

[54] POWER TRANSFORMER
INCORPORATING IMPROVED HEAT
DISSIPATION MEANS

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Related U.S. Application Data

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1968, Pat. No. 3,551,863.
[52] U.S. Cl. 336/57, 336/60, 336/61
[51] Int. Cl. H01f 27/08
[58] Field of Search 336/55, 57, 58, 59, 60, 61,
336/69, 70, 84; 165/185, 107; 174/DIG. 5

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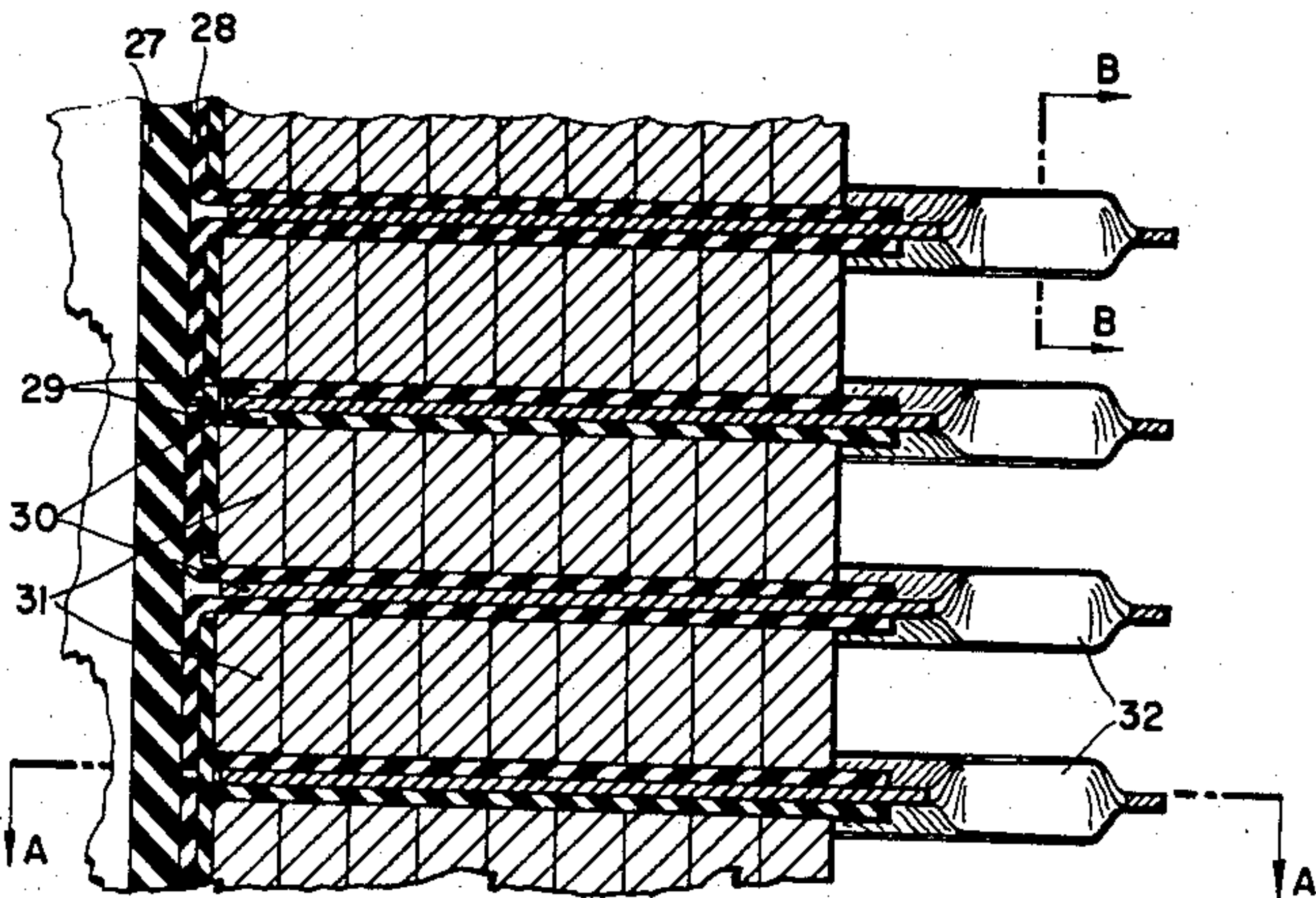
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[57] ABSTRACT

A power transformer constructed so as to exhibit improved heat dissipation characteristics and a longer thermal time constant. The transformer construction is characterized by minimizing or eliminating gaps between the core and coil structure and between sections of the coil structure. Highly heat conductive dissipator layers are mounted between adjacent coil sections and extend beyond the coil structure terminating in fins arranged to assure maximum heat transfer to a cooling medium flowing therepast.

22 Claims, 41 Drawing Figures



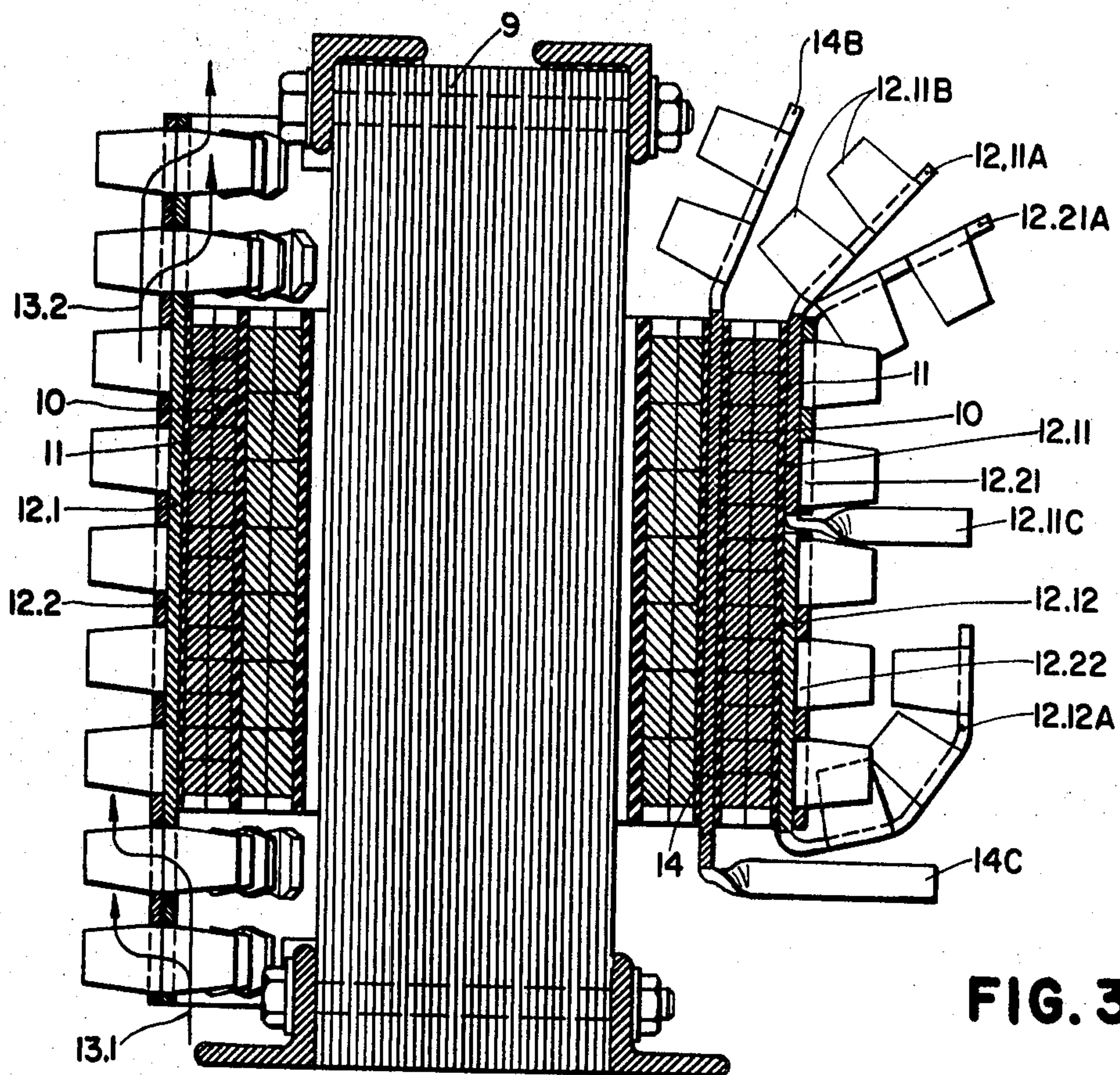
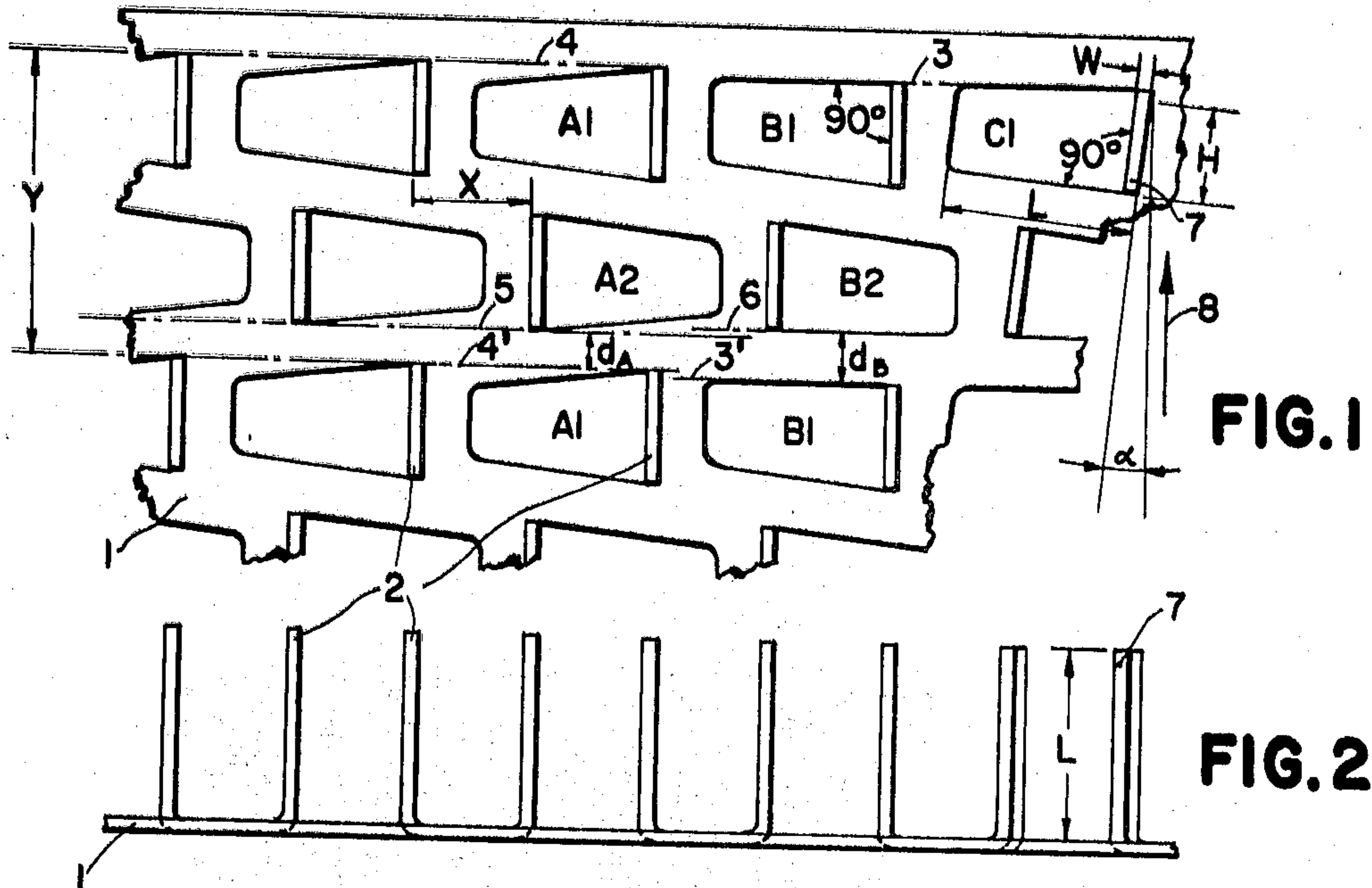


