand greater precoat pressure differentials without damage than a conventional pleated filter.

Furthermore, having the pleats in a laid-over state results in the pleats being uniformly supported and acts to distribute concentrated loads

evenly across the precoat filter. This minimizes pleat movement and increases the ability of the pleats to retain particles in pulsating flow systems. In addition, when the pleats are in a laid-over state, the end surfaces of the filter element are extremely compact and provide greater resistance to damage of the filter medium during the installation of end caps on the ends of the filter pack.

10       The precoat layer 131 is usually applied to the septum 50 after the precoat filter has been installed in a filtration system. The precoat material may be selected in accordance with the fluid which is being filtered, and a precoat filter according to the present invention is not restricted to use with any particular type of precoat material. In a condensate polishing system for a nuclear power plant, the precoat material frequently comprises ion exchange resins. Alternatively, the precoat material may comprise any other suitable material, such as diatomaceous earth. The thickness of the precoat layer 131 will depend upon the desired filtration characteristics and/or ion exchange characteristics. The precoat layer 131 can be applied to the septum 50 by any suitable method, such as those commonly used in existing filtration systems employing precoat filters. For example, a slurry containing the precoat material may be directed outside-in through the precoat filter 130 until a sufficient cake is deposited on the septum 50 and within the protection member 132.

With the precoat layer 131 on the septum 50, the fluid to be filtered, typically a liquid, may be passed through the precoat layer 131, the septum 50, and the filter element 10. The precoat layer 131

may serve both to remove particulates, e.g., by trapping the particulates within the precoat layer 131, and to remove impurities, e.g., by means of ion exchange or sorption. The filter element 10 may  
5 serve to capture small particles of the precoat layer 131 which become dislodged from the precoat layer 131 and pass through the septum 50. Further, the pleated filter element 10, with its large surface area, may have a small enough pore size to  
10 remove fines from the fluid to be filtered which would otherwise pass through the precoat layer 131 and the septum 50. Thus, the pleated filter element may have a pore rating which is smaller than the pore rating of the precoat layer or the septum.

15 The precoat layer 131 can be removed from the septum 50 by backwashing when it becomes depleted or so clogged with particulate matter that the pressure drop across the septum 50 or the filter element 10 is unacceptably high. Backwashing is accomplished  
20 by passing a backwash fluid, such as water, through the precoat filter in the opposite direction from during filtration, e.g., inside-out through the precoat filter, as previously described. The protective member 132 is sufficiently porous that  
25 the precoat layer 131 can be readily dislodged from it and then suitably disposed of. Again, due to the provision of the drainage layers, backwash fluid can readily flow along the upstream and downstream surfaces of the filter medium even with the septum  
30 50 tightly wrapped around the filter element 10. Consequently, the flow rate, pressure, and other parameters of the backwash fluid during backwashing can be those commonly used with conventional precoat filters. The backwashing may be carried out at set  
35 time intervals, or it may be carried out whenever

the pressure drop across the precoat filter 130 during the filtering operation has reached a predetermined level indicating that the filter element 10 or the septum 50 has become clogged. The backwashing serves not only to remove the precoat layer 131 from the septum 50 but also to clean the filter element 10 by dislodging particles from within the filter element 10. After the precoat layer 131 has been removed by backwashing, a fresh precoat layer 131 can be applied in the same manner as the original precoat layer 131, and the precoat element can again be used for filtration.

A precoat element according to the present invention is not restricted to one having laid-over pleats, and it is possible to wrap the septum around a conventional pleated element having radially-extending pleats not in a laid-over state with the septum bearing against and preferably directly contacting the pleats. However, radially-extending pleats have a low buckling strength, and the septum must be wrapped around such a pleated element fairly loosely to prevent buckling. As a result, during the filtering operation, the pleats may undergo relative movement or may compress in response to the differential pressure across the precoat layer, which can result in deformation of the septum with accompanying cracking of the precoat layer. Nevertheless, in applications in which only a small pressure drop occurs across the precoat filter during filtration and the pleats undergo little relative movement, it may be possible to wrap the septum around the conventionally pleated element with a sufficiently low tension to enable a conventional pleated element to be employed as a precoat element.

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Figure 24 illustrates a second precoat filter 140 in accordance with the present invention. To overcome the weakness of conventional radially-extending pleats, the pleats of the filter element 10 are formed into a plurality of groups 141, each containing a plurality of pleats and adjacent groups 141 of pleats are separated by wedge-shaped support members 142. A filter element having pleats grouped by wedge supports is described in detail in U.S. Patent No. 4,154,688. The second precoat filter 140 further comprises end caps and a septum 50 wrapped around the filter element 10 and may include a protection member 132, as previously described. Further, the second precoat filter 140 may be precoated and backwashed as previously described.

The wedge supports 142 of the second precoat filter 140 rigidify the pleats so the septum 50 may be tightly wound around the filter element 10 and the second precoat filter 140 can withstand large pressure differentials. However, the wedge supports 142 decrease the available filtration area, so the second precoat filter 140 is less preferred than the first precoat filter 130.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A filter which removes one or more substances from a fluid flowing through the filter, the filter comprising a pleated filter element including a longitudinal axis, first and second end surfaces, an inner periphery, an outer periphery and a plurality of longitudinal pleats, wherein each pleat includes a crown, a root, and a pair of legs and wherein the legs of each pleat are joined to one another at the crown of the pleat and are joined to legs of adjacent pleats at the root of the pleat, wherein each pleat leg abuts an adjacent pleat leg along the inner periphery of the filter element and the pleats extend from the inner periphery in a curved, an arcuate, an angled or a straight-nonradial direction to the outer periphery, wherein the height of each pleat, measured in a direction along the legs and extending from the inner periphery at the root of the filter element to the outer periphery at the crown of the filter element, is greater than  $(D-d)/2$  and less than  $(D^2 - d^2)/[4(d+2t)]$ , where  $D$  and  $d$  are the outer diameter and the inner diameter of the filter element at the outer periphery and the inner periphery, respectively, and  $t$  is the thickness of each leg, and wherein the pleated filter element comprises a pleated composite including a filter medium having an upstream side and a downstream side, an

upstream drainage medium positioned upstream of the upstream side of the filter medium and a downstream drainage medium positioned downstream from the downstream side of the filter medium, wherein fluid to be filtered flows along the upstream drainage medium to the filter medium, the upstream drainage medium distributing fluid to be filtered along the pleats between the roots and the crowns and along the upstream side of the filter medium and allowing the filter medium to be used for filtration, the fluid to be filtered then flowing through the filter medium, the filter medium having a filtering characteristic which removes one or more substances from fluid flowing through the filter medium, and wherein filtered fluid then flows from the filter medium along the downstream drainage medium, the downstream drainage medium draining filtered fluid from the downstream surface of the filter medium along the pleats between the roots and the crowns, and the filter further comprising first and second end elements sealingly arranged with the first and second end surfaces, respectively, of the pleated filter element, wherein at least one of the end elements comprises an open end element.

2. The filter of claim 1, wherein at least one of the upstream drainage medium and the downstream drainage medium comprises a mesh.

3. The filter of claim 2, wherein the mesh has a mesh count of at least 10 strands per inch.
4. The filter of claim 2 or 3, wherein the mesh comprises an extruded polymeric mesh.
5. The filter of claim 2, 3 or 4, wherein the mesh comprises a first set of strands and a second set of strands disposed between the first set of strands and the filter medium.
6. The filter of claim 1, wherein at least one of the upstream drainage medium and downstream drainage medium comprises a woven or nonwoven fabric.
7. The filter of any one of claims 1 to 6, wherein the upstream and downstream drainage media comprise identical materials.
8. The filter of any one of claims 1 to 7, wherein the upstream and downstream drainage media have approximately the same edgewise flow resistance.

9. The filter of any one of claims 1 to 6, wherein the upstream drainage medium and the downstream drainage medium have different drainage characteristics.

10. The filter of claim 9, wherein the upstream drainage medium and the downstream drainage medium have different thicknesses.

11. The filter of claim 10, wherein the upstream drainage medium is thicker than the downstream drainage medium.

12. The filter of any one of claims 1 to 11, wherein the filter element further comprises a cushioning layer positioned between the filter medium and at least one of the upstream drainage medium and the downstream drainage medium.

13. The filter of any one of claims 1 to 12, wherein the filter medium comprises a porous polymeric membrane.

14. The filter of any one of claims 1 to 12, wherein the filter medium comprises a fibrous material.

15. The filter of any one of claims 1 to 14, wherein the filter medium has a graded pore structure including a finer

pored region and a coarser pored region disposed upstream of the finer pored region.

16. The filter of any one of claims 1 to 15, wherein the filter medium comprises at least first and second filter medium layers.

17. The filter of claim 16, wherein the first and second filter medium layers have different filtering characteristics.

18. The filter of claim 16 or 17, wherein the first filter medium layer comprises a prefilter.

19. The filter of any one of claims 1 to 18, further comprising a retaining member for retaining the pleats.

20. The filter according to claim 19, wherein the retaining member comprises a porous wrap.

21. The filter according to claim 19, wherein the retaining member comprises a perforated cage.

22. The filter of any one of claims 1 to 21, further comprising a perforated core disposed along the inner periphery of the filter element.

23. The filter of any one of claims 1 to 21, wherein the filter is coreless.

24. The filter according to any one of claims 1 to 23, wherein one of the first and second end elements comprises an end cap.

25. The filter according to claim 24, wherein both of the first and second end elements comprise end caps.

26. The filter of any one of claims 1 to 25, wherein the pleats extend in a curved or arcuate fashion.

27. The filter of any one of claims 1 to 26, wherein each pleat has a height of at least about 80% of  $(D^2 - d^2)/[4(d+2t)]$ .

28. The filter of claim 27, wherein each pleat has a height of at least about 90% of  $(D^2 - d^2)/[4(d+2t)]$ .

29. A method of making a filter comprising:

corrugating a composite including an upstream drainage medium, a filter medium, and a downstream drainage medium to form a plurality of pleats wherein each pleat includes a crown, a root, and a pair of legs and wherein the legs of each pleat are joined to one another at the crown of the pleat and are joined to legs of adjacent pleats at the root of the pleat;

arranging the plurality of pleats into a cylindrical filter element including first and second end surfaces and longitudinally extending pleats wherein the height of each pleat, measured in a direction along the legs and extending from the inner periphery at the root to the outer periphery at the crown, is greater than  $(D-d)/2$  and is less than or equal to about  $(D^2 - d^2)/[4(d+2t)]$  where  $D$  and  $d$  are the outer diameter and the inner diameter of the filter element at the outer periphery and the inner periphery, respectively, and  $t$  is the thickness of a pleat leg;

sealing first and second end elements to the first and second end surfaces, respectively, of the pleated filter element, wherein at least one of the end elements comprises an open end element; and

positioning a retainer around the plurality of pleats.

30. The method of claim 29, wherein at least one of the upstream drainage medium and the downstream drainage medium comprises a mesh and wherein arranging the pleats includes pressing a mesh drainage medium of one leg against a mesh drainage medium of an adjoining leg.

31. The method of claim 30, wherein pressing the mesh drainage media includes pressing the strands of the mesh drainage medium of one leg against the strands of the mesh drainage medium of the adjoining leg.

32. The method of any one of claims 29 to 31, wherein corrugating the composite includes forming each pleat with a first leg and a second longer leg.

33. The method of any one of claims 29 to 32, wherein arranging the plurality of pleats includes sealing longitudinal edges of the pleated filter composite to each other.

34. The method of any one of claims 29 to 33, wherein arranging the plurality of pleats includes forming the pleats into a cylindrical configuration and then twisting the pleats.

35. The method of any one of claims 29 to 34, further comprising positioning the plurality of pleats around a perforated core.

36. The method of any one of claims 29 to 35, wherein positioning a retainer includes positioning a perforated cage around the plurality of pleats.

37. The method of any one of claims 29 to 35, wherein positioning a retainer includes wrapping a wrap member around the filter element.

38. The method of claim 37, wherein wrapping the wrap member comprises helically wrapping a porous strip around the filter element.

39. The method of any one of claims 29 to 38, wherein arranging the pleats includes forming the filter element to include longitudinally extending pleats each having a height at least approximately 80% of  $(D^2 - d^2)/[4(d+2t)]$ .

40. The method of any one of claims 29 to 39, further comprising forming a substantially smooth radius at the crown of each pleat.

41. A filter comprising:

a cylindrical filter element having a filter medium and a drainage means extending along at least one side of the filter medium, a longitudinal axis, first and second end surfaces, and a plurality of longitudinal pleats, each of the pleats having a pair of legs, each of the legs having a first and a second surface, the pleats being in a laid-over state in which the heights of the pleats are greater than  $(D-d)/2$ , where D and d are the outer and inner diameters of the filter element, respectively, and in which the first surface of one leg of one pleat is in intimate contact with the first surface of an adjoining leg of said one pleat and the second surface of said one leg is in intimate contact with the second surface of an adjoining leg of an adjacent pleat over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element; and

a first impervious end cap connected to the first end surface of the filter element.