FIG. 4

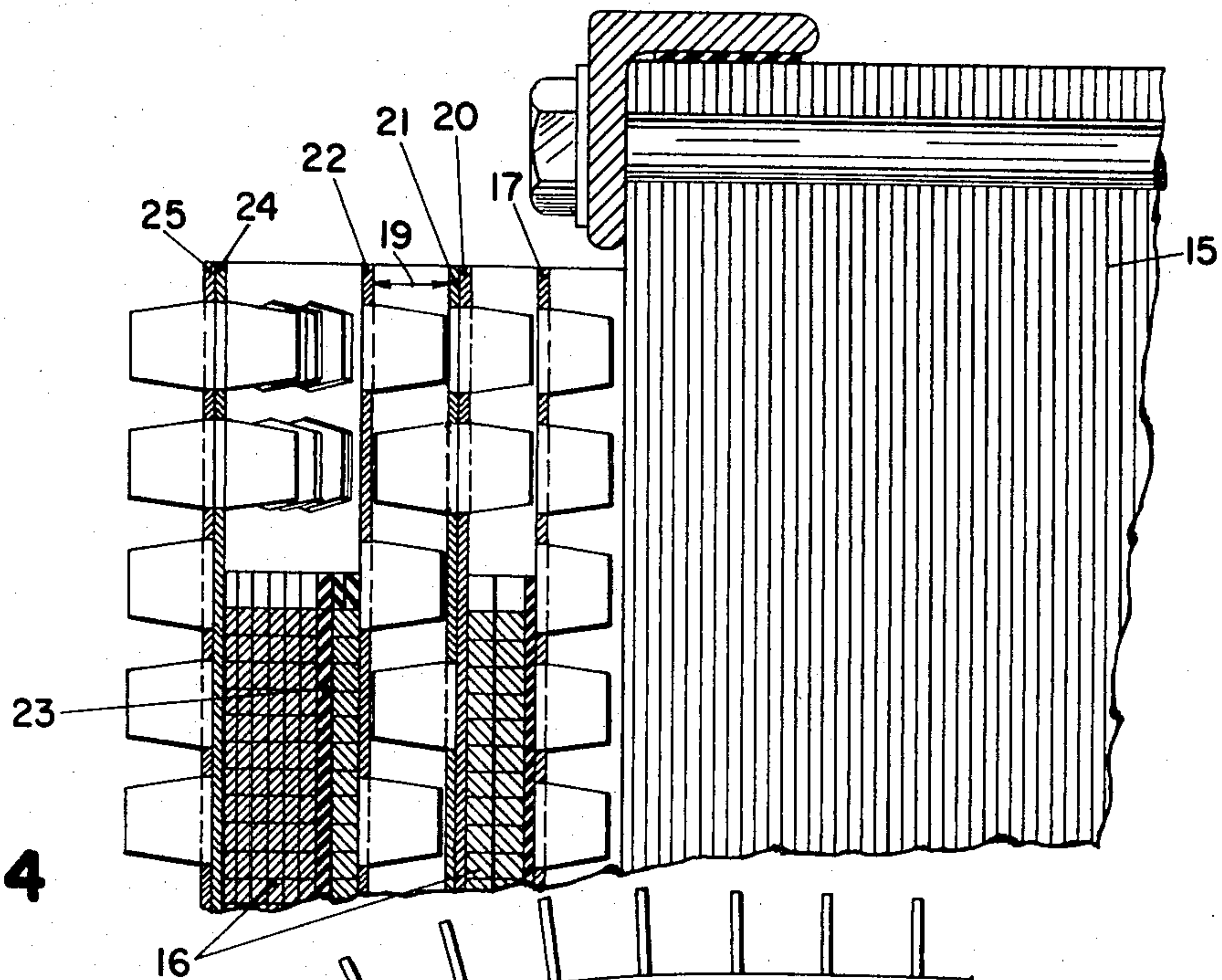
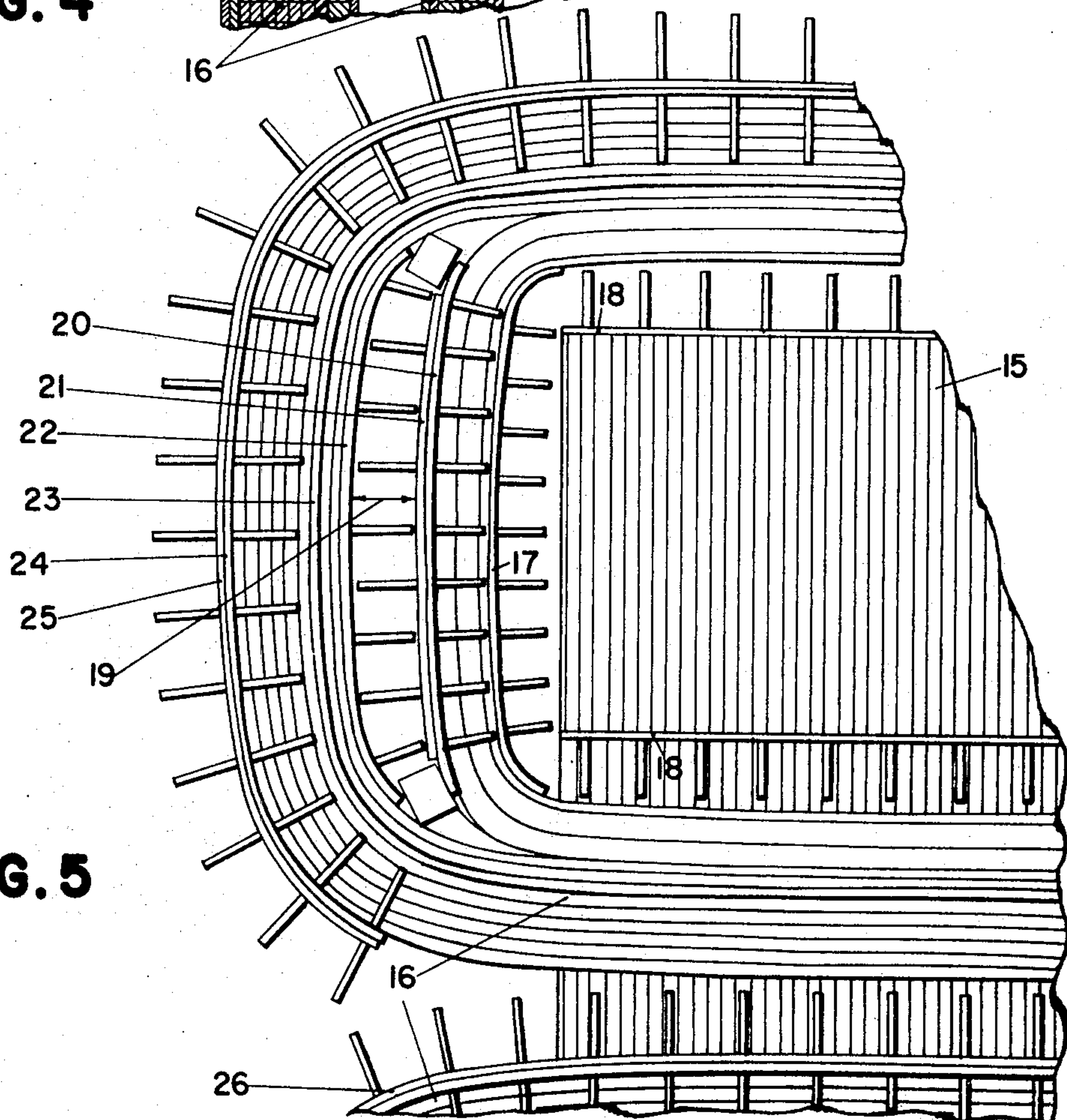
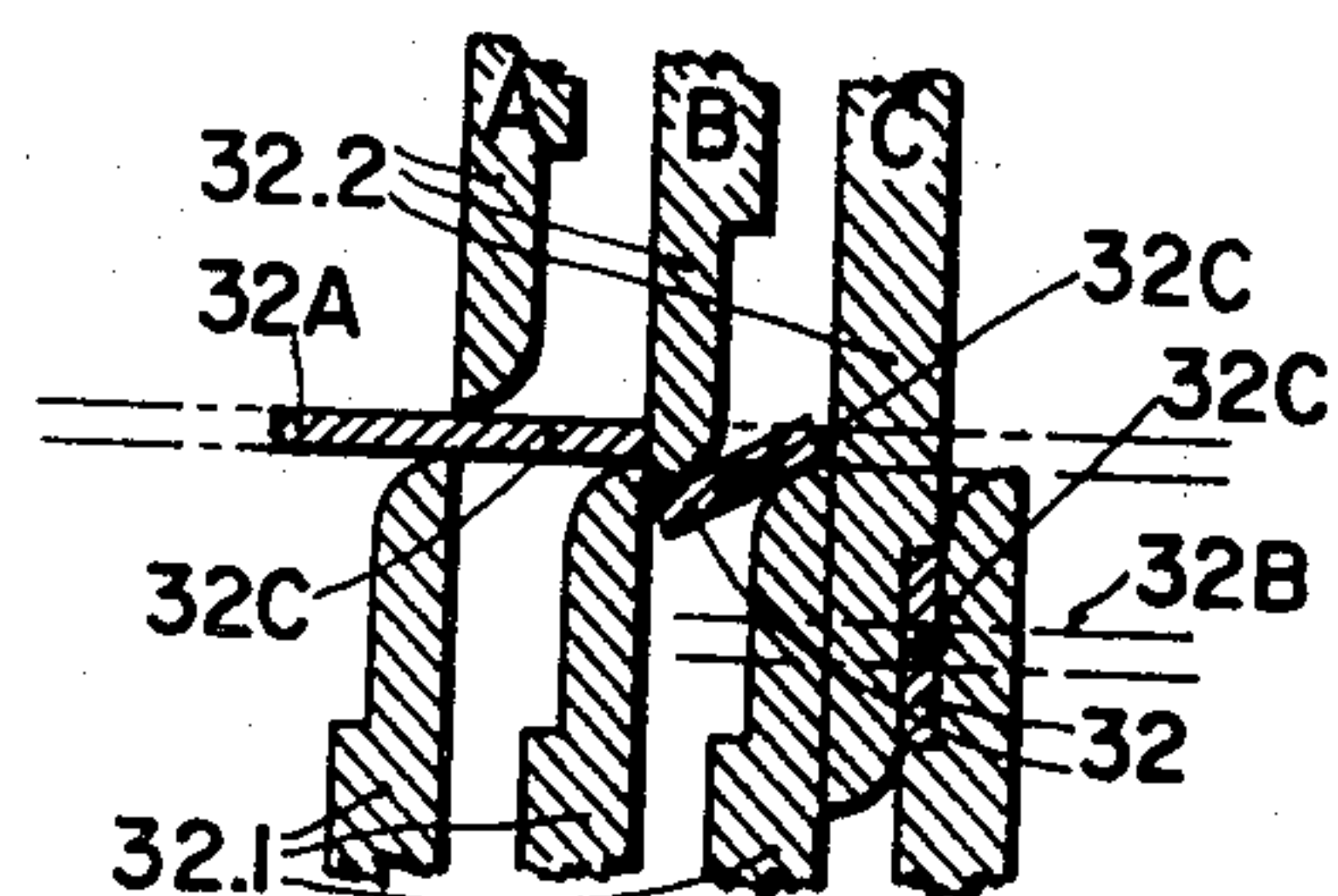
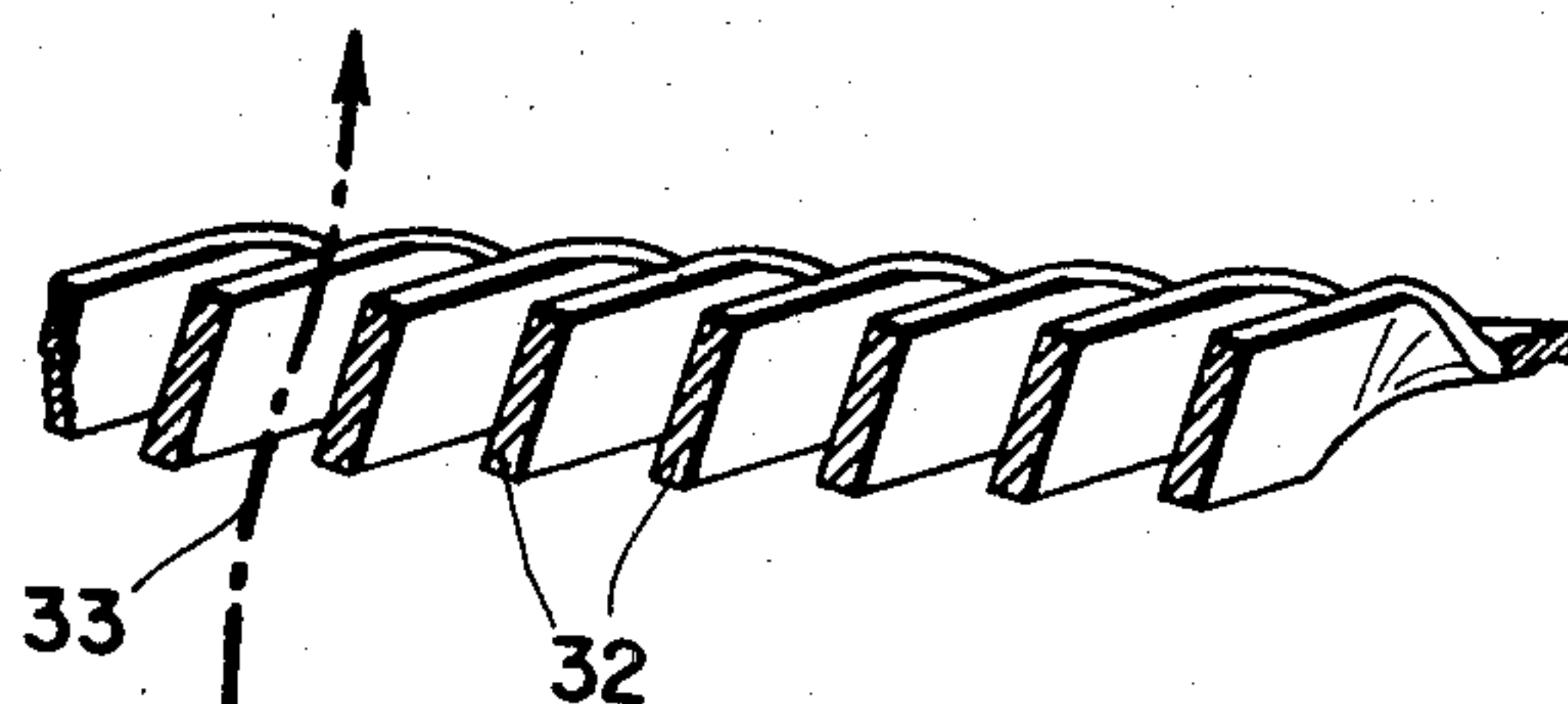
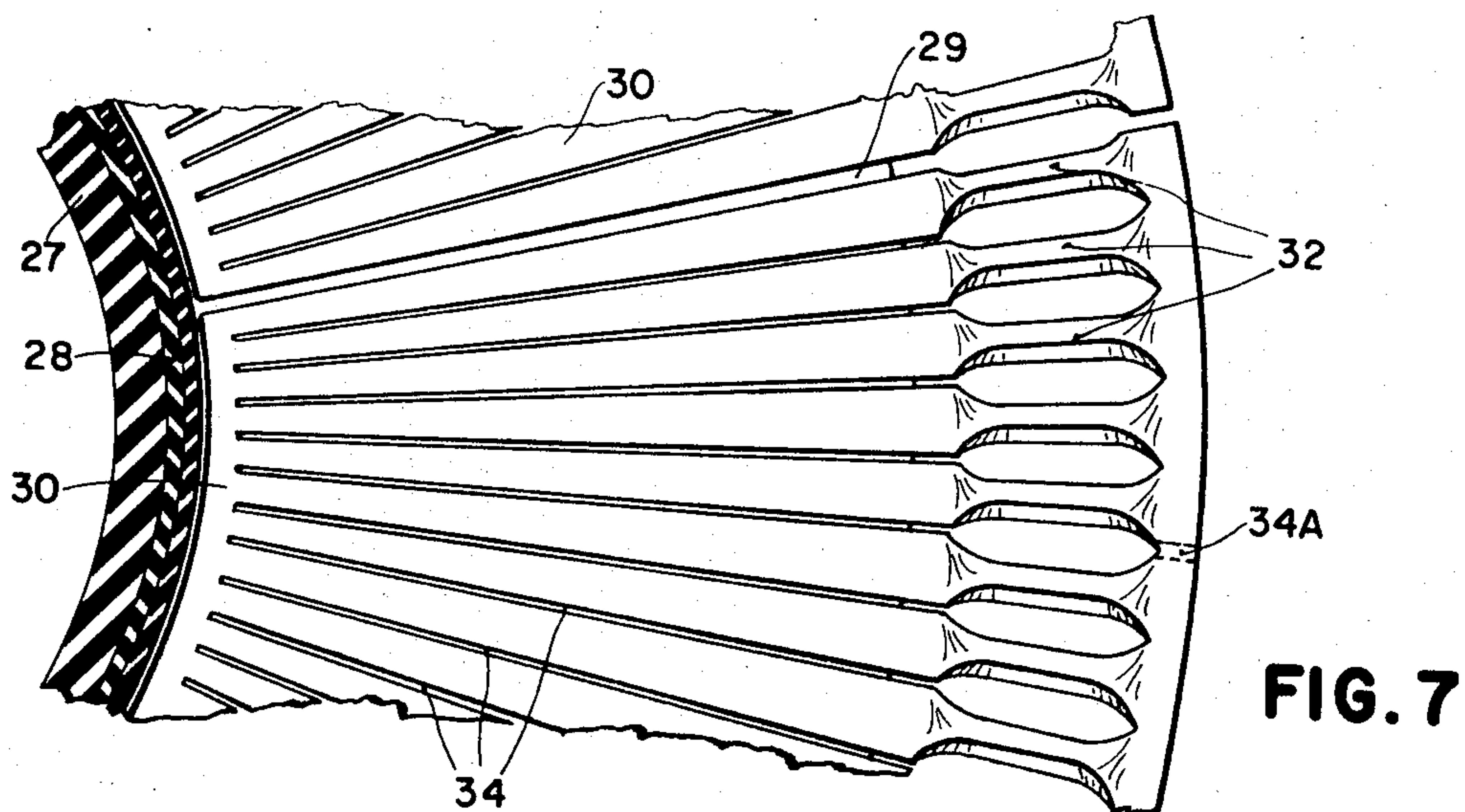
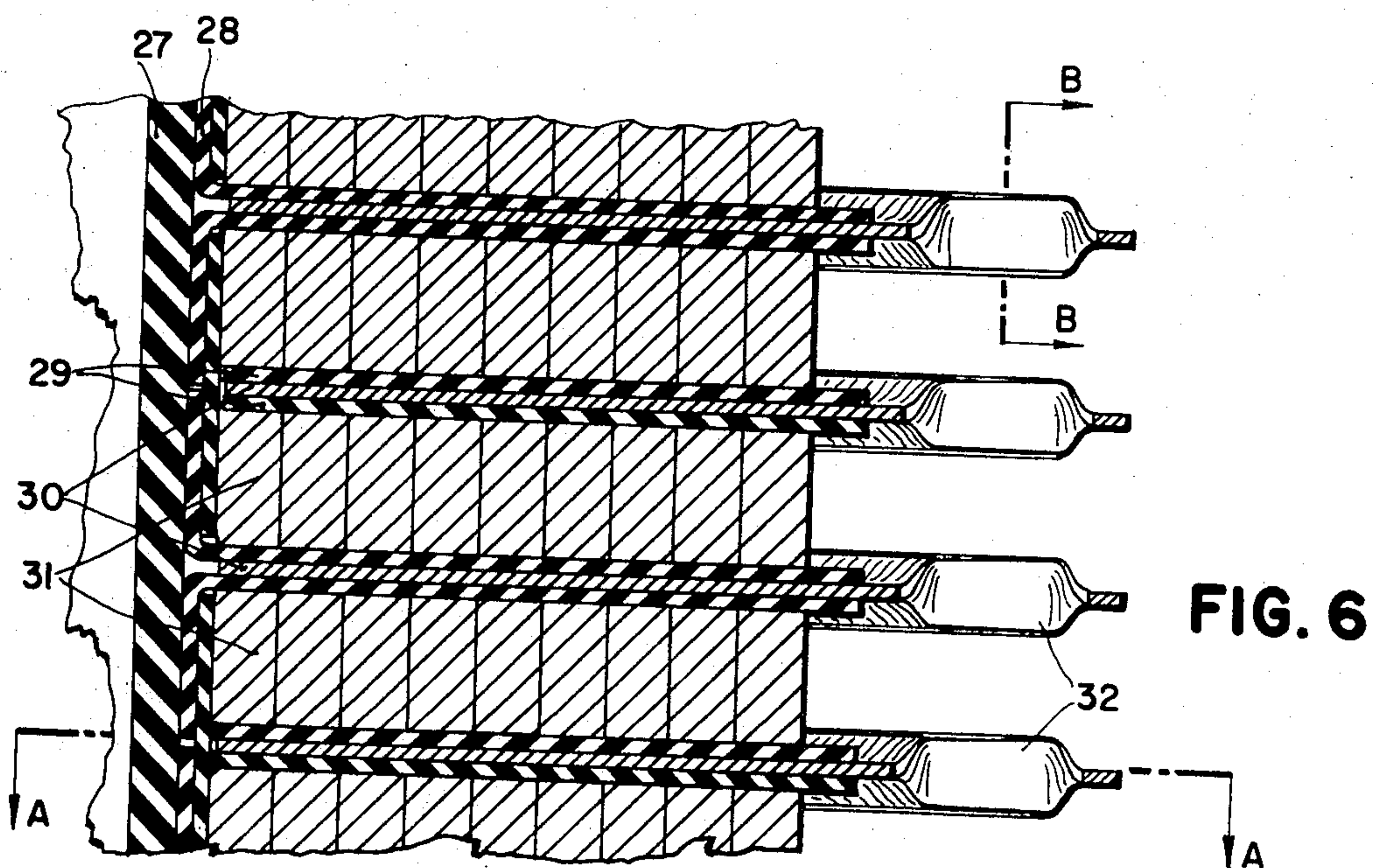