42. The filter of claim 41, wherein the filter element comprises a pleated composite comprising the filter medium and the drainage means, wherein the filter medium has an upstream side and a downstream side and the drainage means

includes at least one of an upstream drainage layer disposed upstream of the upstream side of the filter medium and a downstream drainage layer disposed downstream of the downstream side of the filter medium.

43. The filter of claim 42, wherein at least one of the drainage layers comprises a mesh.

44. The filter of claim 43, wherein the mesh has a mesh count of at least 10 strands per inch (25.4 mm) and the strands of the mesh in one leg are pressed against the strands of the mesh in an adjoining leg.

45. The filter of claim 42, wherein at least one of the drainage layers comprises a woven or nonwoven fabric.

46. The filter of any one of claims 42 to 45, wherein the filter medium comprises a porous polymeric membrane.

47. The filter of any one of claims 42 to 45, wherein the filter medium comprises a fibrous material.

48. The filter of any one of claims 41 to 47, wherein the pleats extend in a curved or an arcuate manner from a

radial inner periphery towards a radial outer periphery of the filter element.

49. The filter of any one of claims 41 to 48, wherein each pleat has a smooth radius along a radial outer periphery of the filter element.

50. The filter of any one of claims 41 to 49, wherein the continuous region extends from at least approximately 75% of the axial length of the filter element.

51. The filter of claim 50, wherein the continuous region extends for at least approximately 95% of the axial length of the filter element.

52. The filter of any one of claims 41 to 51, wherein each pleat has a height of at least approximately 80% of  $(D^2 - d^2)/[4(d+2t)]$  wherein D is an outer diameter of the filter element, d is an inner diameter of the filter element, and t is a thickness of each leg of the pleat.

53. The filter of any one of claims 41 to 52, further comprising a retaining member for retaining the pleats in the laid-over state.

54. The filter of claim 53, wherein the retaining member comprises a cage disposed around the filter element and having openings for the passage of fluid.

55. The filter of claim 53, wherein the retaining member comprises a wrap member helically wrapped around the filter element in a plurality of turns.

56. The filter of any one of claims 41 to 55, further comprising a second impervious end cap attached to the second end surface of the filter element, at least one of the first and second end caps being an open end cap.

57. The filter of any one of claims 41 to 56, wherein there is substantially no empty space between adjacent pleats.

58. The filter of any one of claims 41 to 57, wherein substantially all of the volume between inner and outer peripheries of the filter element is occupied by the pleated filter element.

59. The filter of any one of claims 41 to 58, wherein the filter is coreless.

60. A method of making a filter comprising:

arranging a plurality of pleats into a cylindrical, laid-over state to form a filter element including longitudinally extending pleats having a height greater than  $(D-d)/2$ , where  $D$  and  $d$  are the outer and inner diameters of the filter element, wherein the pleats of the filter element include a filter medium and a drainage means extending along at least one side of the filter medium and wherein arranging the pleats includes intimately contacting a first surface of one leg of one pleat with the first surface of an adjoining leg of said one pleat and a second surface of said one leg with the second surface of an adjoining leg of an adjacent pleat over substantially the entire height of each leg and over a continuous region extending for at least approximately 50% of the axial length of the filter element; and

sealing at least a first end of the filter element to prevent axial flow through the filter medium at the first end.

61. The method of claim 60, further comprising corrugating a composite including the filter medium and the drainage means, the drainage means including at least one of an upstream drainage layer and a downstream drainage layer, to form a plurality of pleats, wherein arranging the plurality of

pleats comprises arranging a plurality of pleats of the composite into a cylindrical, laid-over state.

62. The method of claim 60, further comprising corrugating a composite including the filter medium and the drainage means, the drainage means including an upstream drainage layer and a downstream drainage layer and the filter medium being disposed between the upstream drainage layer and the downstream drainage layer, to form a plurality of pleats, wherein arranging the plurality of pleats comprises arranging a plurality of pleats of the composite into a cylindrical, laid-over state.

63. The method of claim 61 or 62, wherein corrugating the composite includes forming each pleat with a first leg and a second longer leg.

64. The method of any one of claims 60 to 63, wherein arranging the plurality of pleats includes forming the pleats into a cylindrical configuration and then forming the pleats into a laid-over state.

65. The method of claims 64, wherein contacting the surfaces of the legs includes twisting the pleats to lay the pleats over against one another.

66. The method of any one of claims 60 to 63, wherein arranging the plurality of pleats includes forming the pleats into a laid-over state and then forming the pleats into a cylindrical configuration.

67. The method of any one of claims 60 to 66, further comprising sealing longitudinal edges of the pleated filter composite or medium to each other.

68. The method of any one of claims 60 to 67, further comprising positioning the plurality of pleats around a perforated core.

69. The method of any one of claims 60 to 68, further comprising retaining the pleats in the laid-over state.

70. The method of claim 69, wherein retaining the pleats includes positioning a perforated cage around the plurality of pleats.

71. The method of claim 69, wherein retaining the pleats includes wrapping a wrap member around the filter element.

72. The method of claim 71, wherein wrapping the wrap member includes helically wrapping the wrap member around the filter element.

73. The method of any one of claims 60 to 72, wherein contacting adjoining legs includes pressing the strands of a drainage mesh of one leg against the strands of the drainage mesh of an adjoining leg.

74. A pleating apparatus comprising:

- a support surface for supporting a filter material to be pleated;

- a first member having a first pleating surface;

- a second member having a second pleating surface spaced from the first pleating surface by a gap for receiving the filter material to be pleated, at least one of the first and second pleating surfaces being curved or extending at an acute angle to the support surface; and

- a driver for producing relative movement of the first member and the second member and compressing the filter material within the gap between the first and second pleating surfaces to form a pleat.

75. The pleating apparatus of claim 74, wherein both pleating surfaces are curved or extend at an acute angle to the support surface.

76. The pleating apparatus of claim 74, wherein both pleating surfaces extend at an acute angle to the support surface.

77. The pleating apparatus of claim 74, wherein both pleating surfaces are curved.

78. The pleating apparatus of claim 74, wherein at least one of the pleating surfaces extends at an angle within the range from about  $15^{\circ}$  to about  $75^{\circ}$  with respect to the support surface.

79. The pleating apparatus of claim 74, wherein at least one of the pleating surfaces extends at an angle within the range from about  $30^{\circ}$  to about  $60^{\circ}$  with respect to the support surface.

80. The pleating apparatus of any one of claims 74 to 79, wherein both pleating surfaces are curved or extend at an acute angle towards a direction from which the filter

material is introduced to the first and second members during pleating.

81. The pleating apparatus of any one of claims 74 to 80, wherein the first pleating surface is on a wedge-shaped portion of the first member.

82. The pleating apparatus of any one of claims 74 to 81, further comprising a driver for raising and lowering the second member with respect to the support surface.

83. The pleating apparatus of any one of claims 74 to 82, wherein the pleating surfaces are non-parallel to each other.

84. The pleating apparatus of any one of claims 74 to 83, wherein the pleating surfaces converge towards the support surface.

85. The pleating apparatus of any one of claims 74 to 84, wherein the pleating surfaces are sloped with respect to each other by an angle of approximately  $5^{\circ}$ .

86. The pleating apparatus of any one of claims 74 to 85, wherein the second member comprises a plate.

87. The pleating apparatus of any one of claims 74 to 86, wherein the second member is pivotable about an axis parallel to the support surface.

88. The pleating apparatus of any one of claims 74 to 87, further comprising a third member movably disposed between the first and second members for urging the filter material away from the support surface.

89. The pleating apparatus of claim 88, wherein the third member is movable perpendicular to the support surface.

90. A pleating method comprising:

disposing a filter material on a support surface;

inserting a portion of the filter material between first and second pleating surfaces, at least one of the first and second pleating surfaces being curved or extending at an acute angle with respect to the support surface; and

compressing the portion of the filter material between the pleating surfaces and forming a pleat.

91. The pleating method of claim 90, wherein forming a pleat comprises forming a pleat having adjoining legs of unequal length.

92. The pleating method of claim 90 or 91, wherein compressing the filter material includes compressing the filter material between pleating surfaces both of which are curved or extend at an acute angle to the support surface.

93. The pleating method of claim 90 or 91, wherein compressing the filter material includes compressing the filter material between pleating surfaces both of which extend at an acute angle to the support surface.

94. The pleating method of claim 90 or 91, wherein compressing the filter material includes compressing the filter material between pleating surfaces both of which are curved.

95. The pleating method of claim 90 or 91, wherein compressing the filter material includes compressing the filter material between pleating surfaces at least one of which extends at an angle within the range from about 15° to about 75° with respect to the support surface.

96. The pleating method of claim 90 or 91, wherein compressing the filter material includes compressing the filter material between pleating surfaces at least one of

which extends at an angle within the range from about 30° to about 60° with respect to the support surface.

97. The pleating method of any one of claims 90 to 96, wherein compressing the filter material includes compressing the filter material between pleating surfaces both of which are curved or extend at an acute angle towards a direction from which filter material is introduced to the first and second members during pleating.

98. The pleating method of any one of claims 90 to 97, wherein compressing the filter material includes forming a crease between adjoining unequal length legs.

99. The pleating method of any one of claims 90 to 98, wherein disposing the filter material on the support surface includes disposing a filter medium and a drainage layer on the support surface and wherein compressing the filter material includes compressing the filter medium and the drainage layer.

100. The pleating method of any one of claims 90 to 99, wherein compressing the filter material includes compressing the filter material between pleating surfaces which are non-parallel to each other.

101. The pleating method of any one of claims 90 to 100, further comprising biasing the second member to rotate about an axis towards the first member.

102. The pleating method of any one of claims 90 to 101, further comprising biasing the second member to rotate about an axis parallel to the support surface.

103. The pleating method of any one of claims 90 to 102, further comprising raising and lowering the second member with respect to the support surface.

104. The pleating method of any one of claims 90 to 103, further comprising raising the portion of the filter material between the first and second members above the support surface with a third member.

105. The pleating method of any one of claims 90 to 104, further comprising raising the portion of the filter material between the first and second members above the support surface with a bar extending in a widthwise direction of the filter material.

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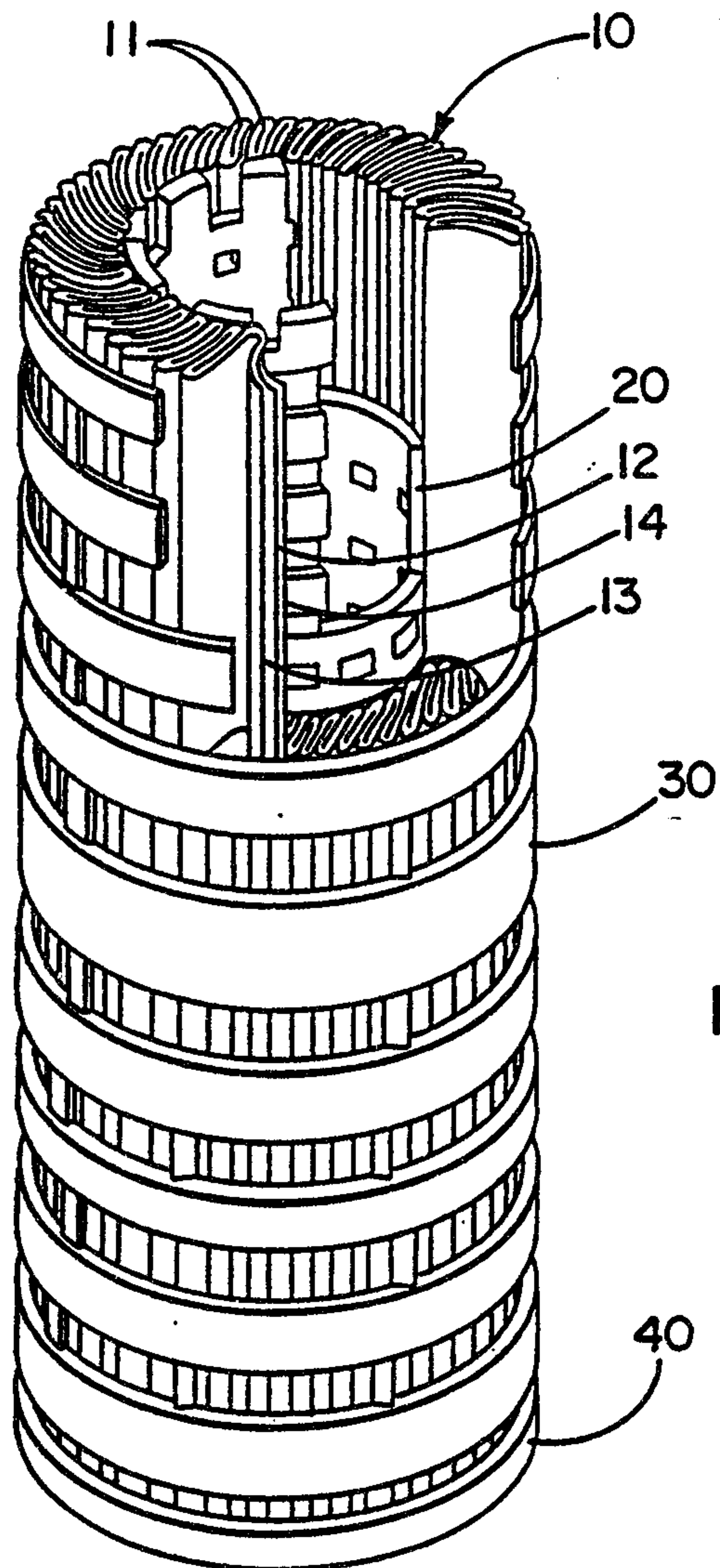


FIG. 1

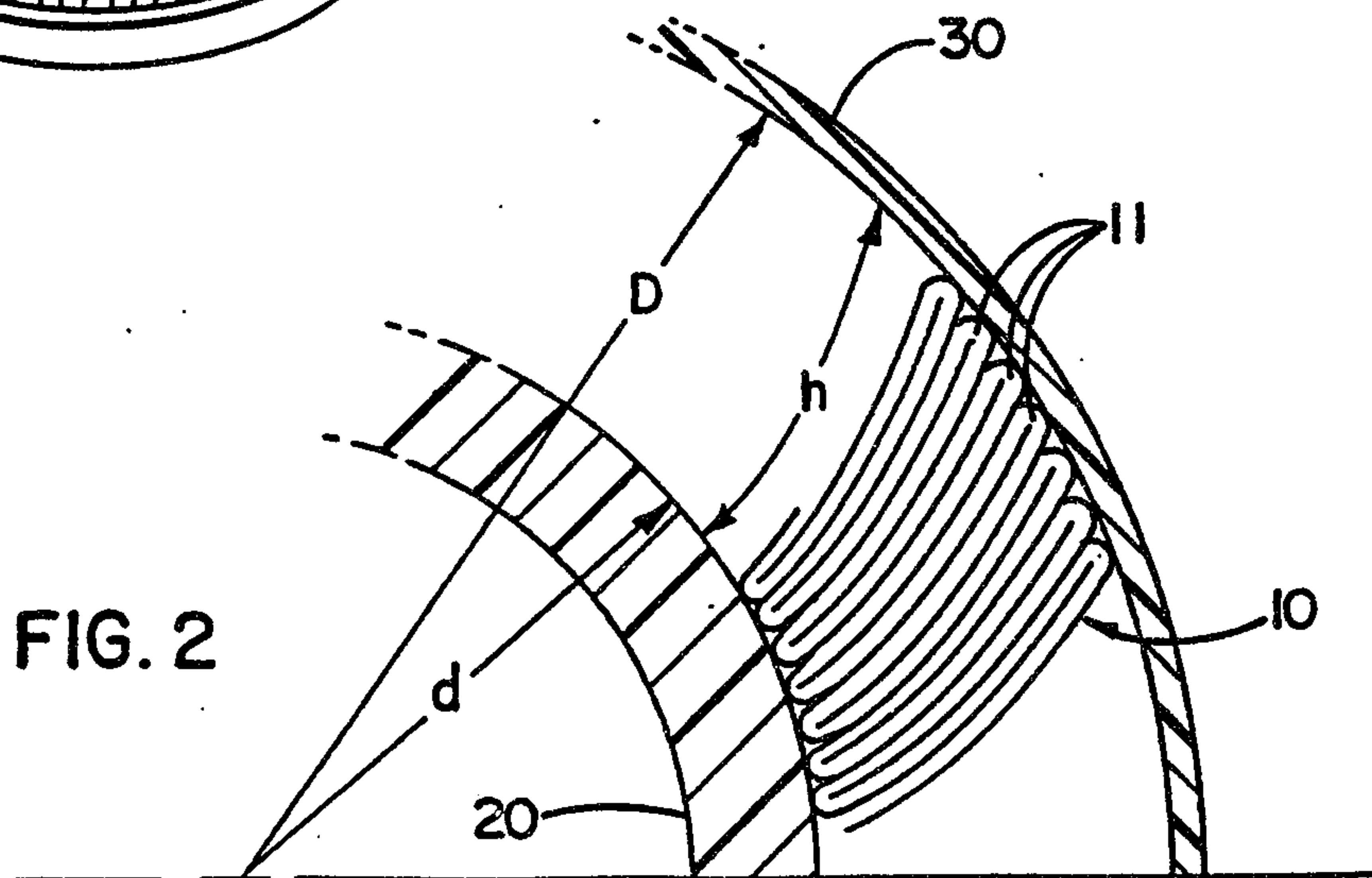


FIG. 2

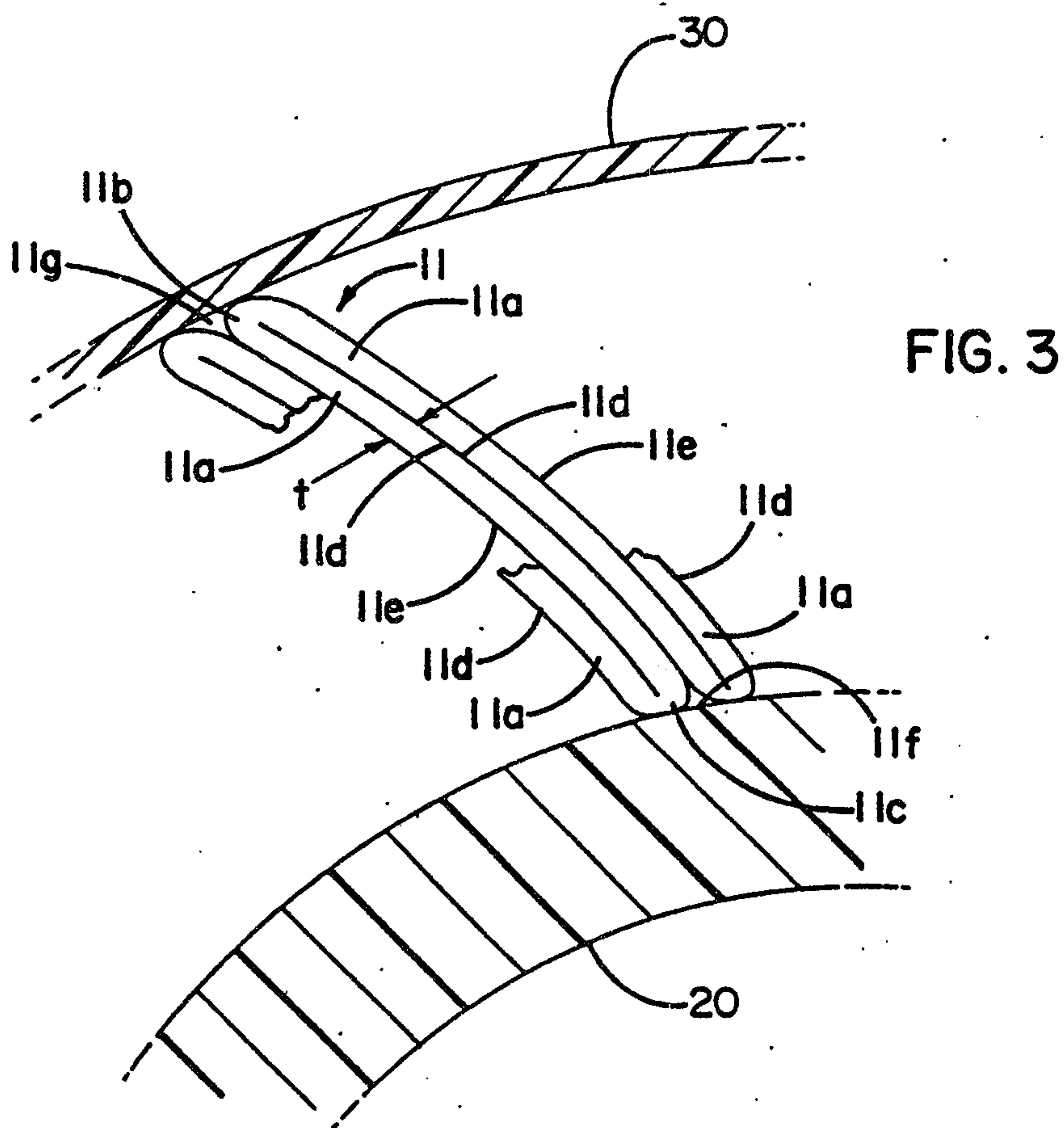
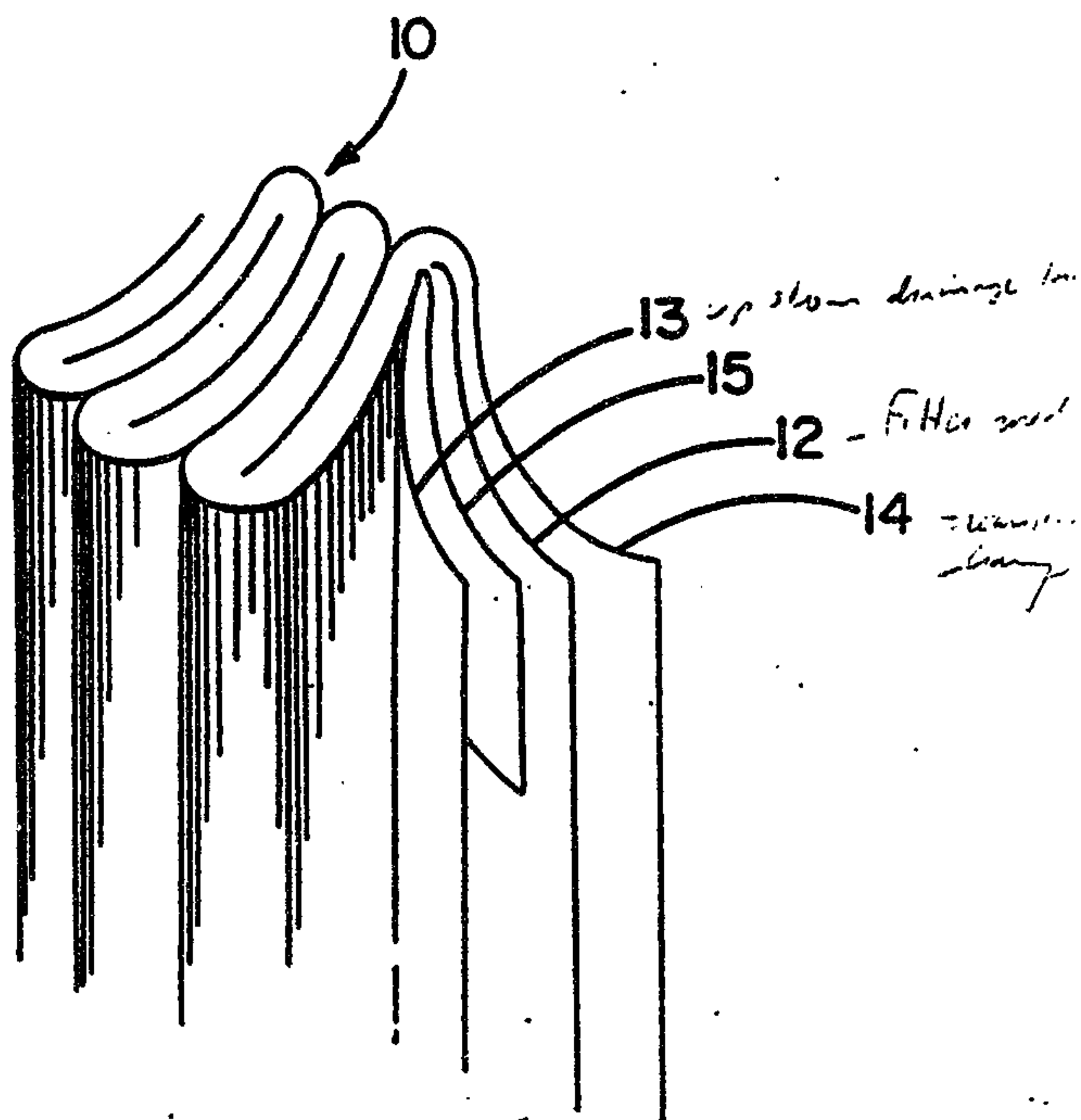