FIG. 5





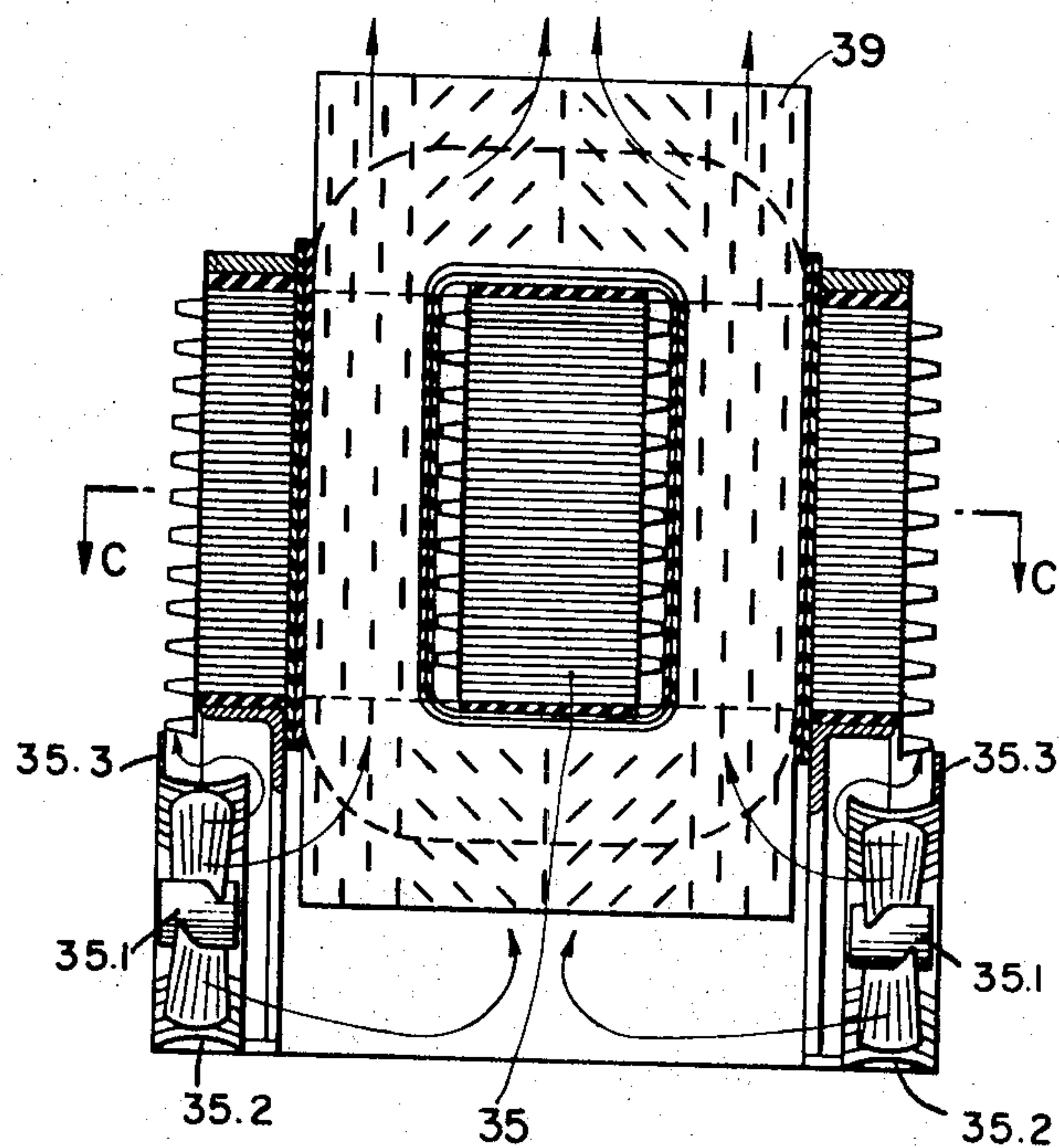


FIG. 10

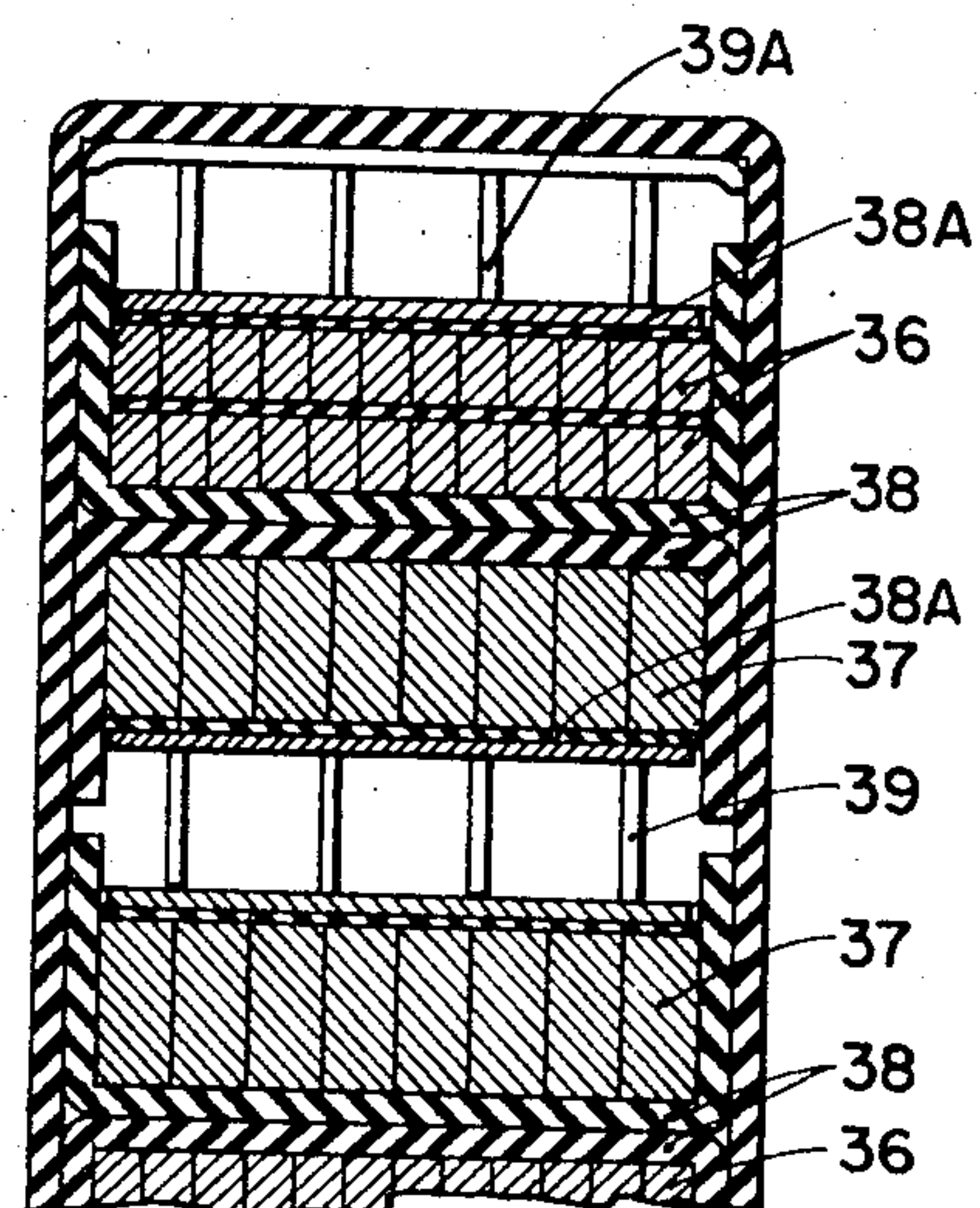


FIG. 12

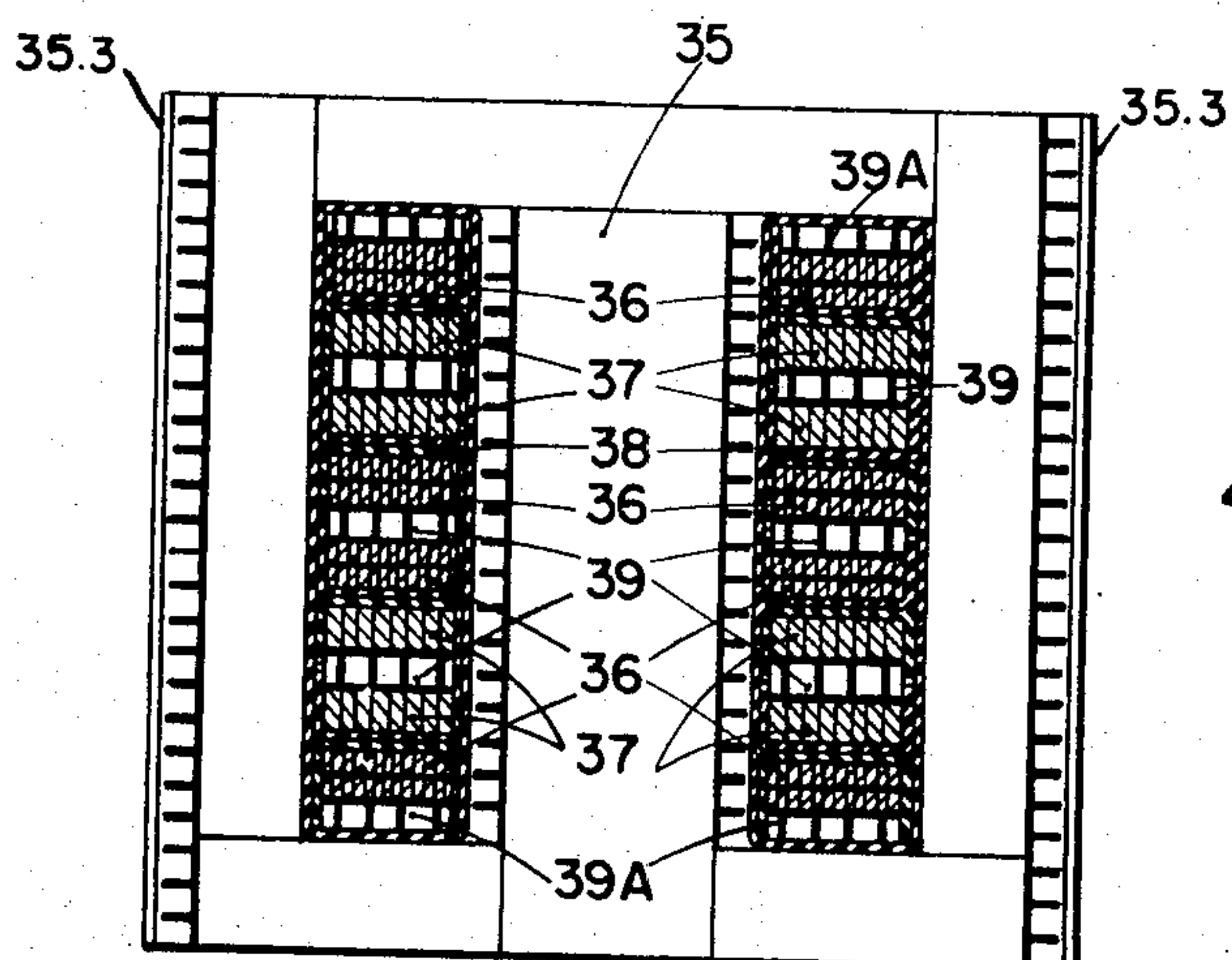


FIG. 11

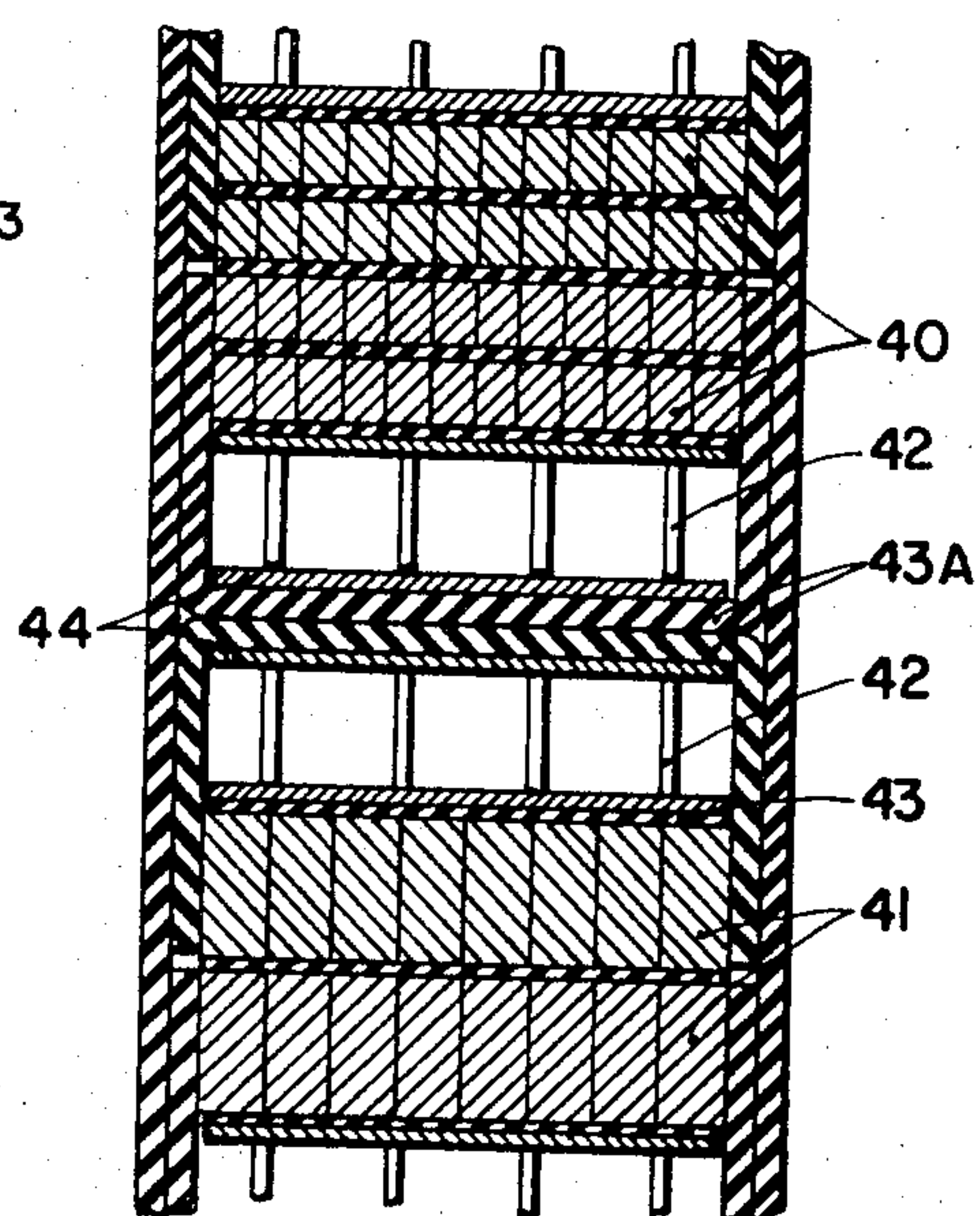


FIG. 13