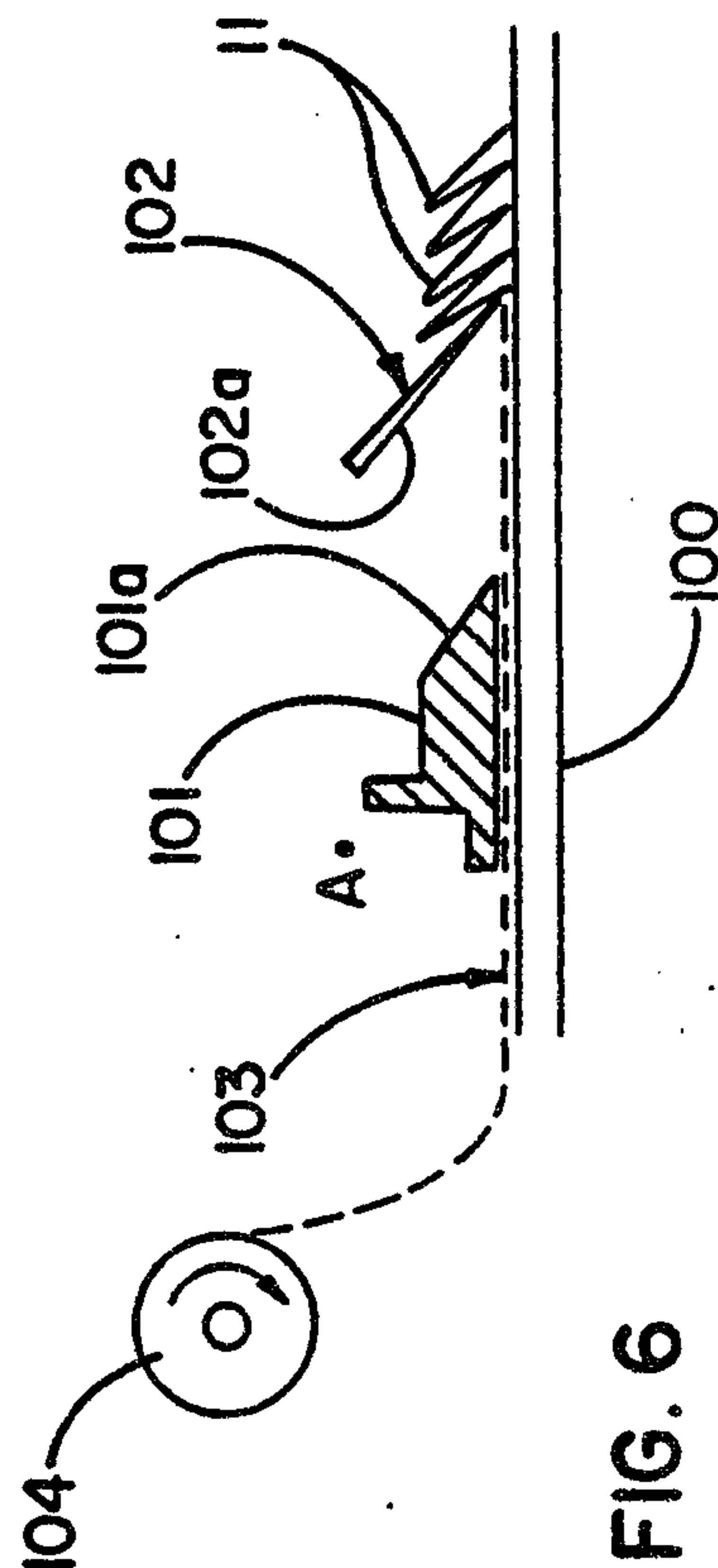
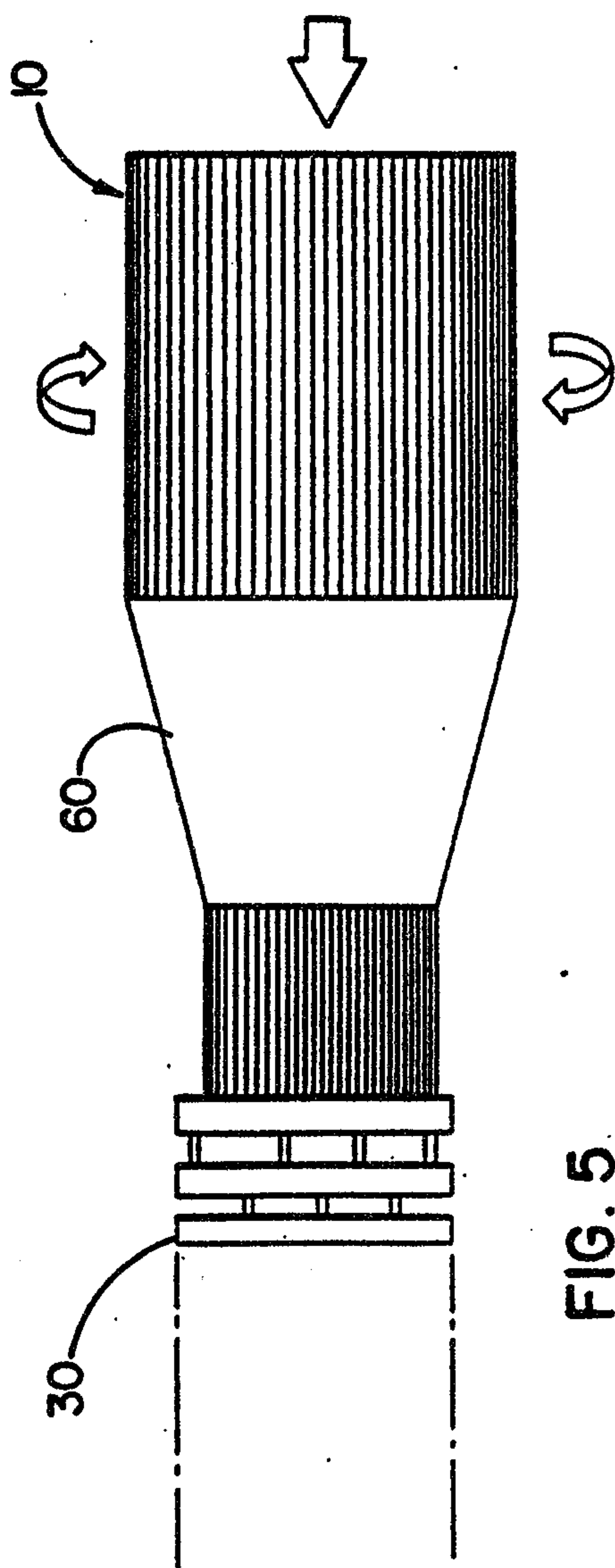
FIG. 3