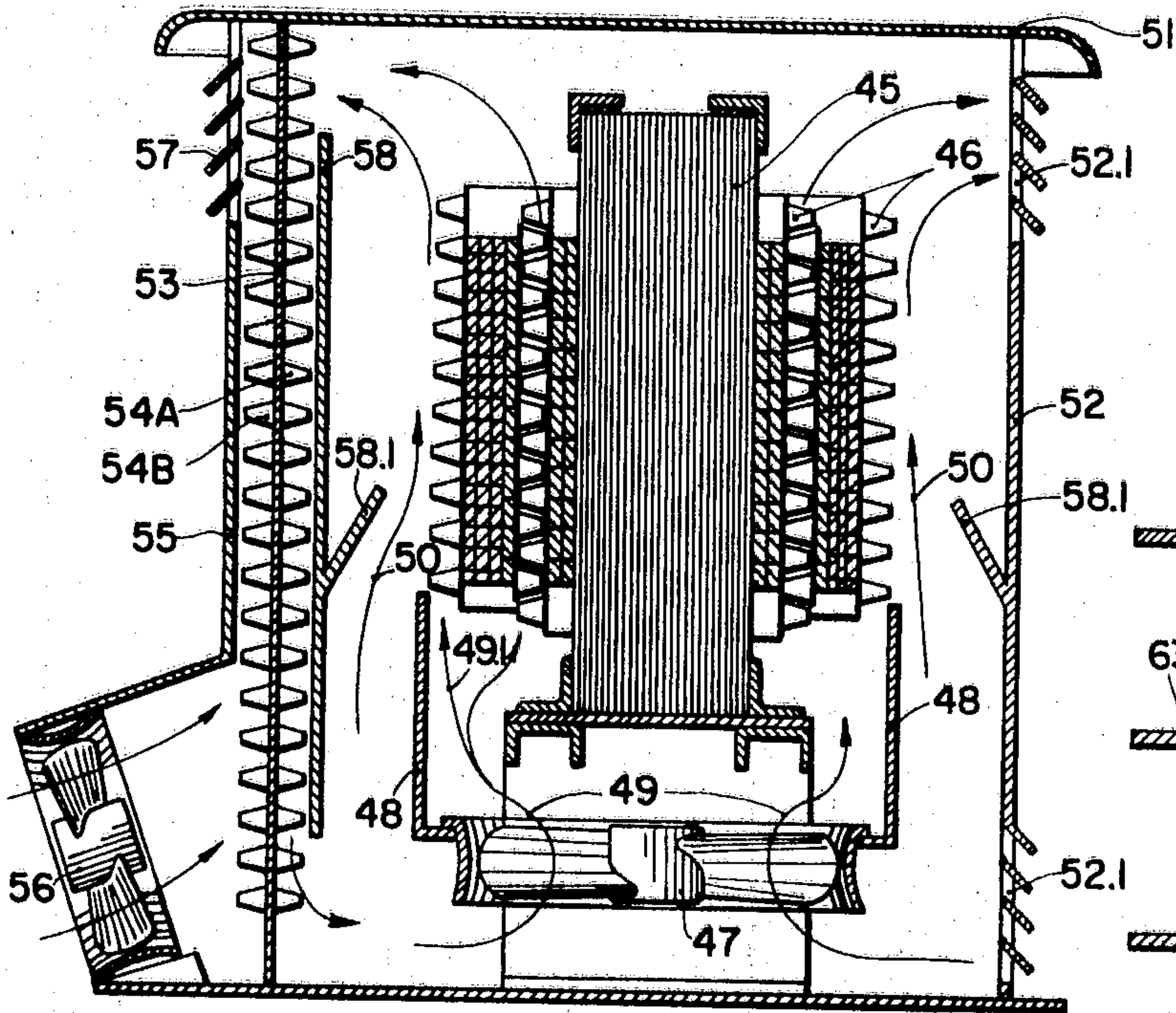


FIG. 14

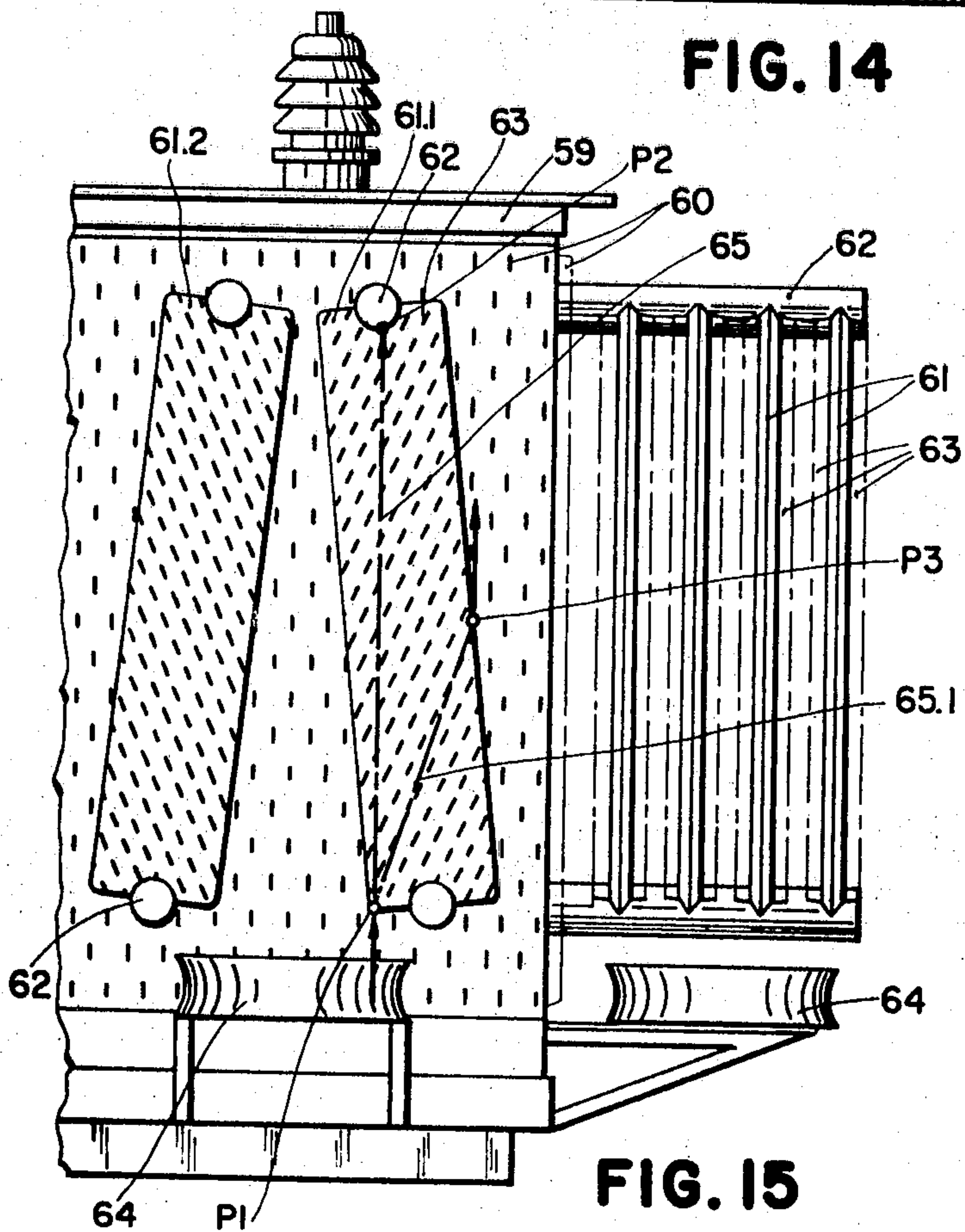


FIG. 15

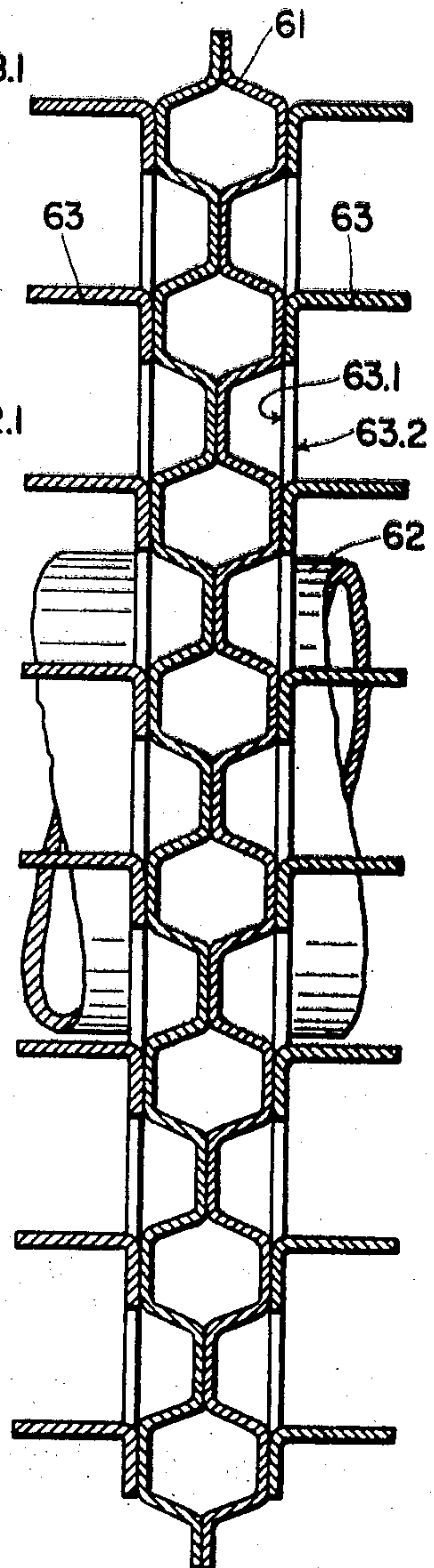


FIG. 16

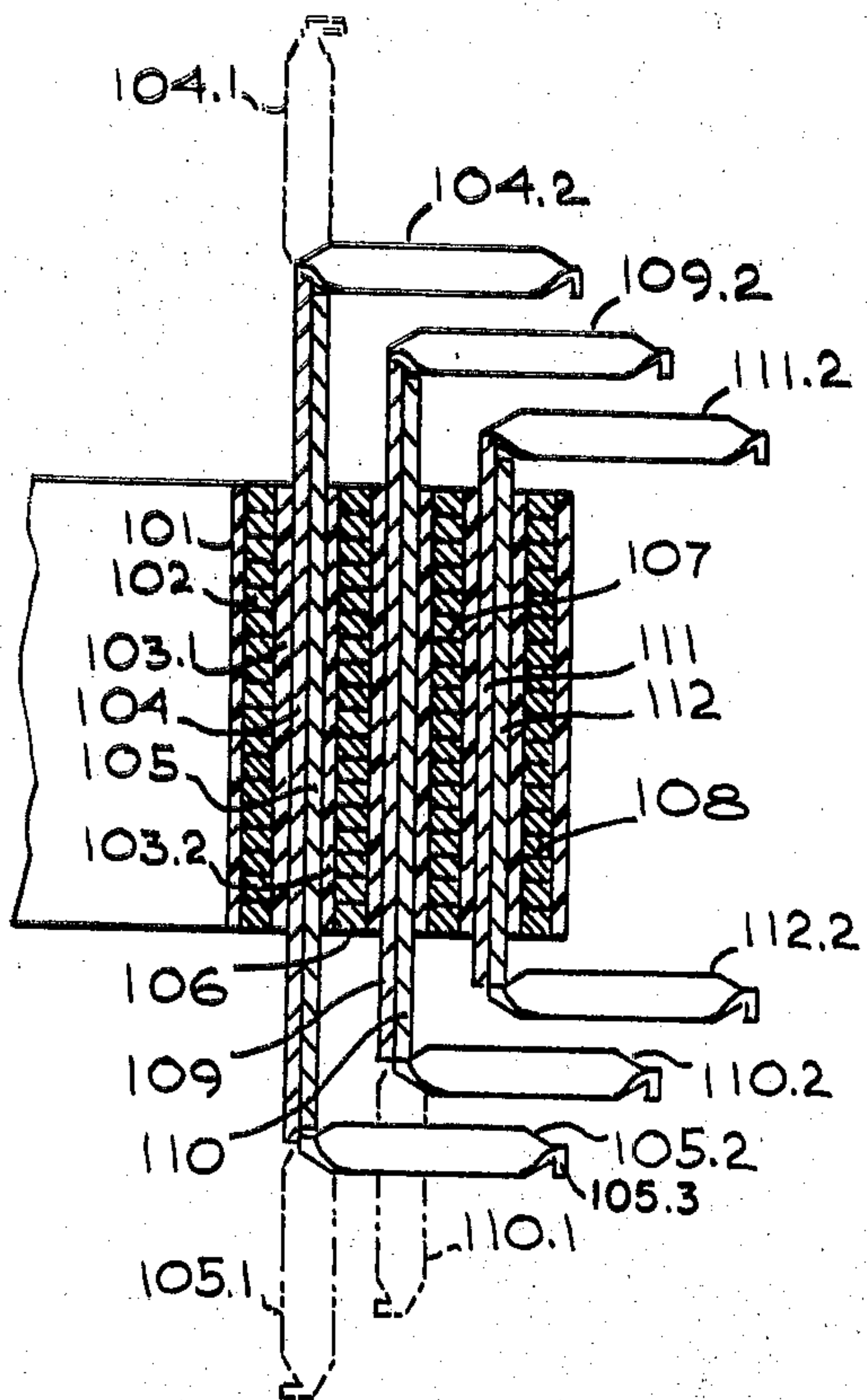


Fig. 17

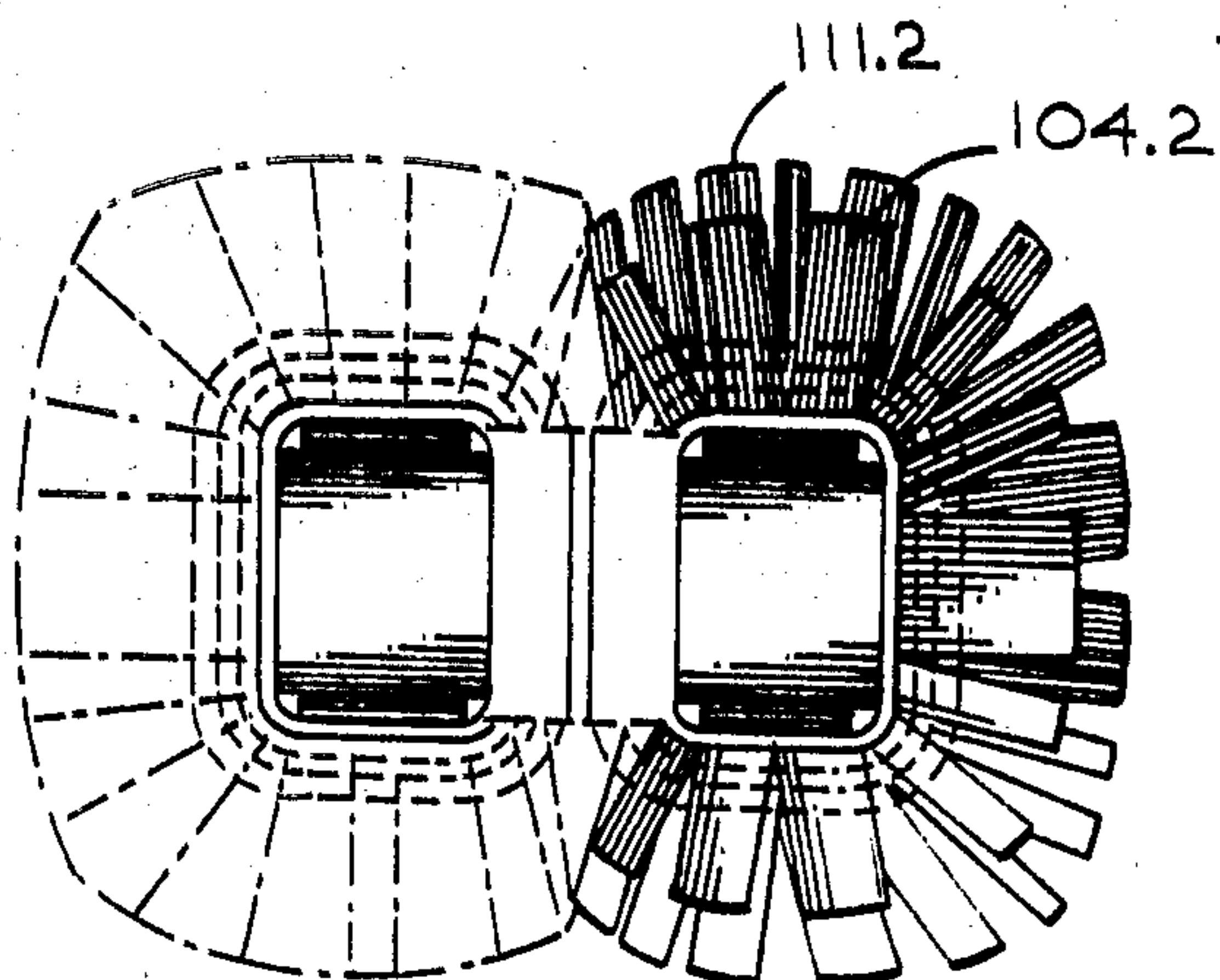