FIG. 4

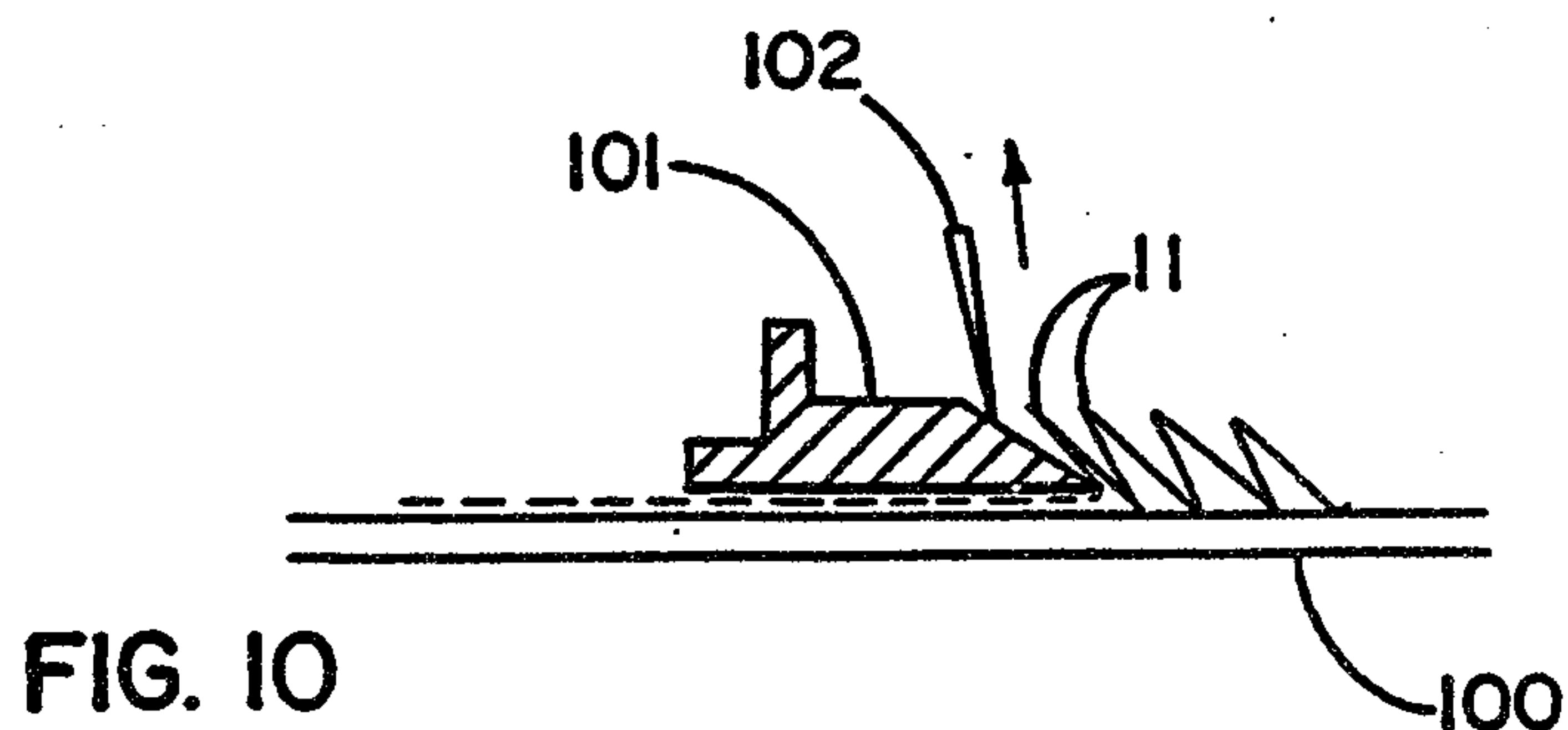
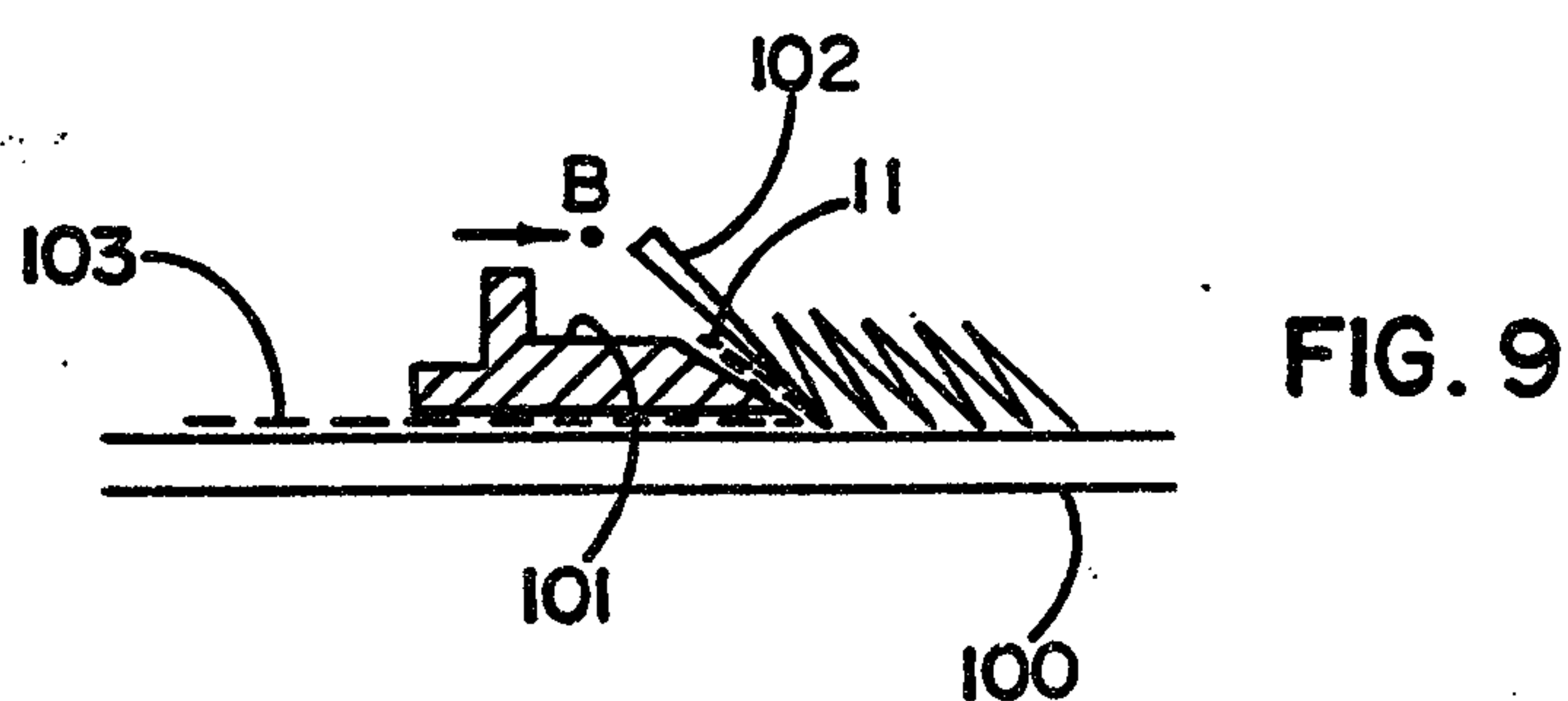
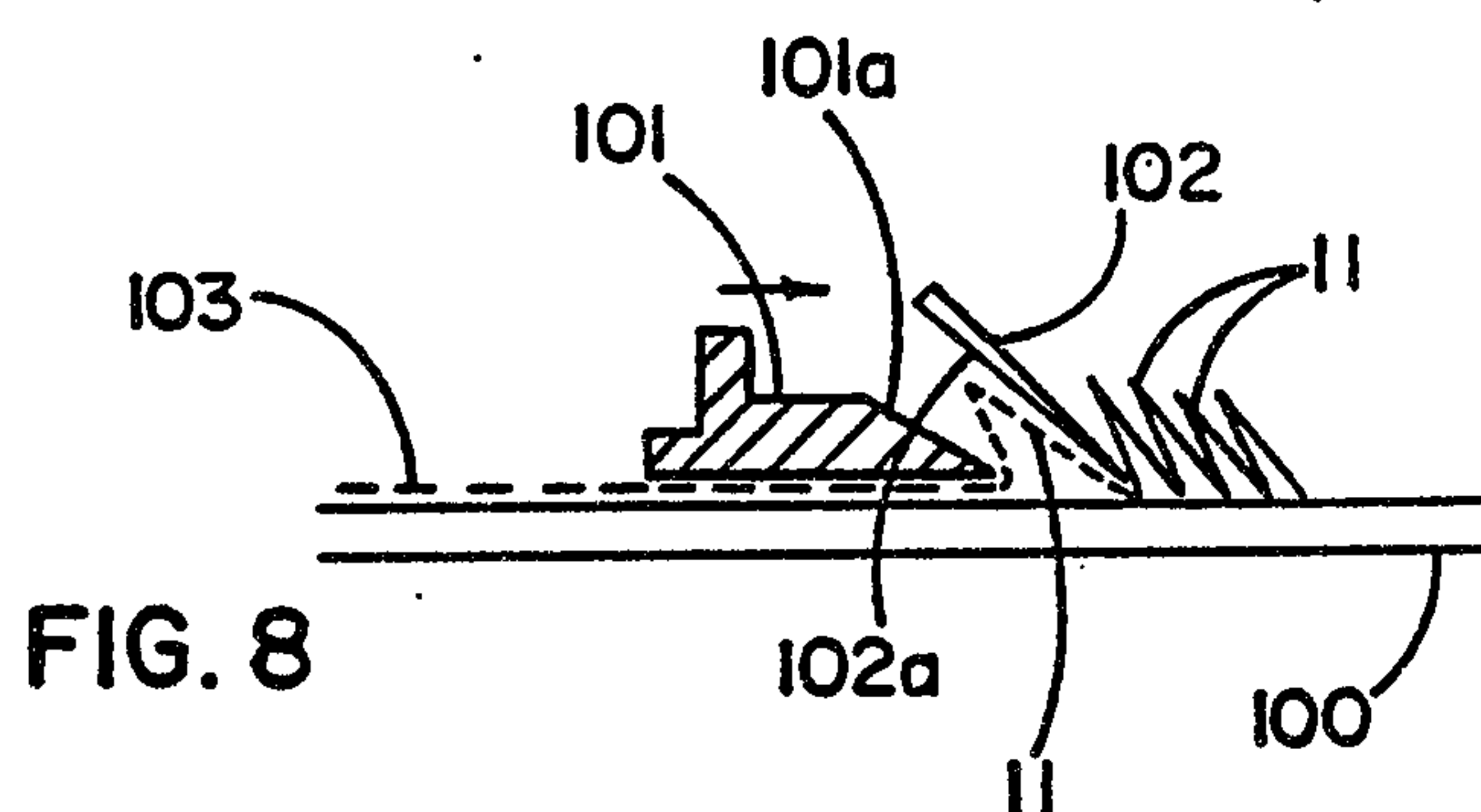
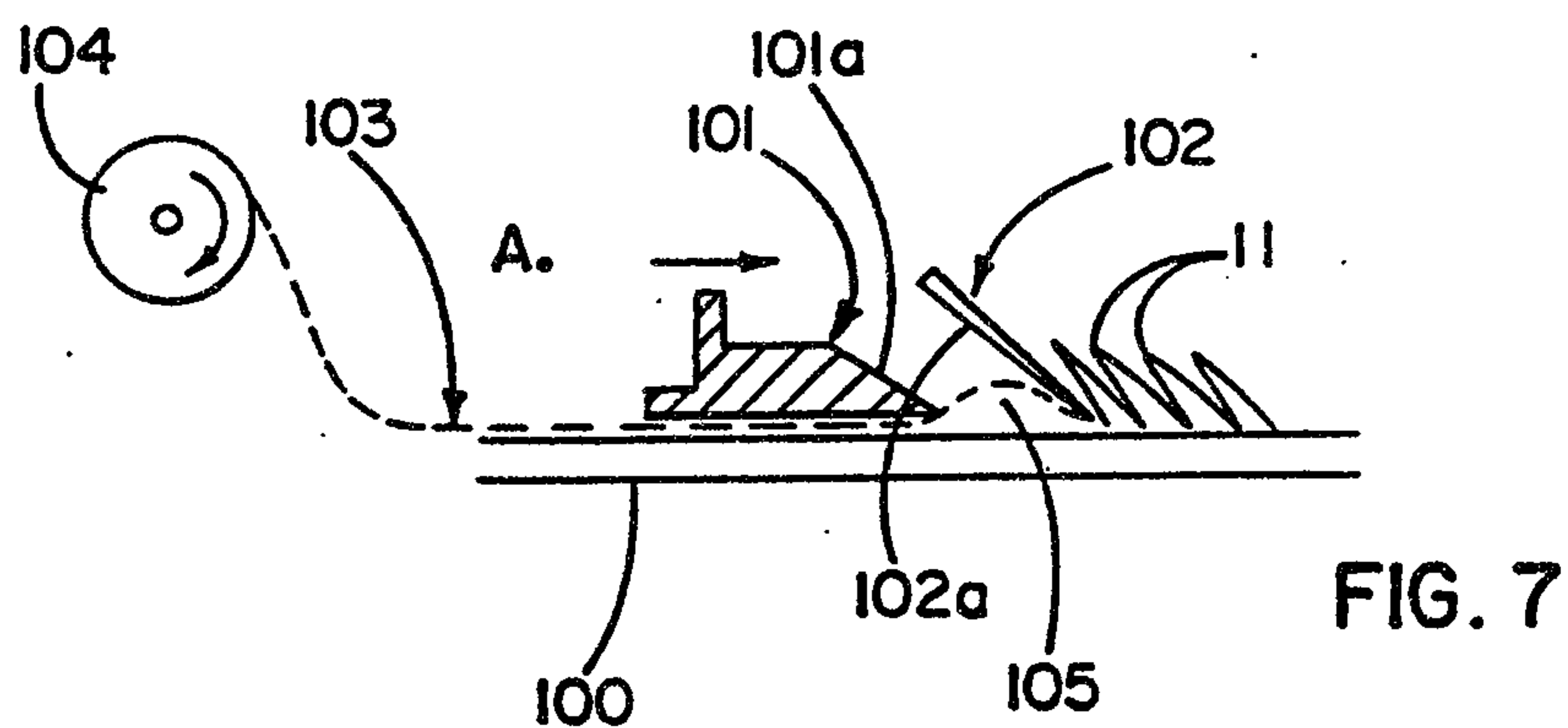


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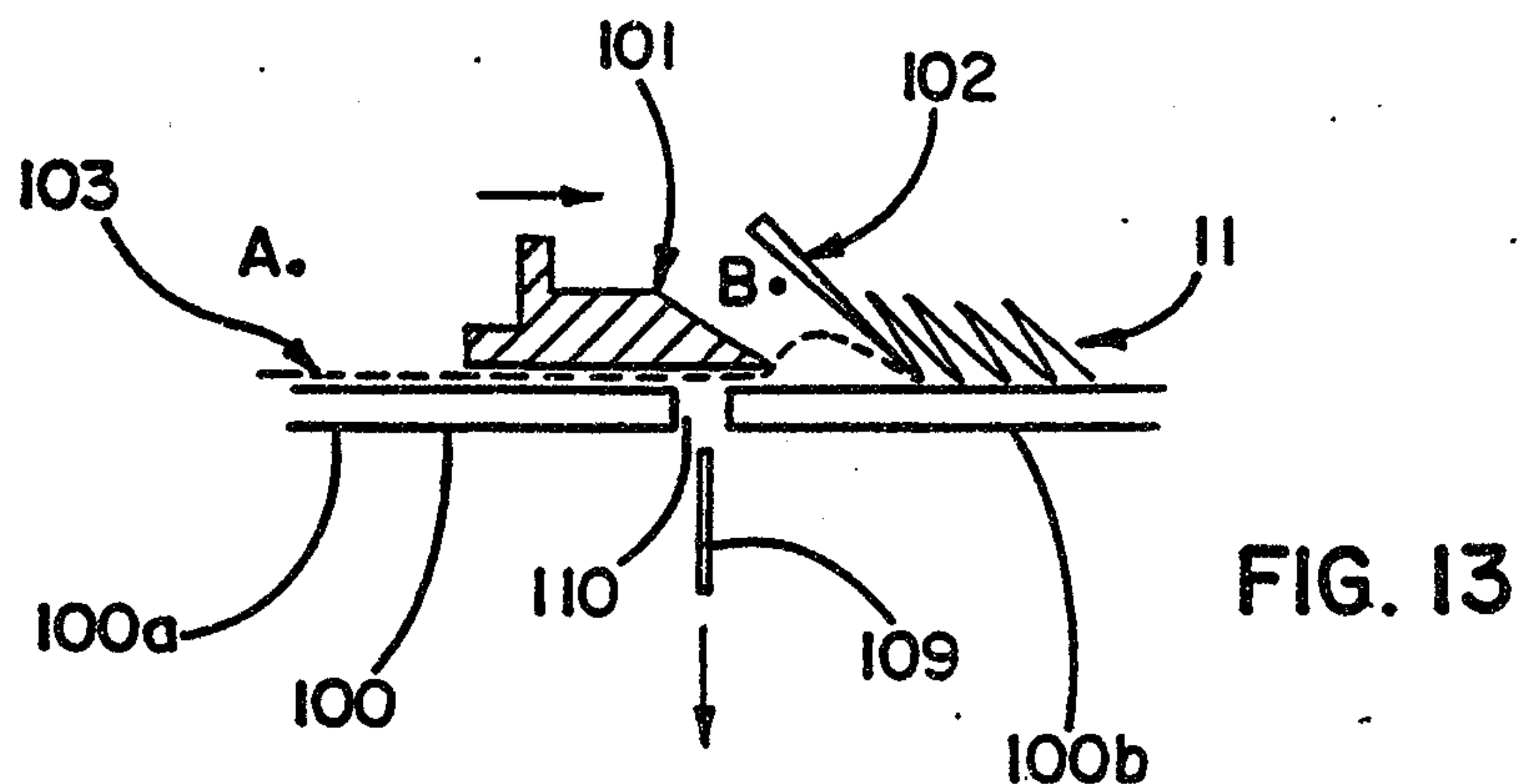
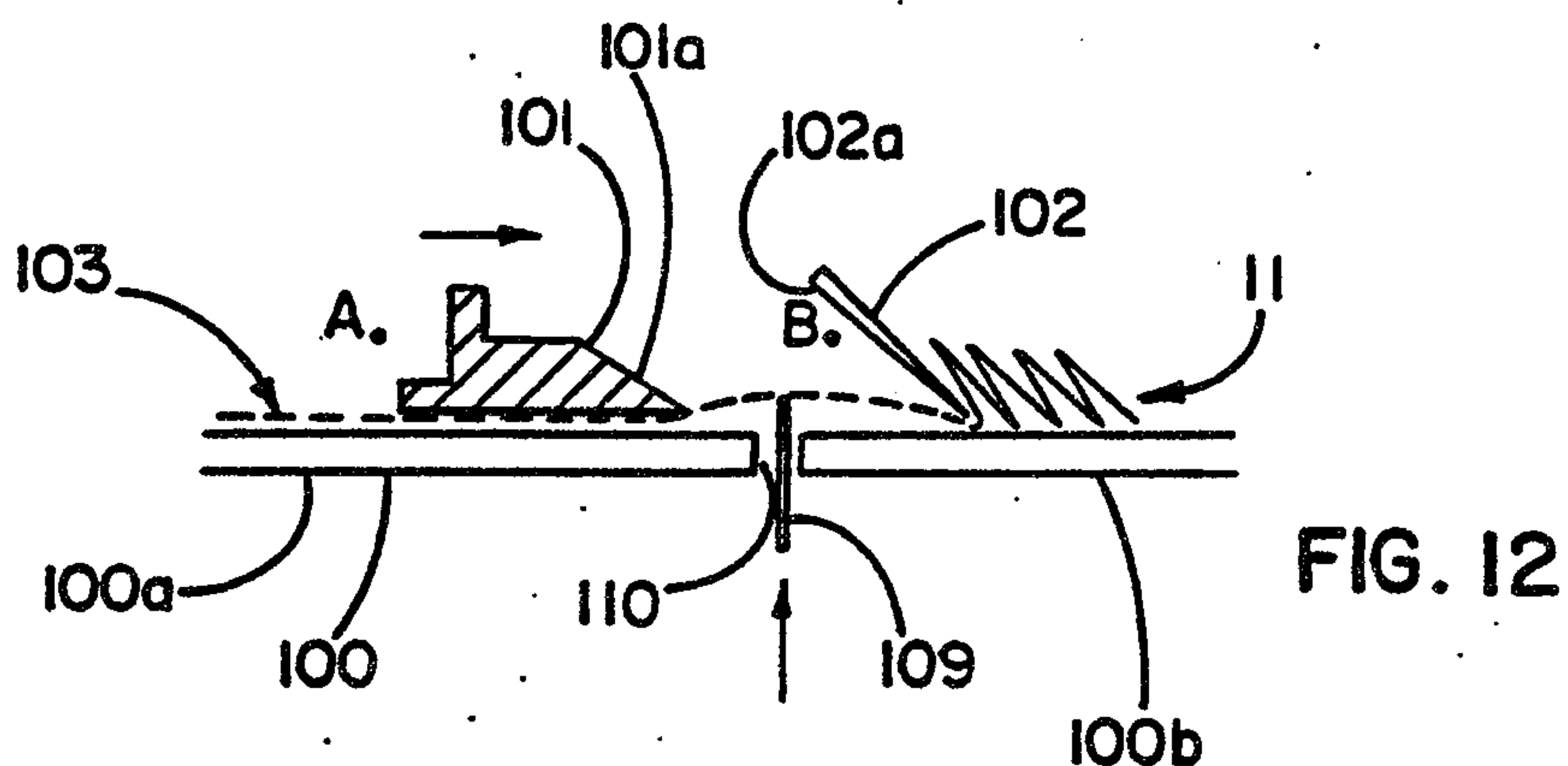
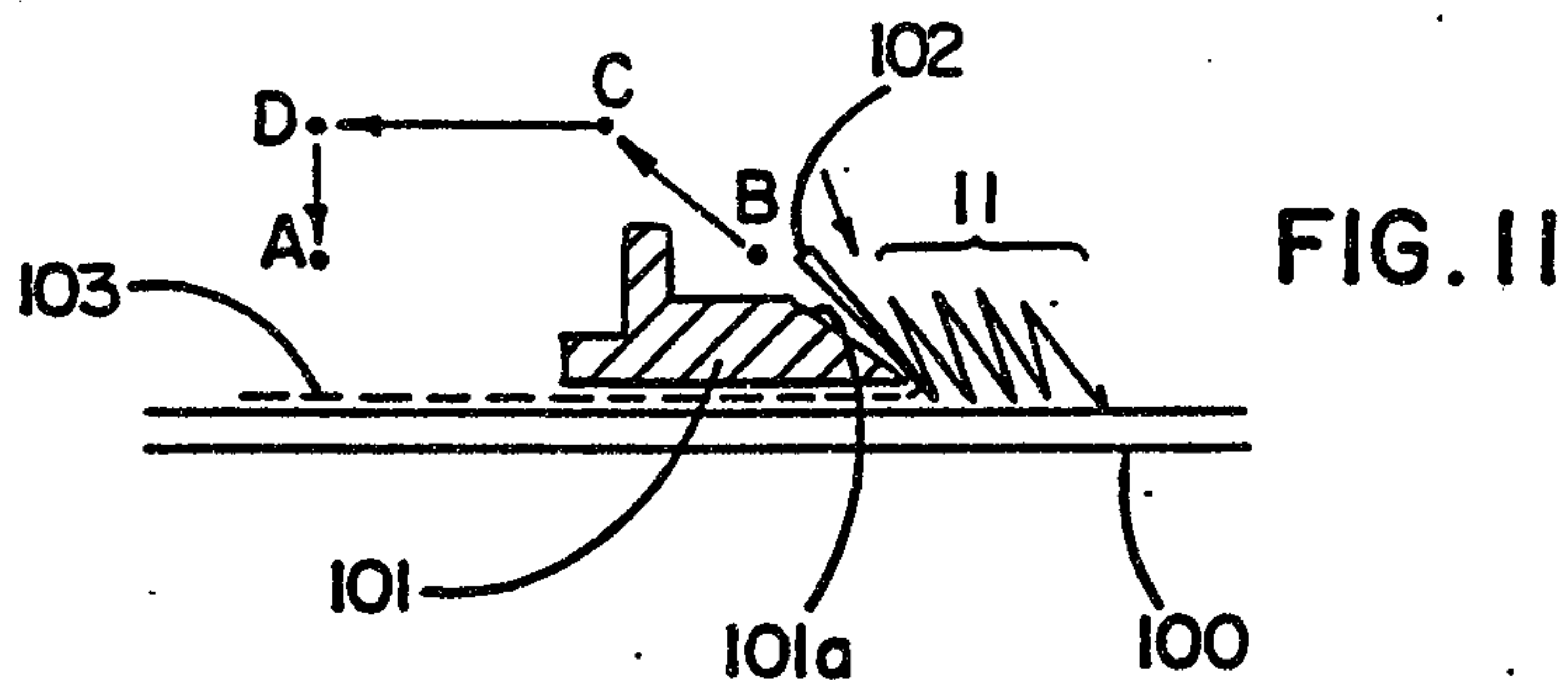