Fig. 18

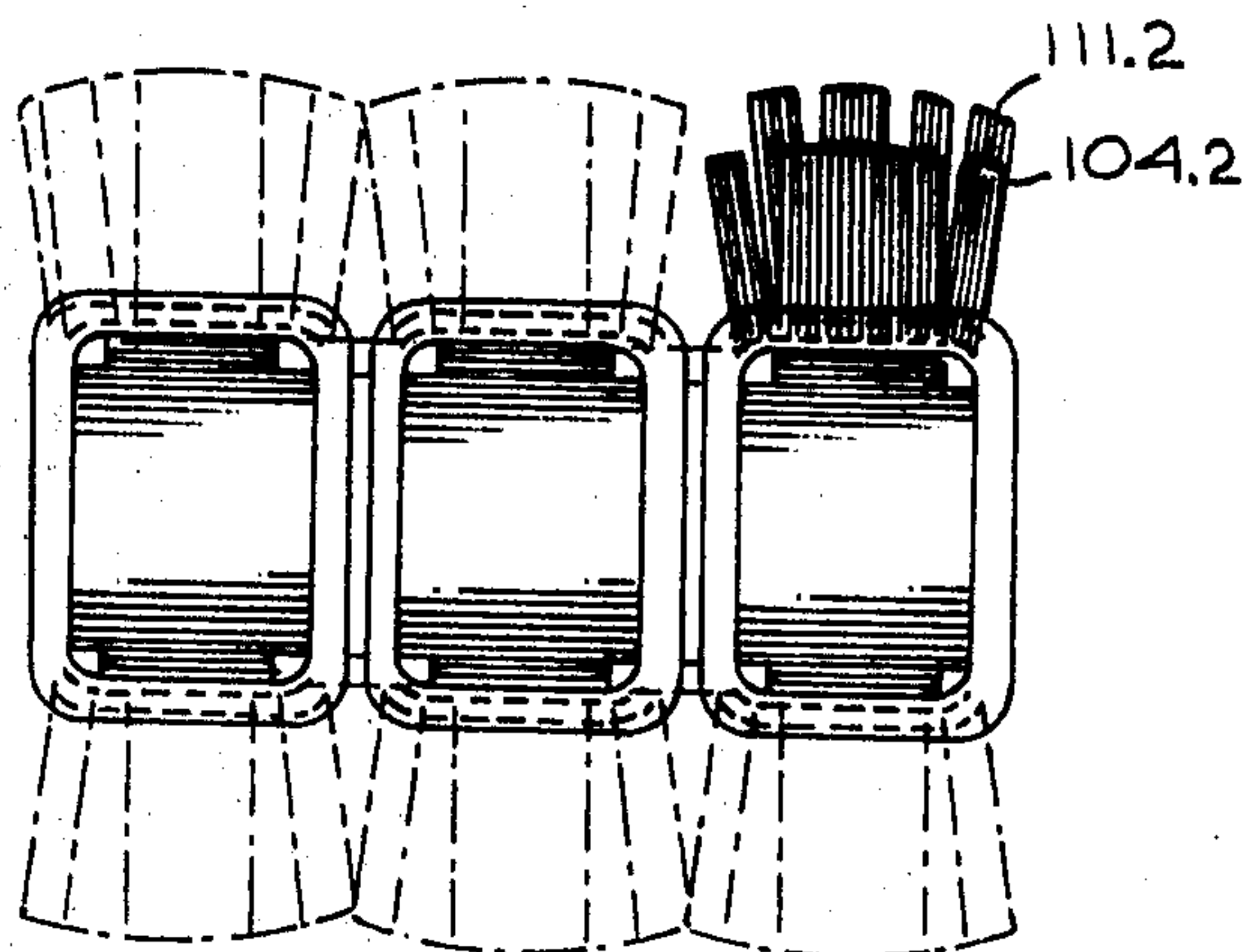


Fig. 19

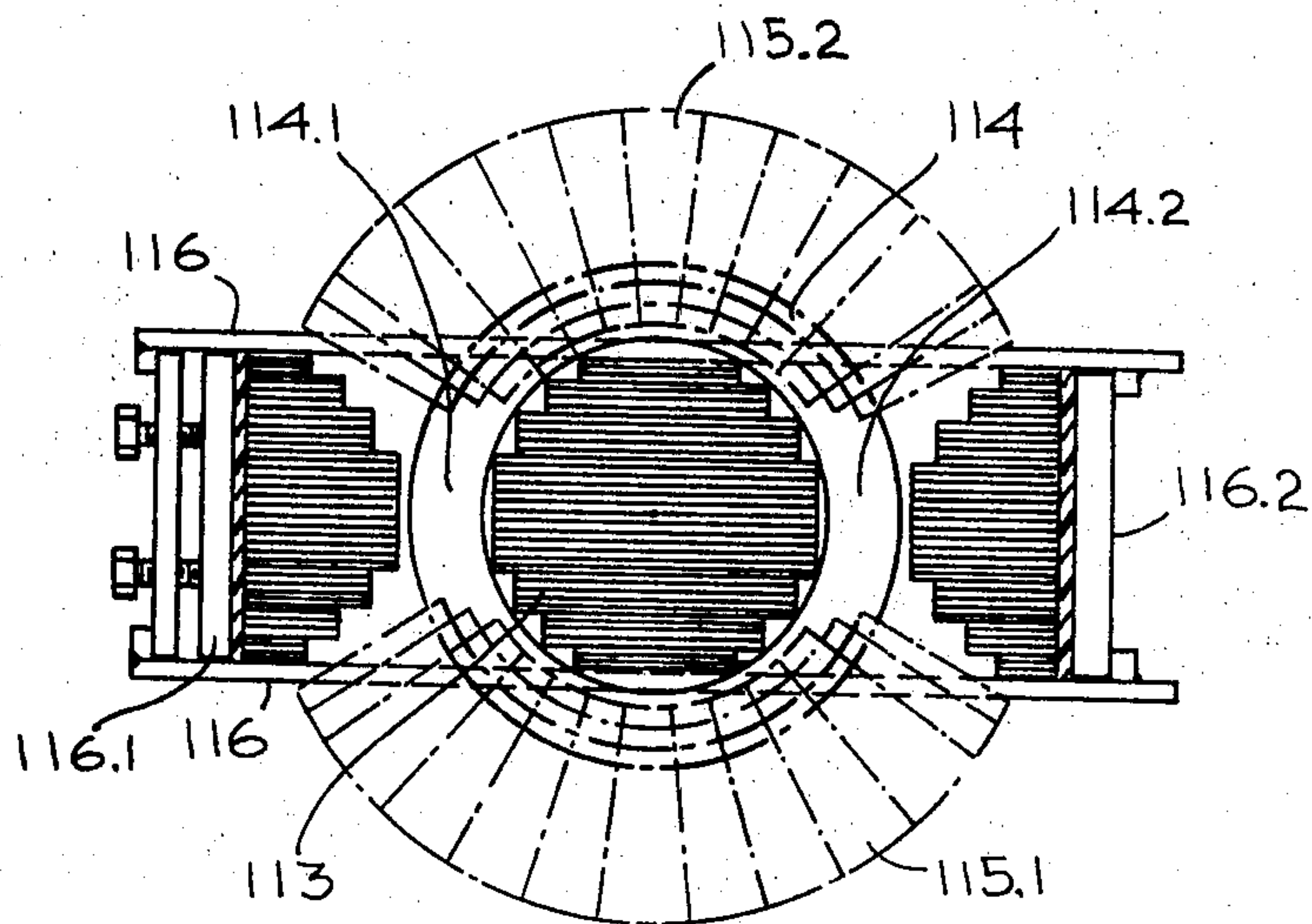


Fig. 20

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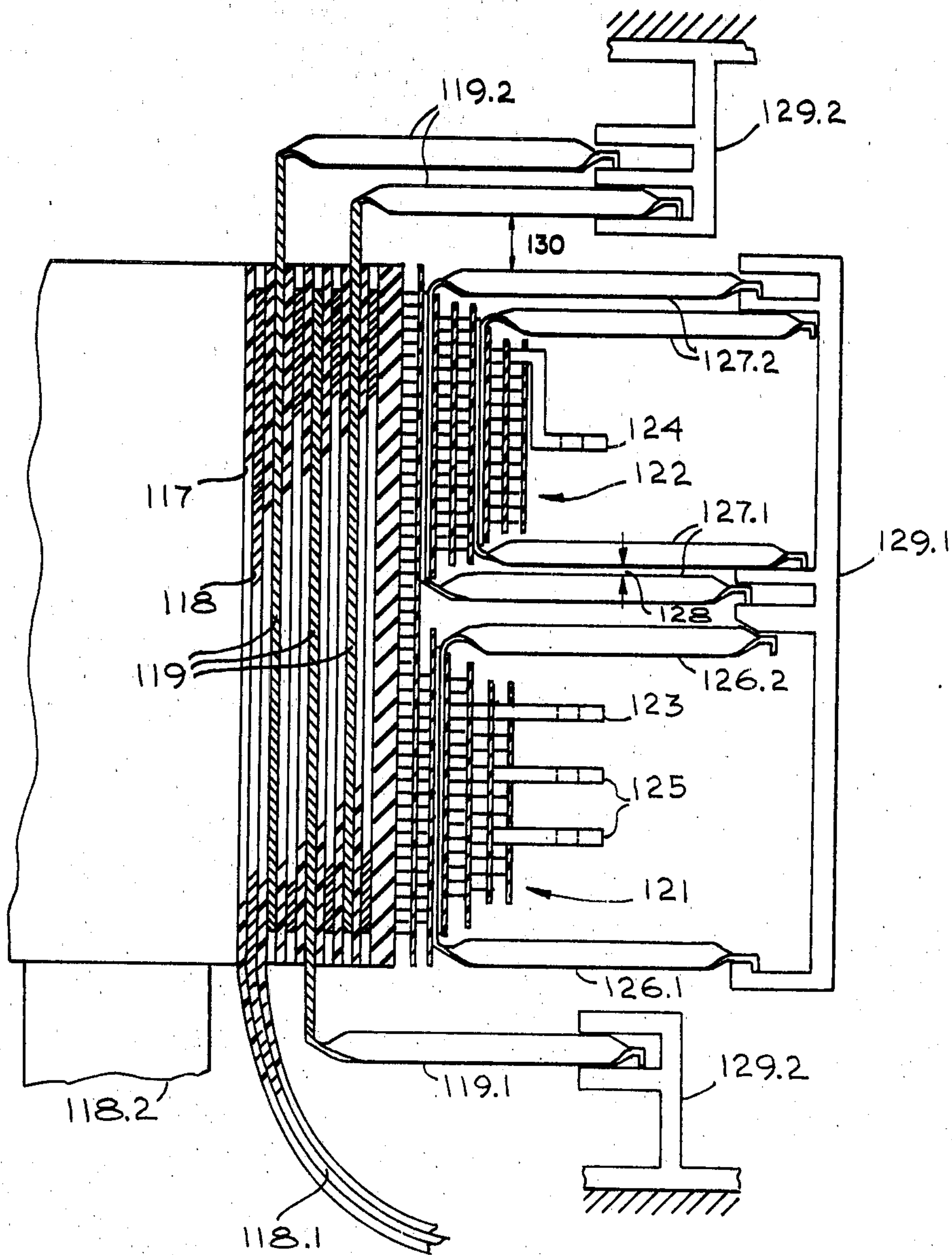


Fig. 21

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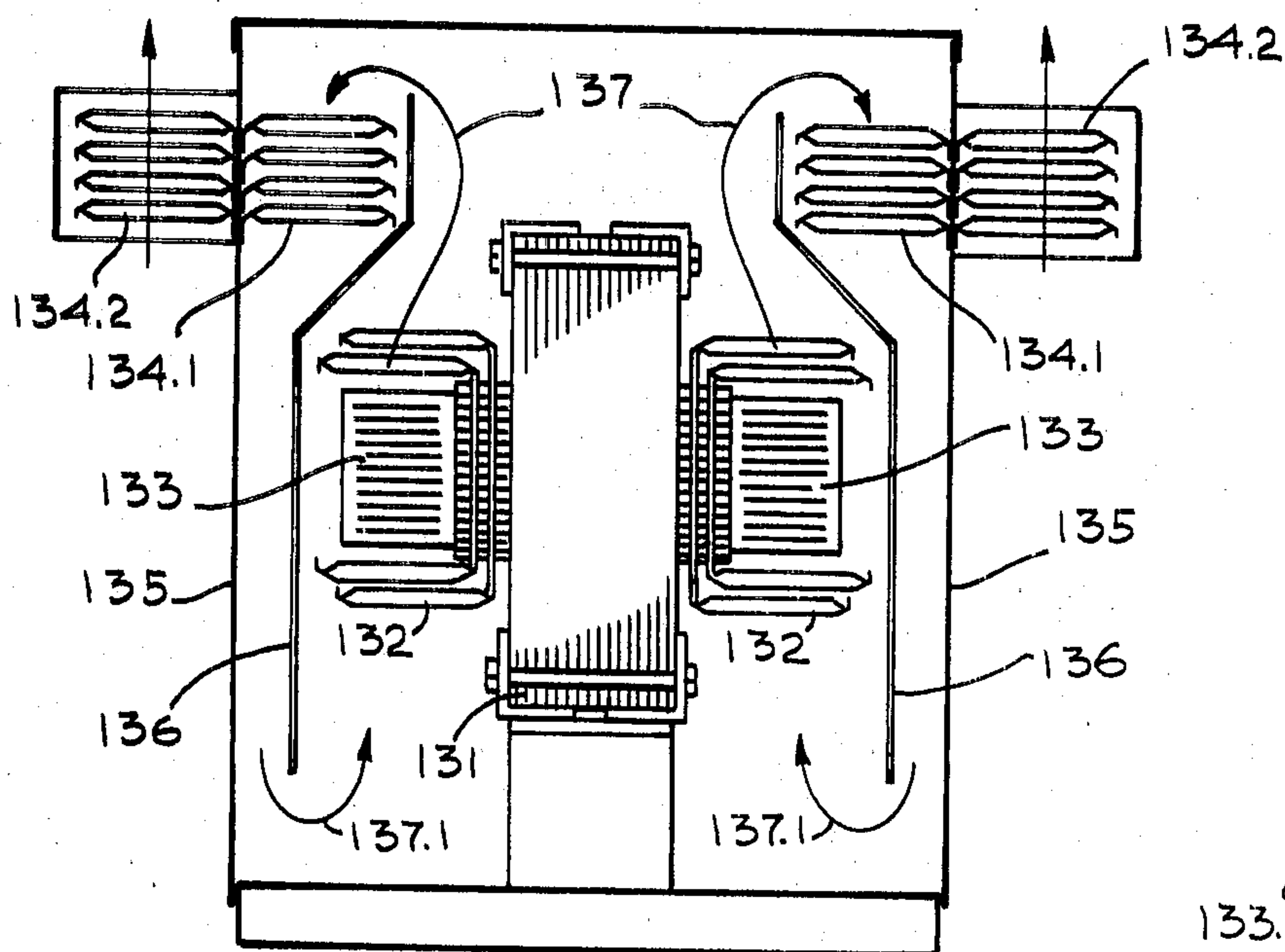


Fig. 22

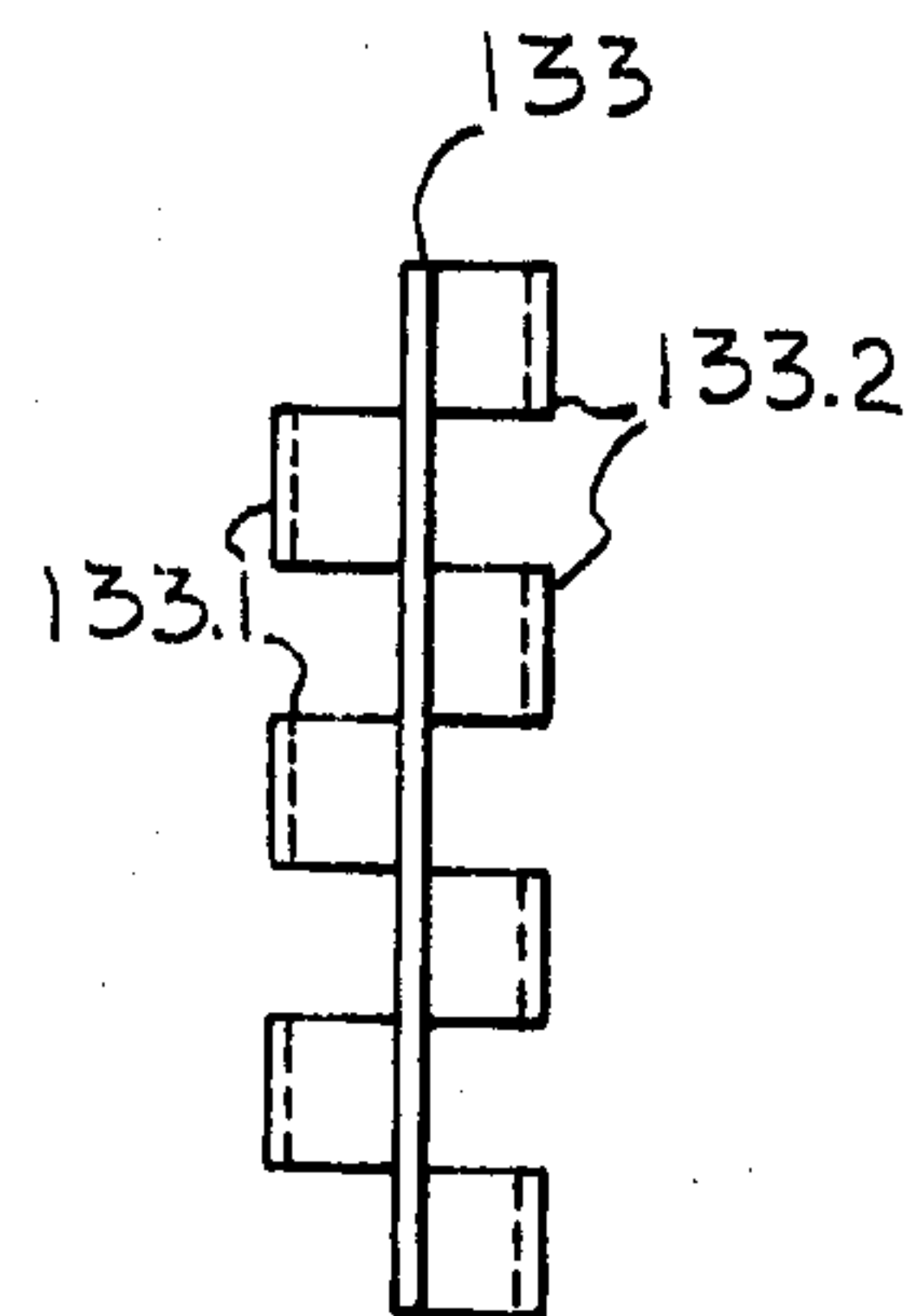


Fig. 23

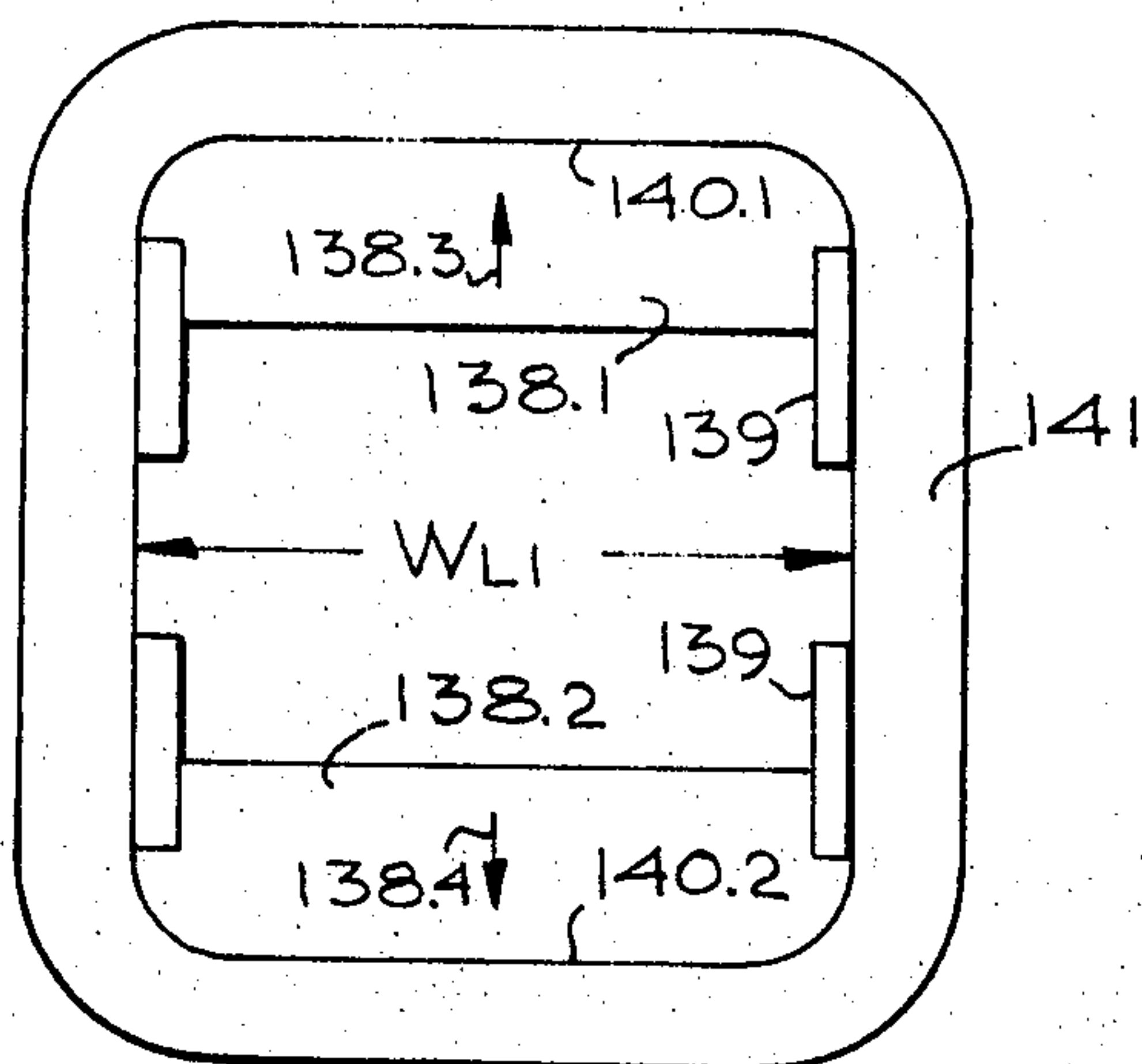


Fig. 24

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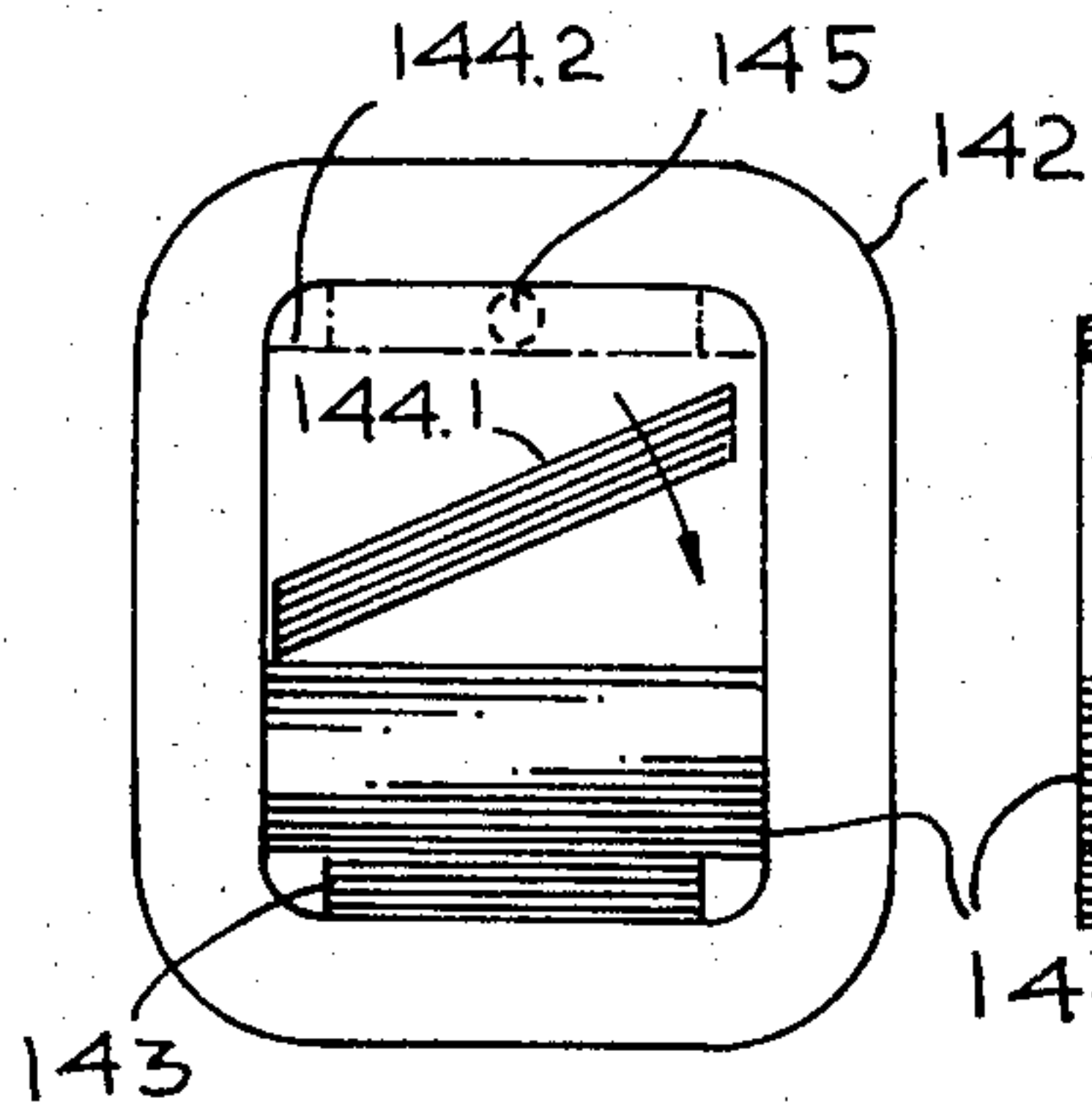