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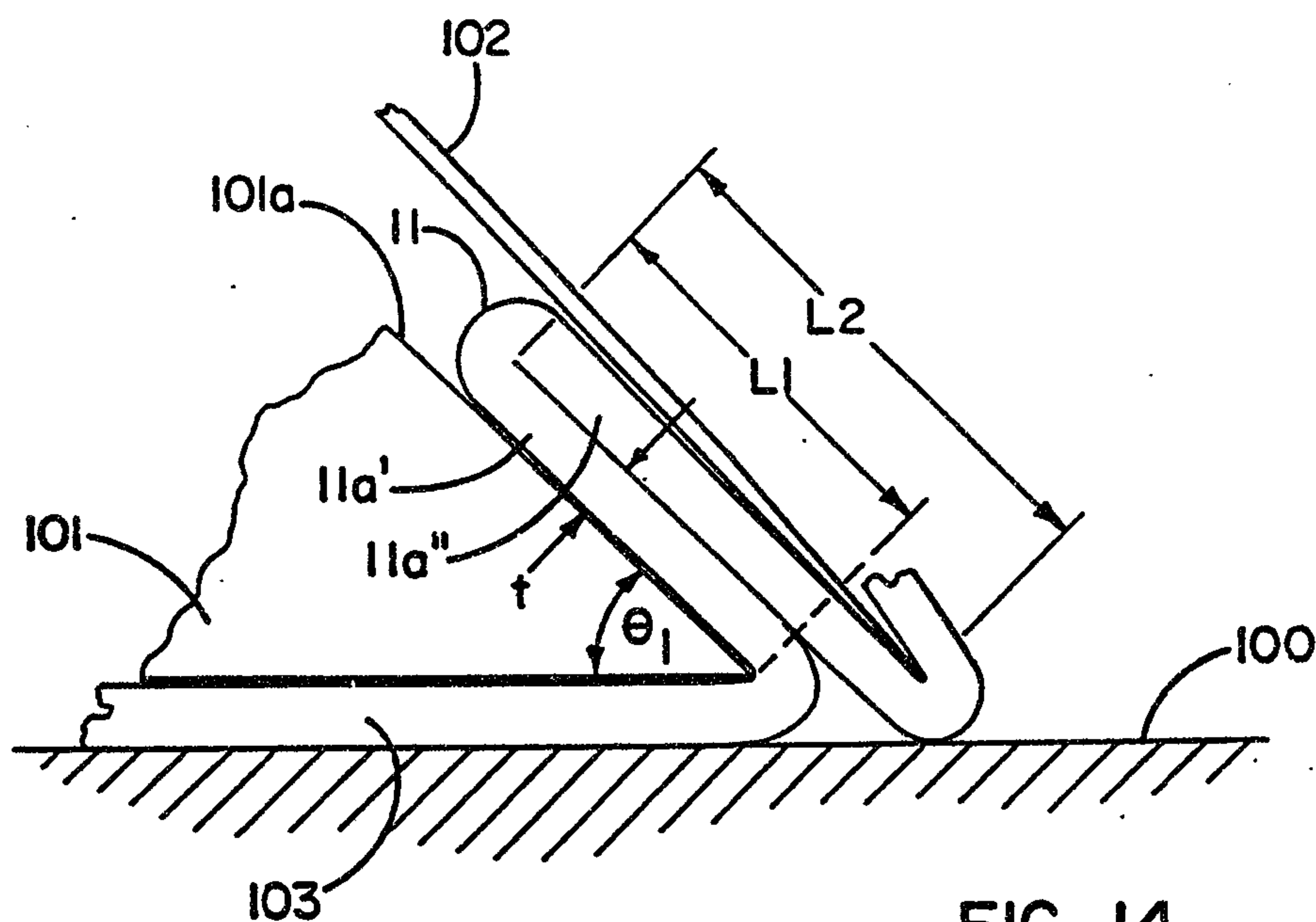


FIG. 14

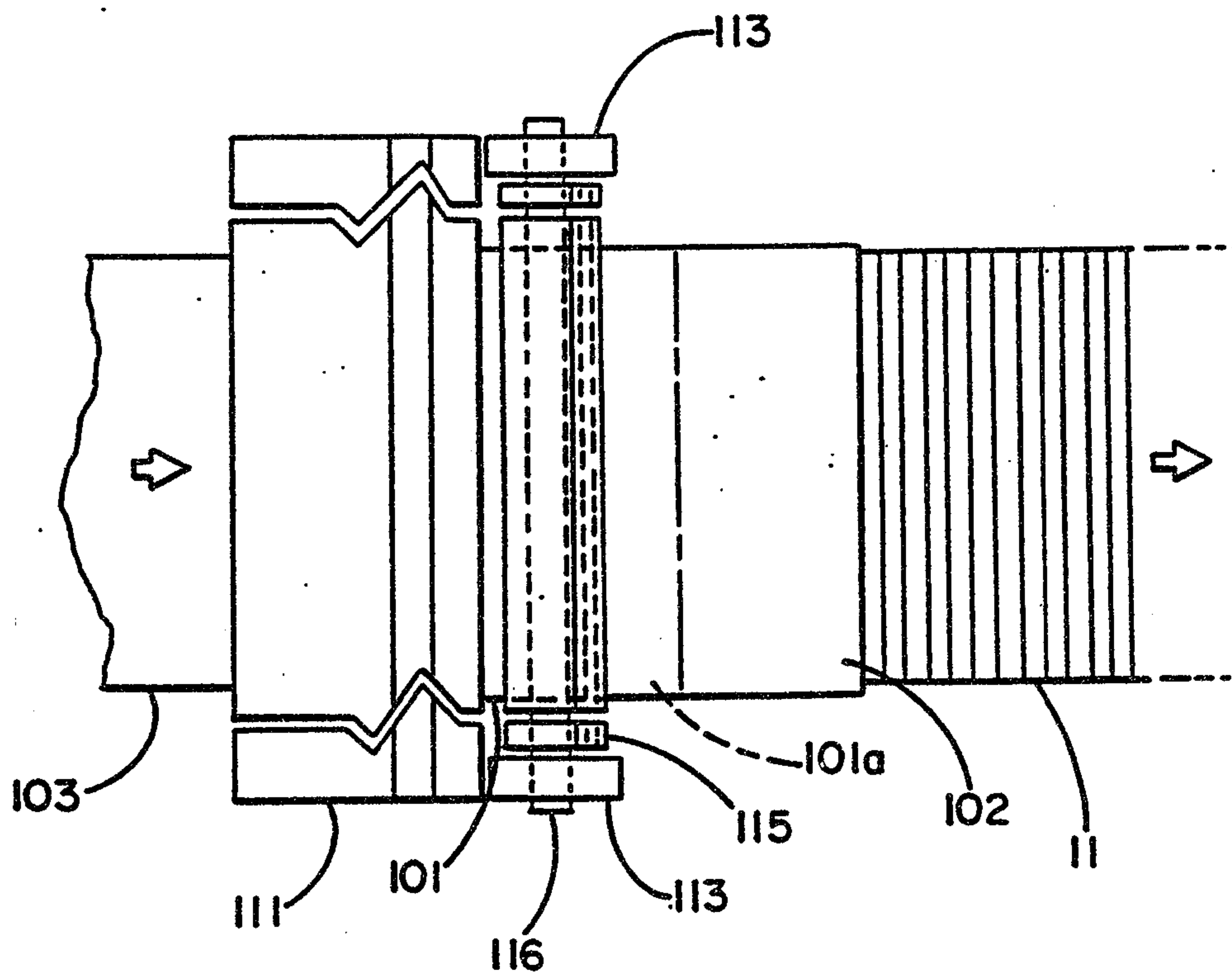


FIG. 16

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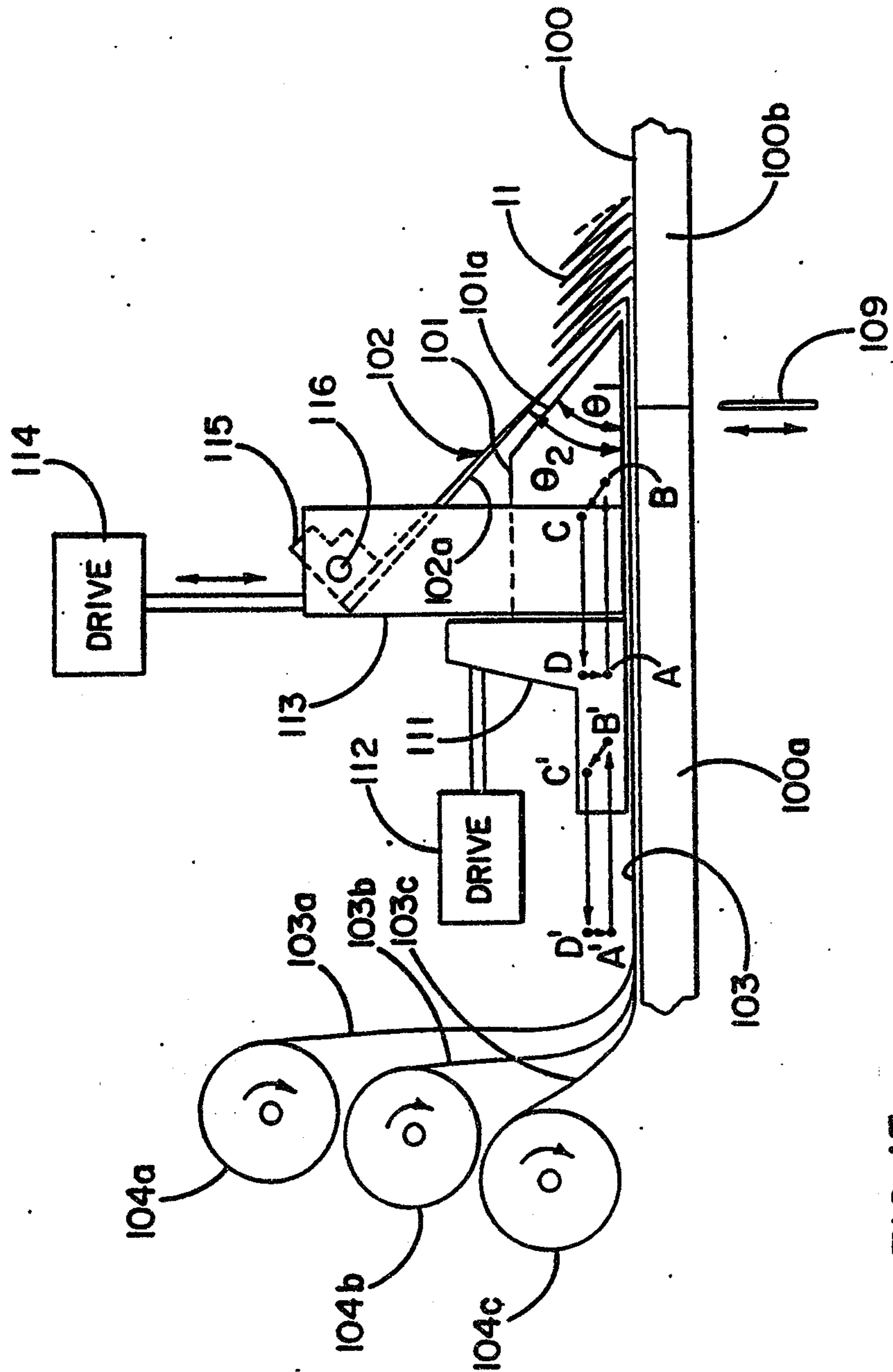
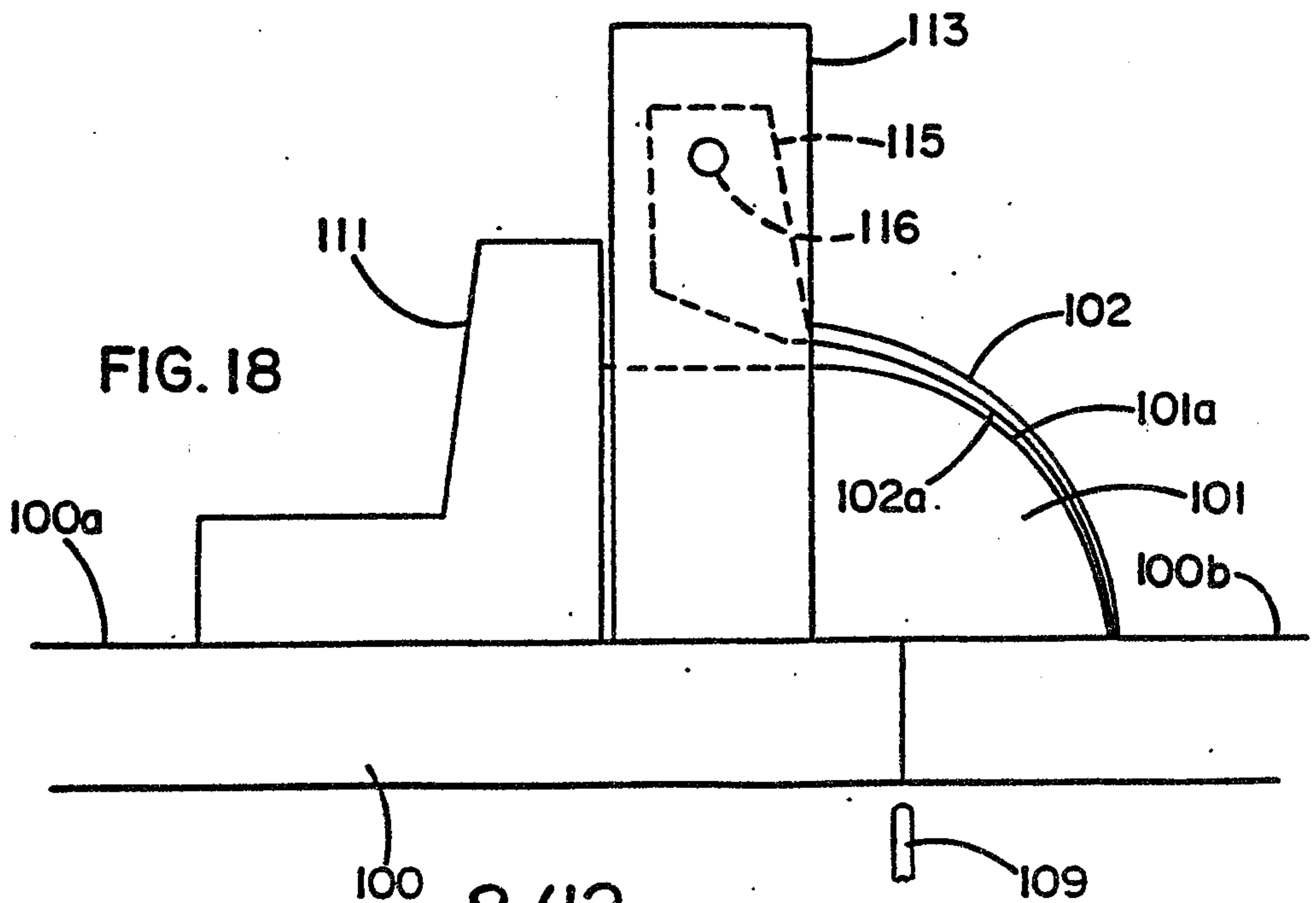
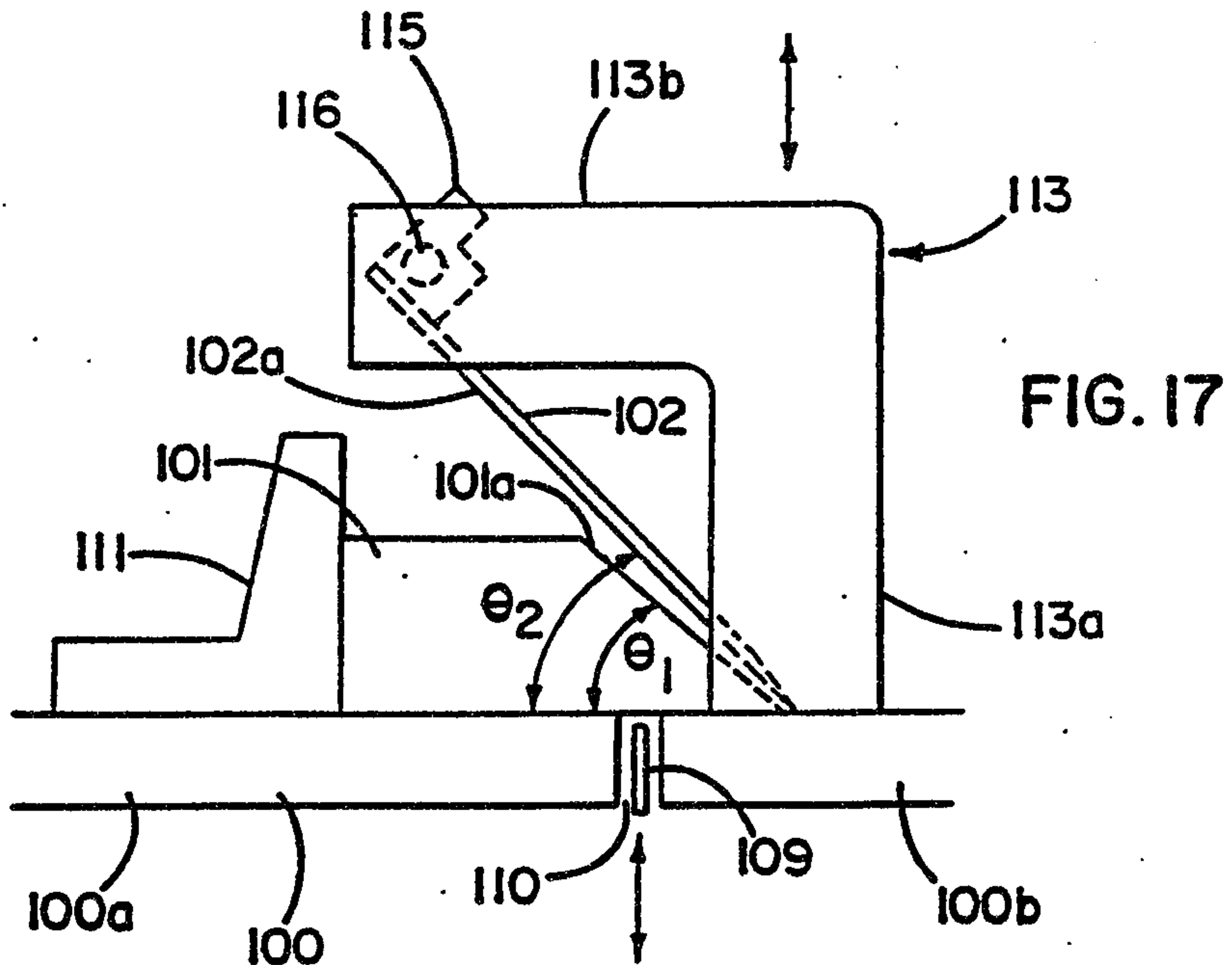