Fig. 25

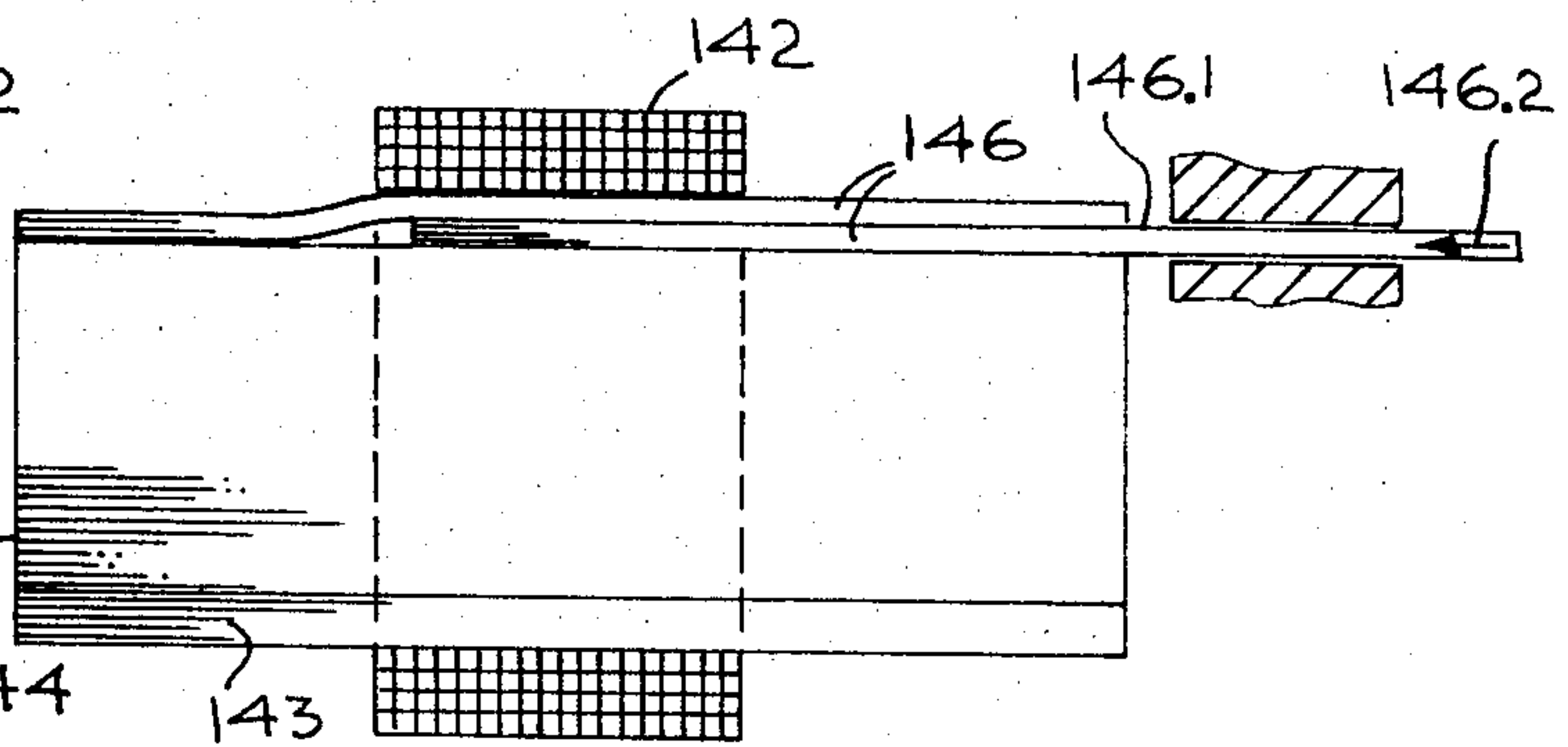


Fig. 26

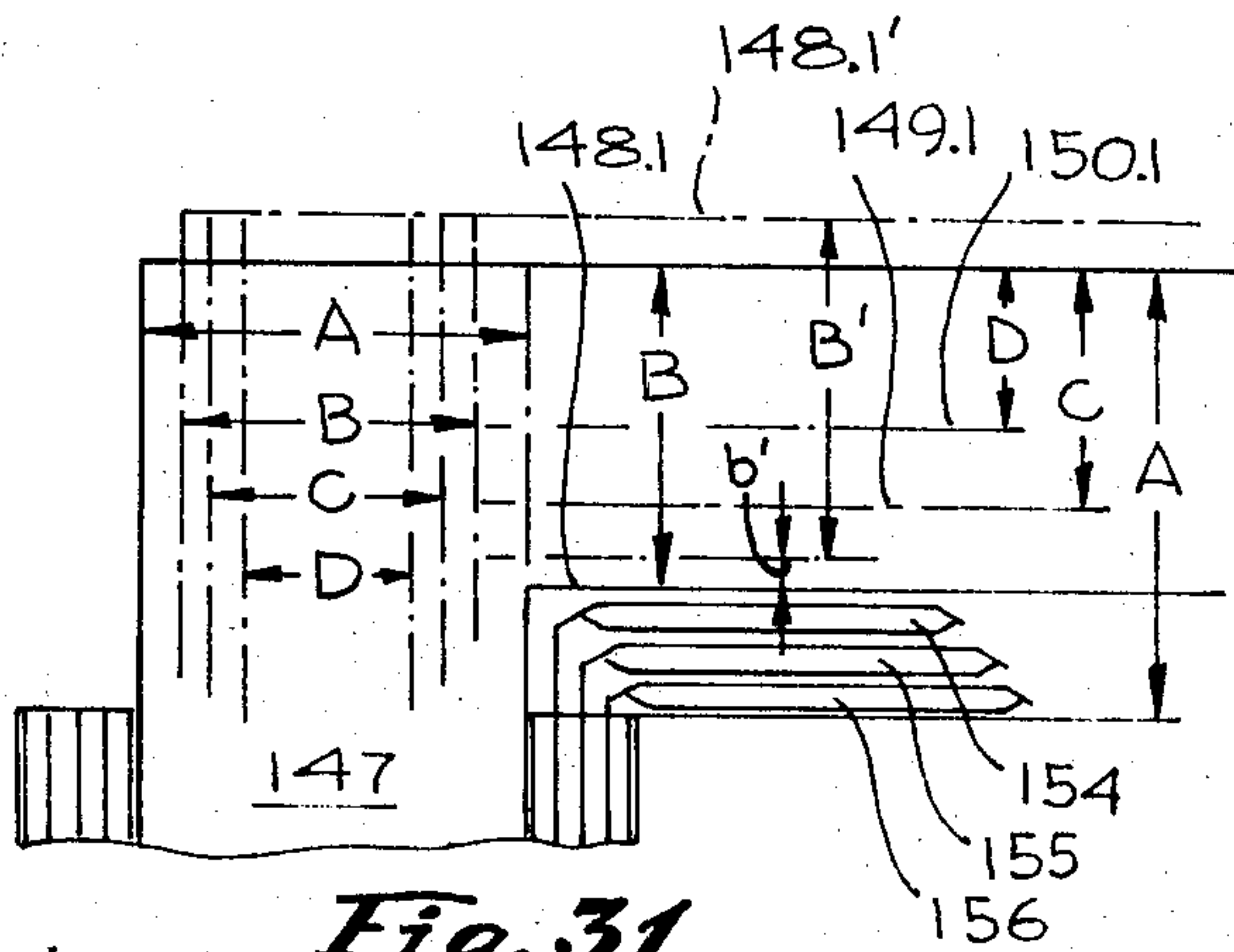


Fig. 31

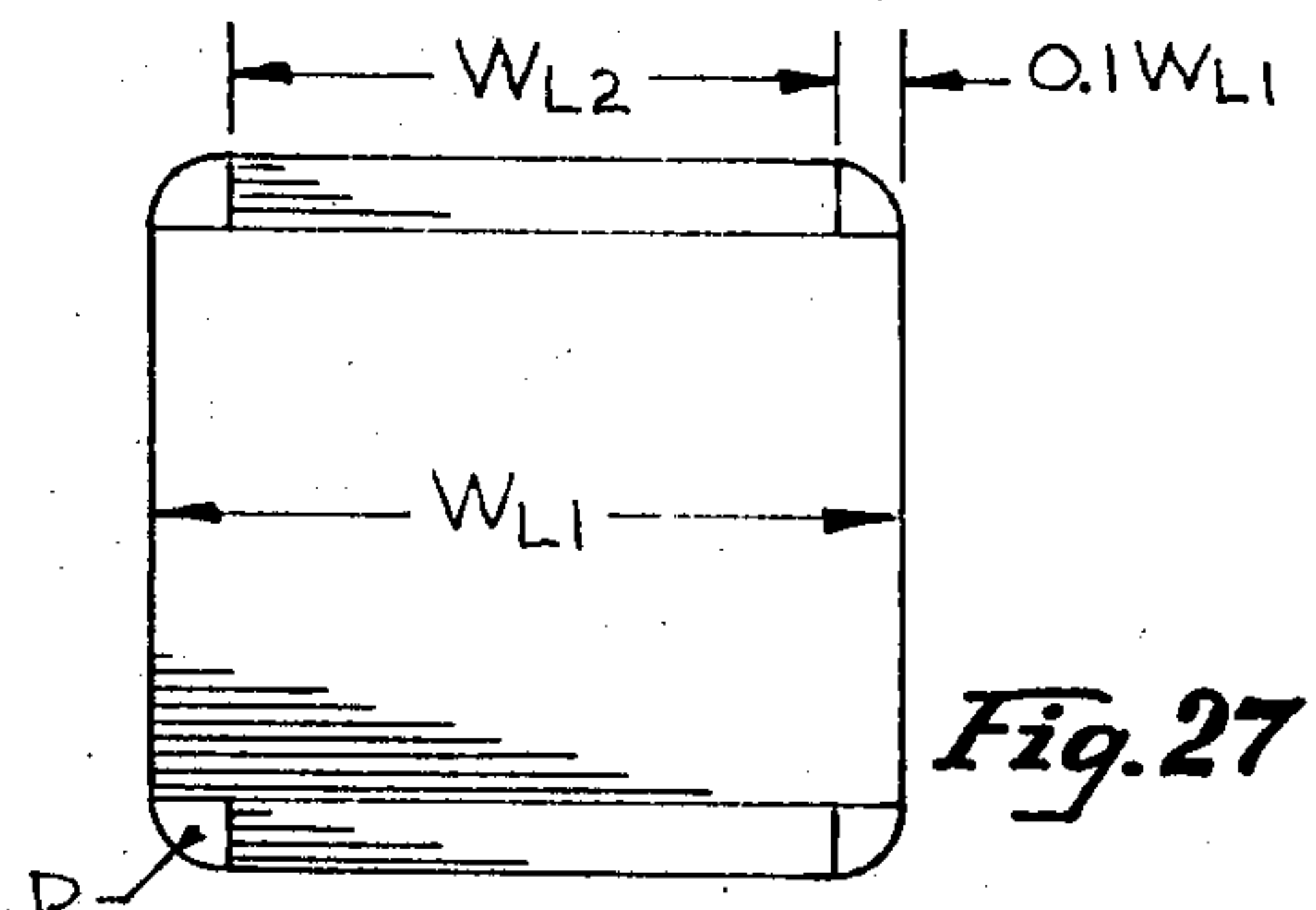


Fig. 27

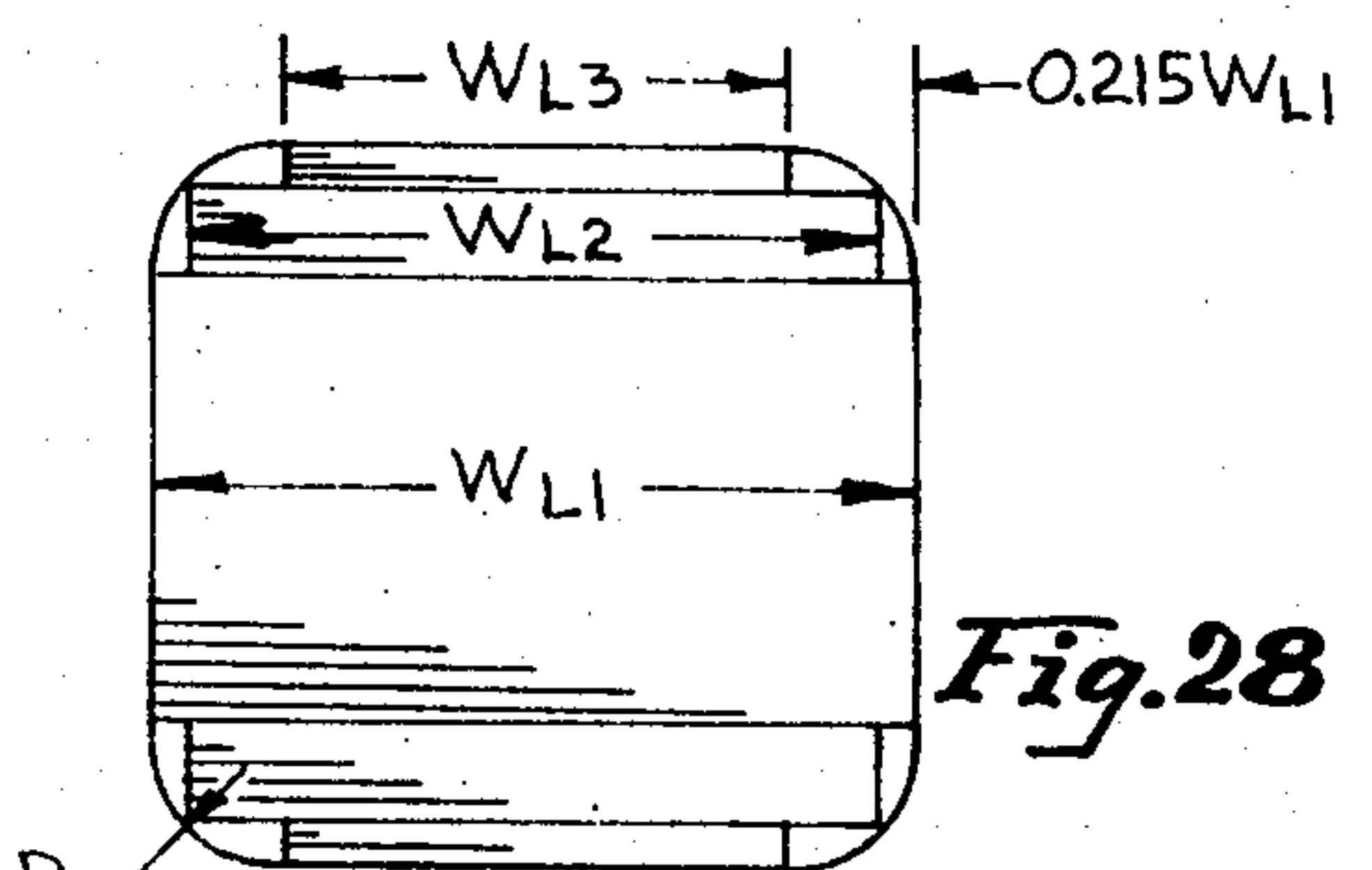


Fig. 28