FIG. 15



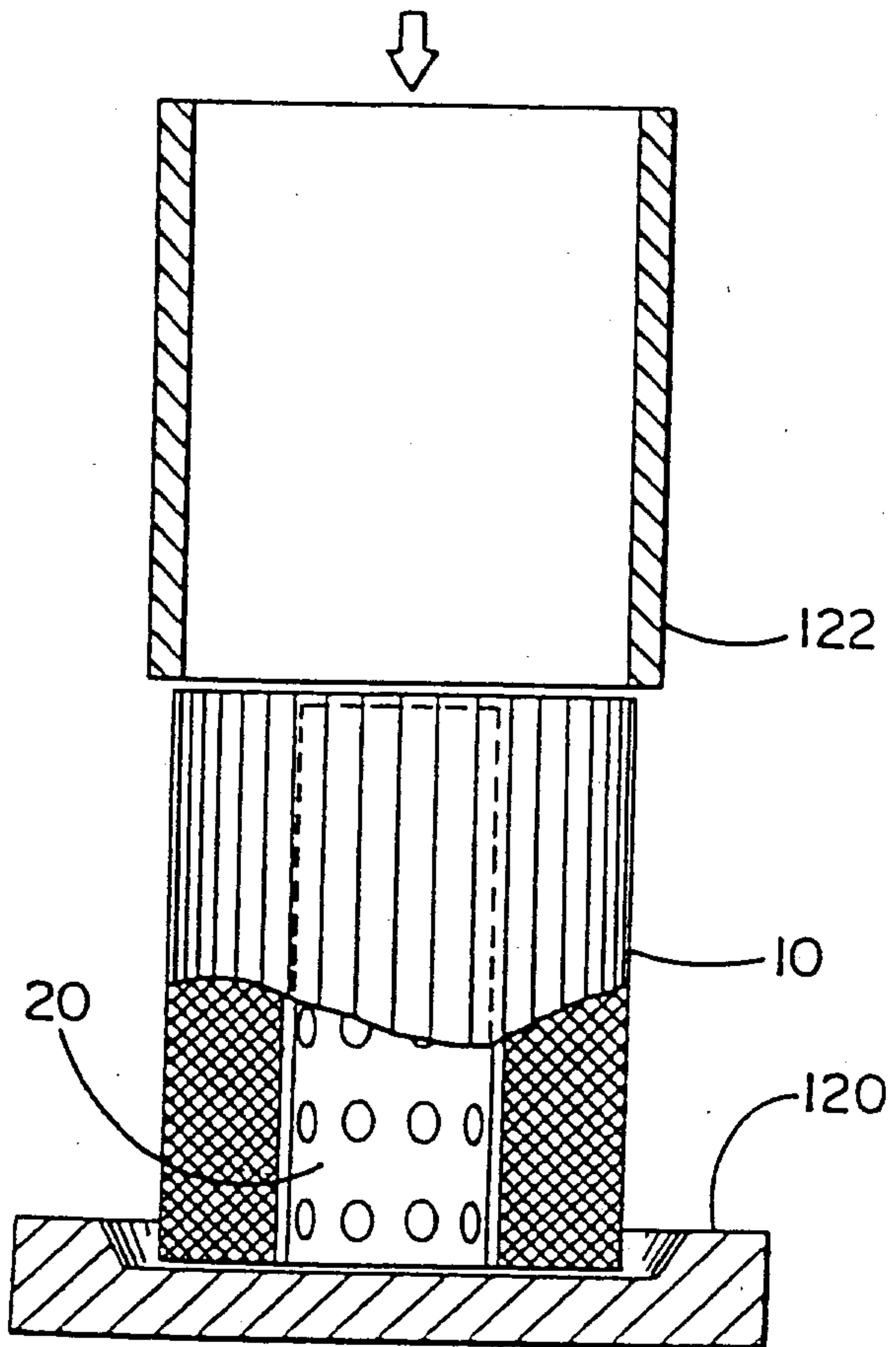


FIG. 19

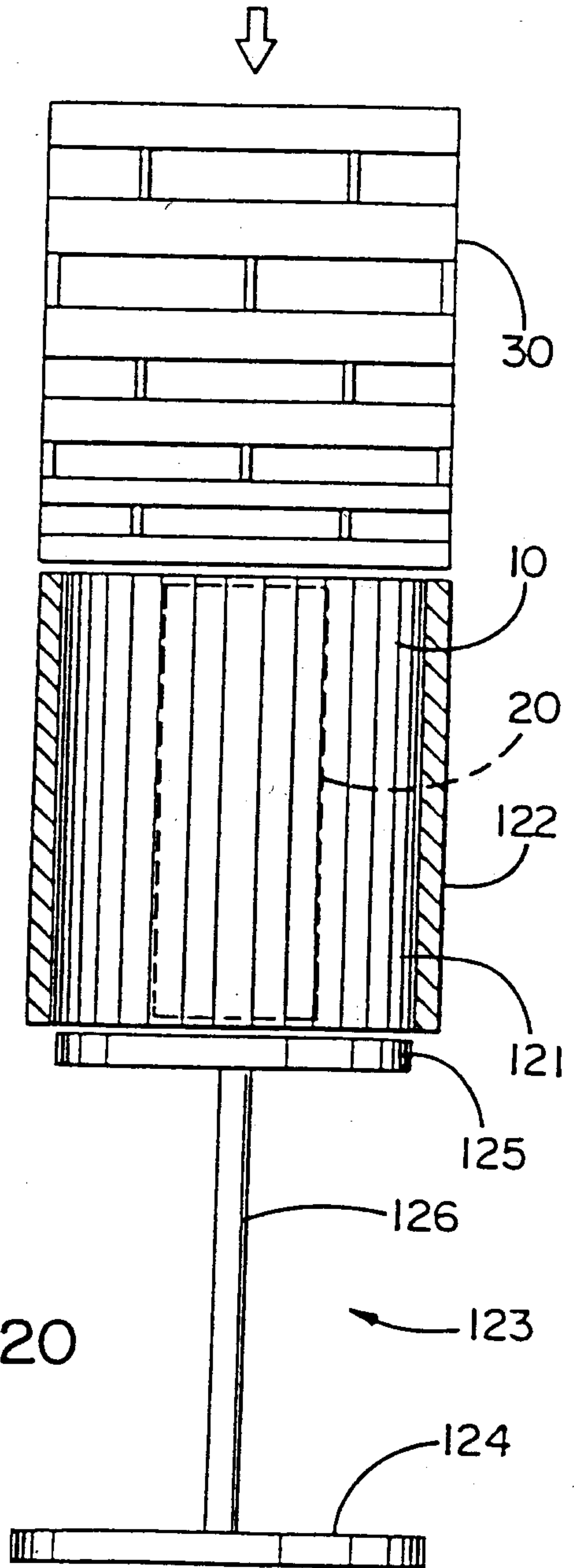


FIG. 20

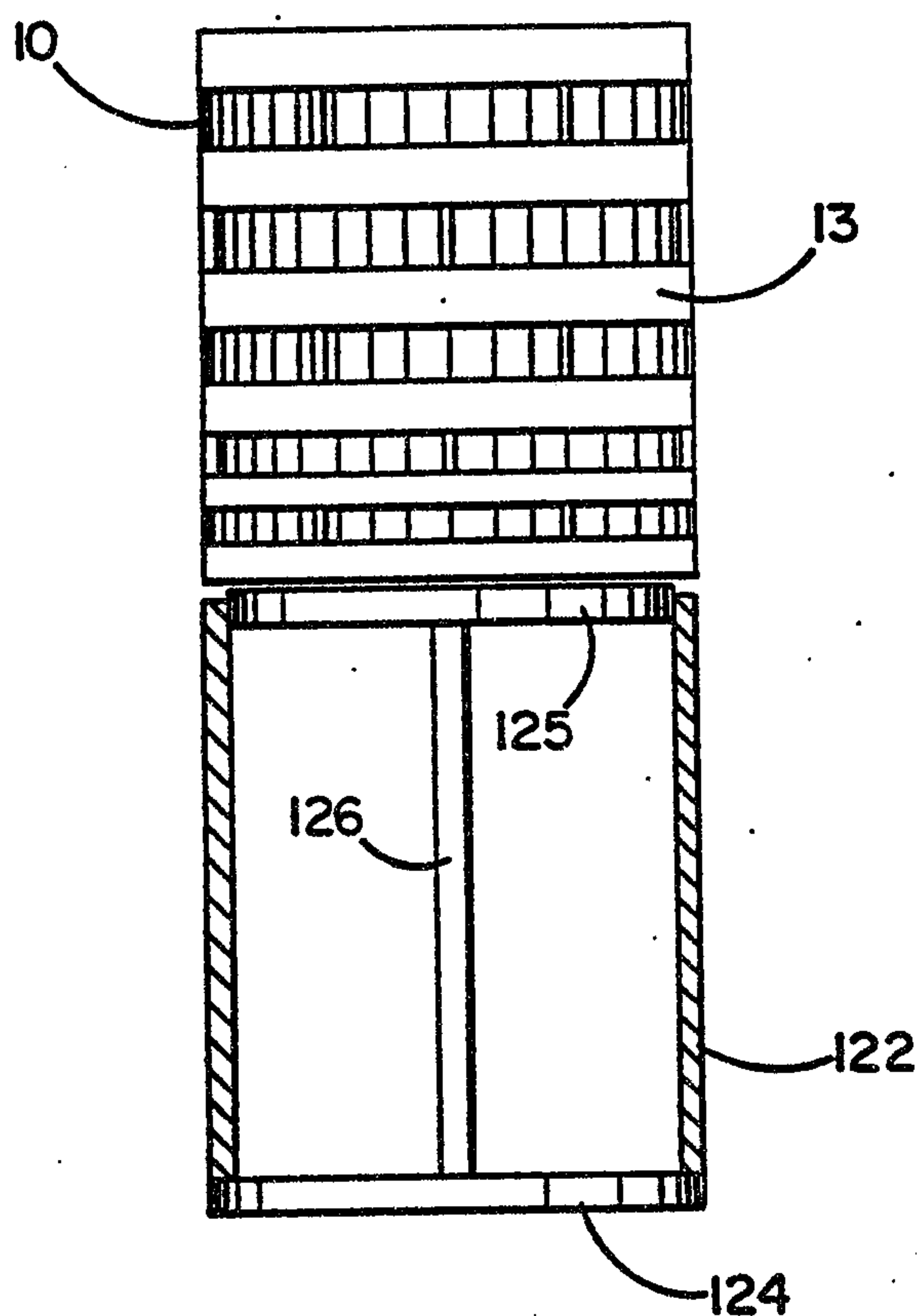


FIG. 21

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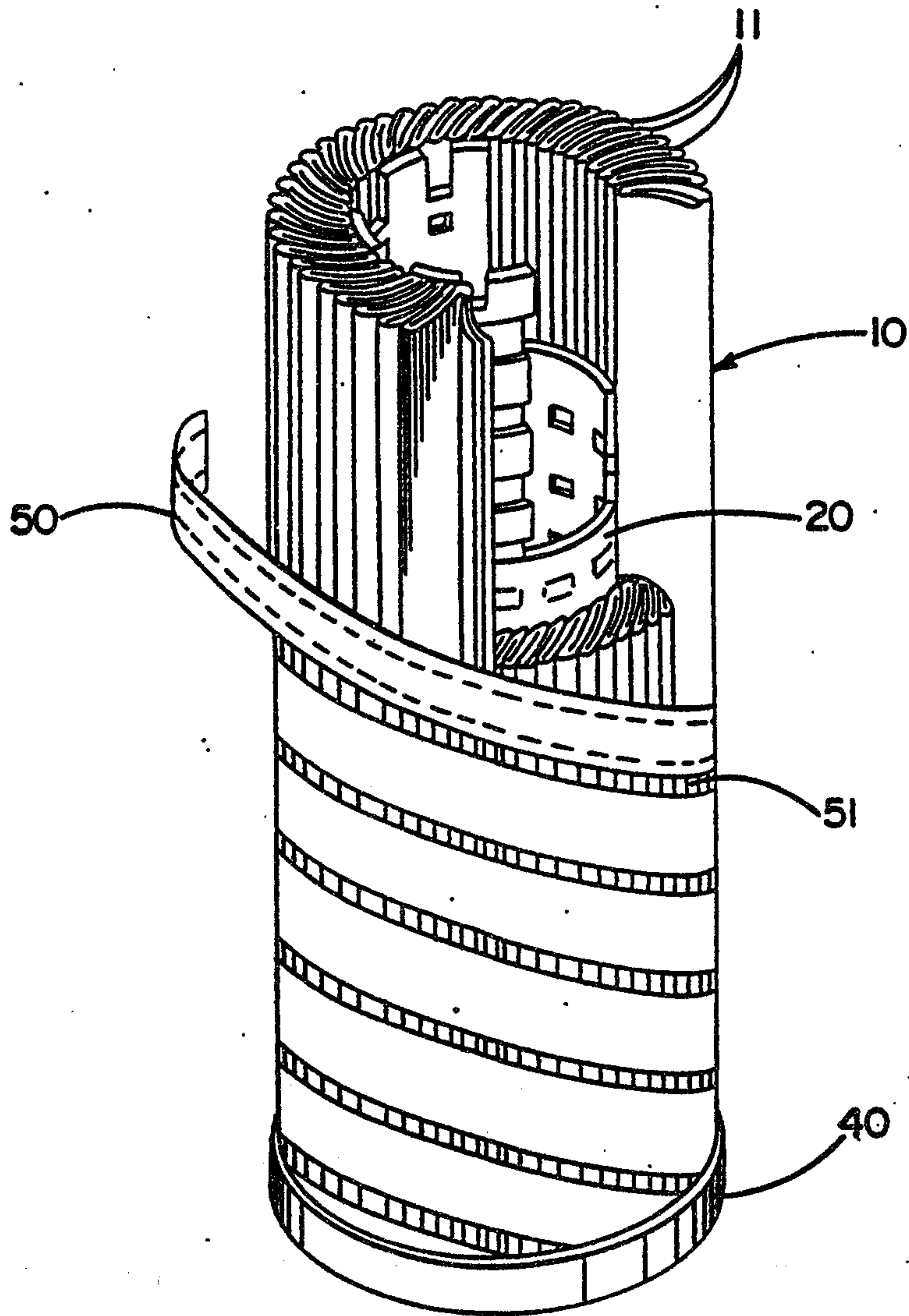


FIG. 22

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