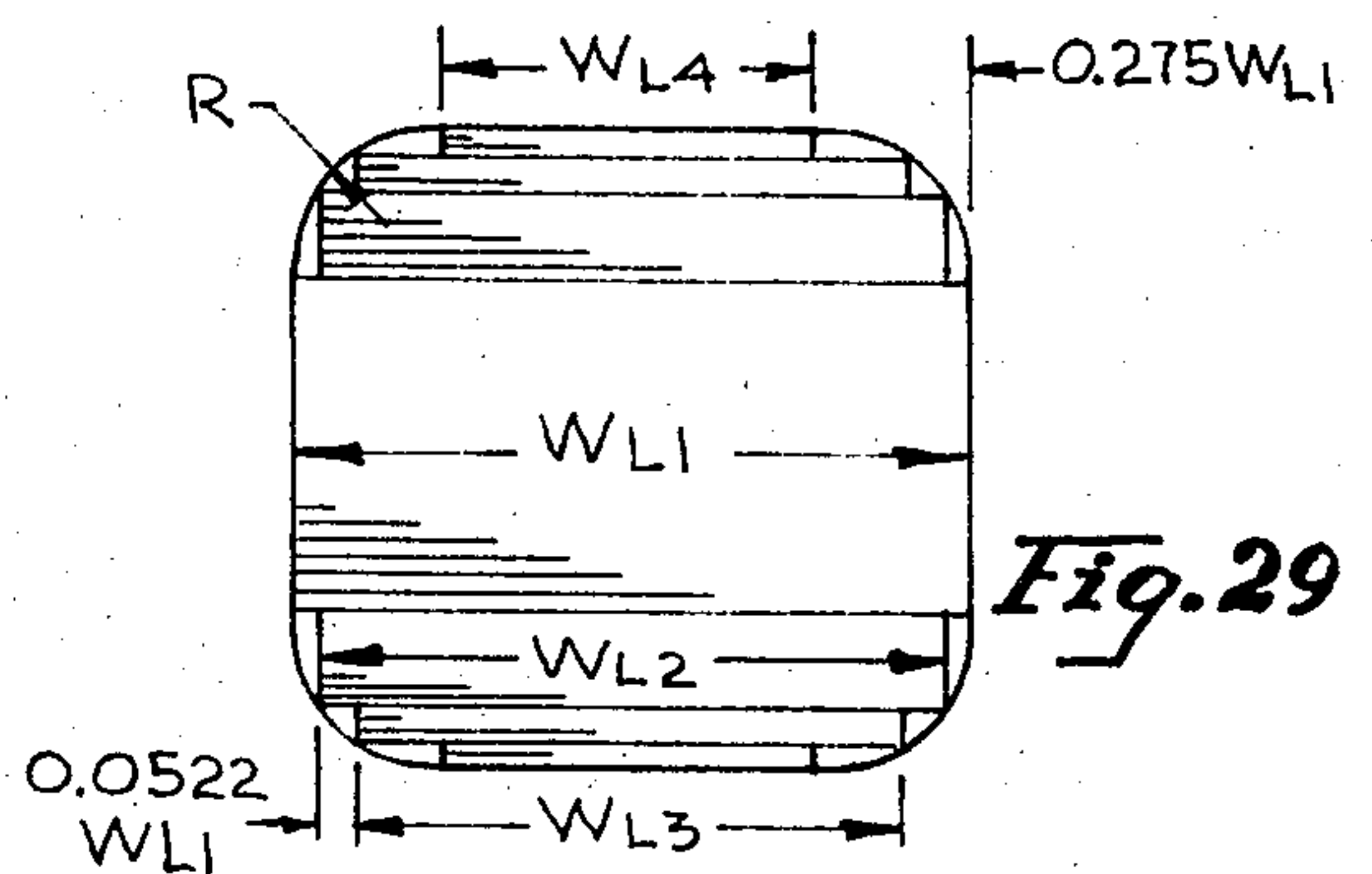


Fig. 29

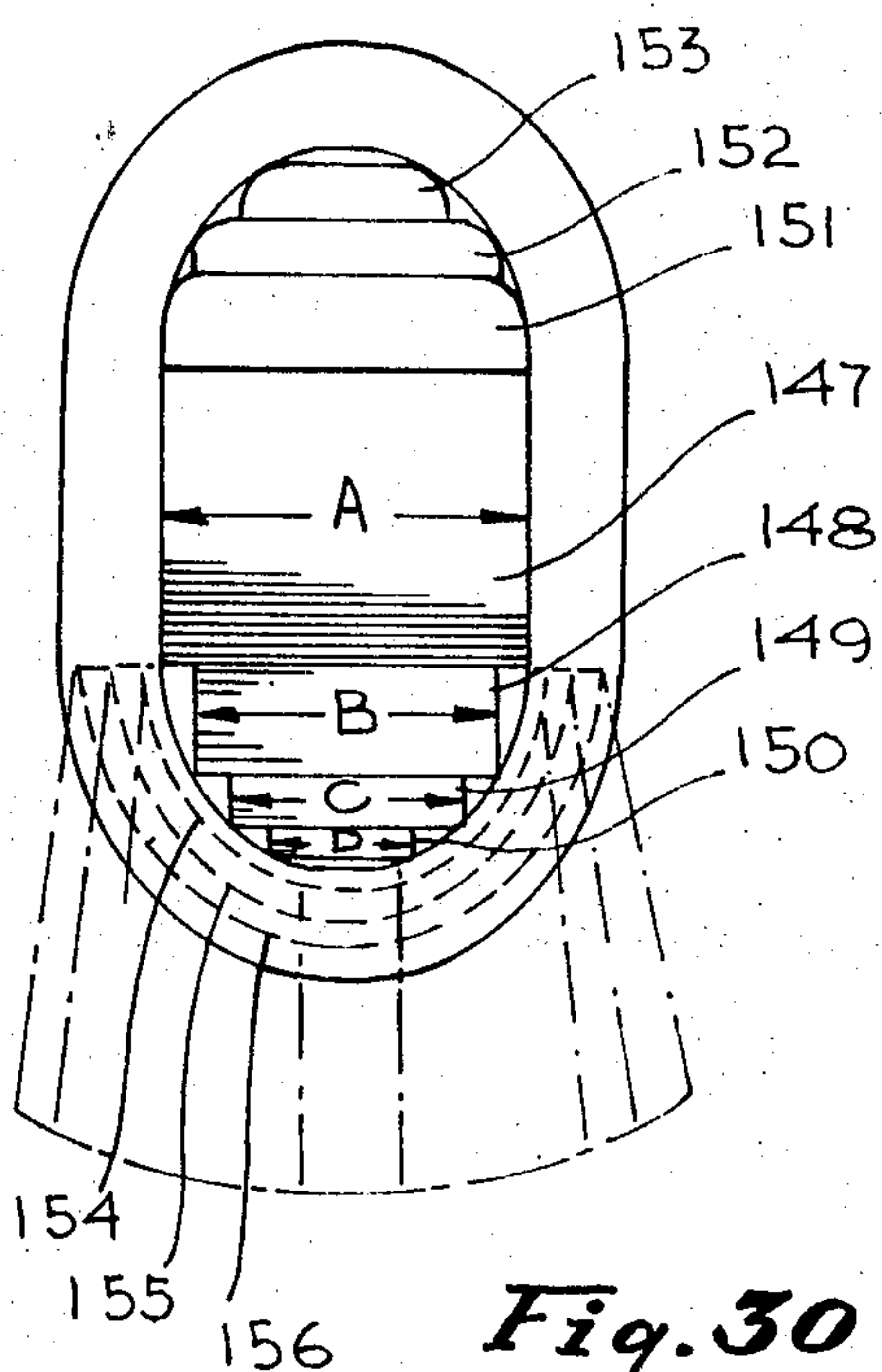


Fig. 30

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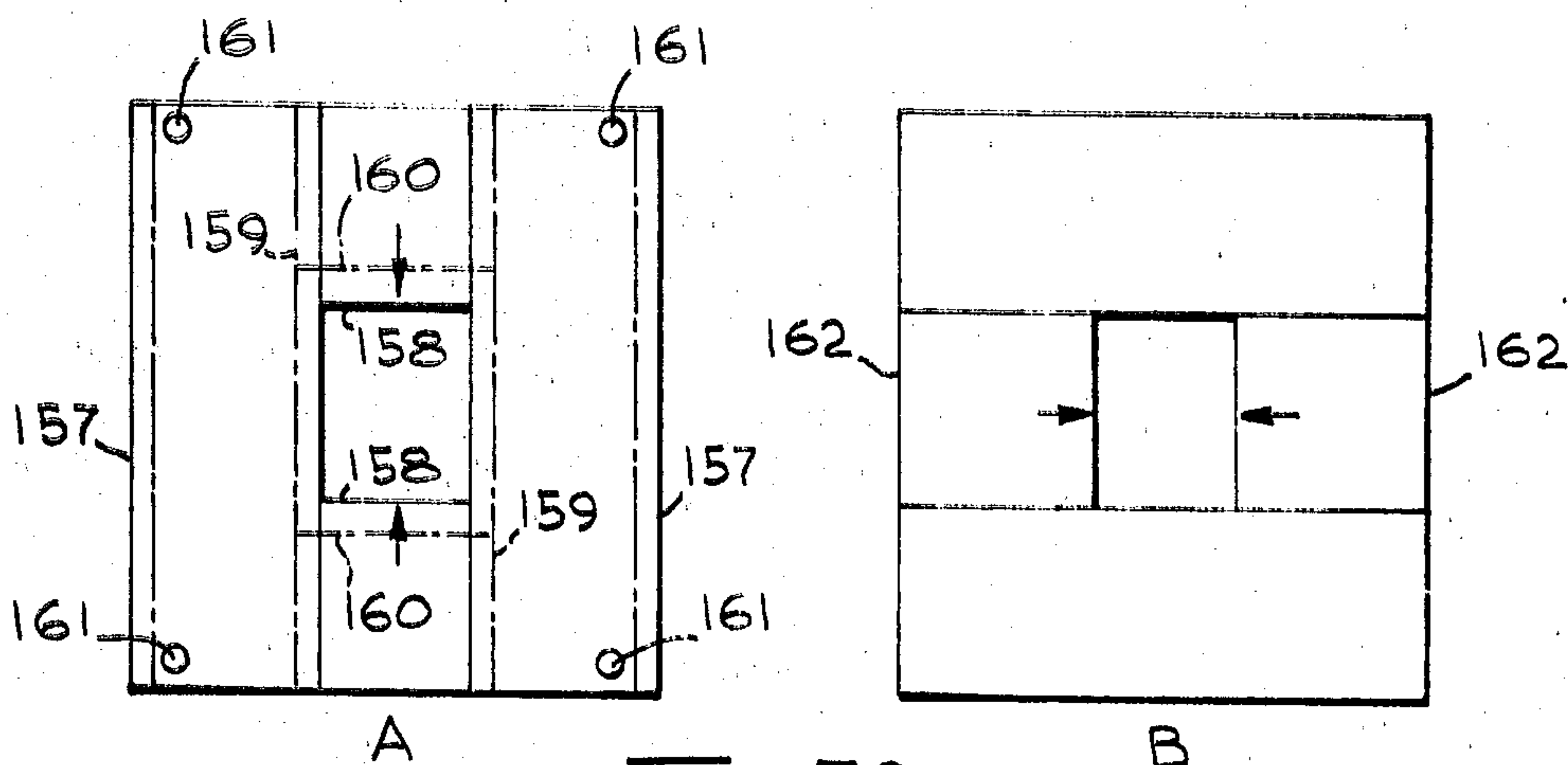


Fig. 32

Fig. 33

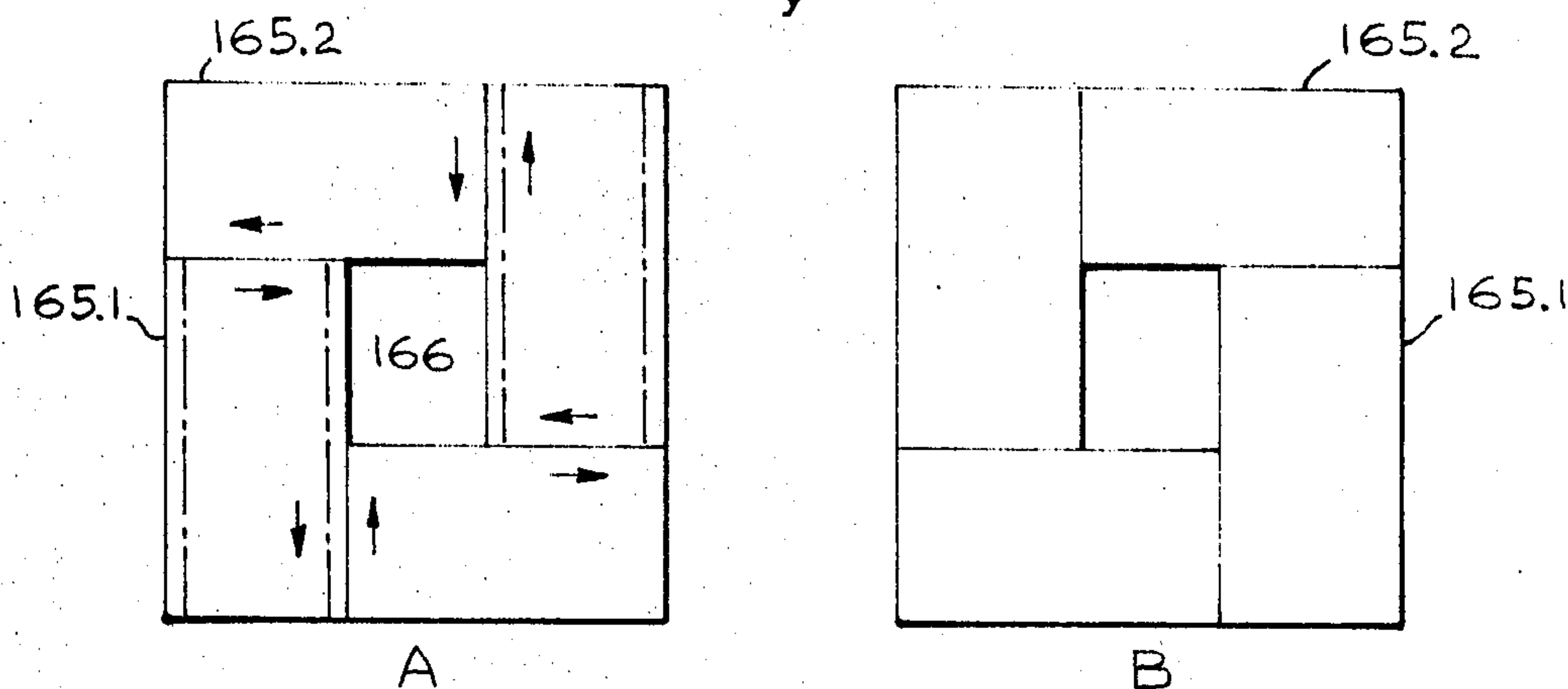
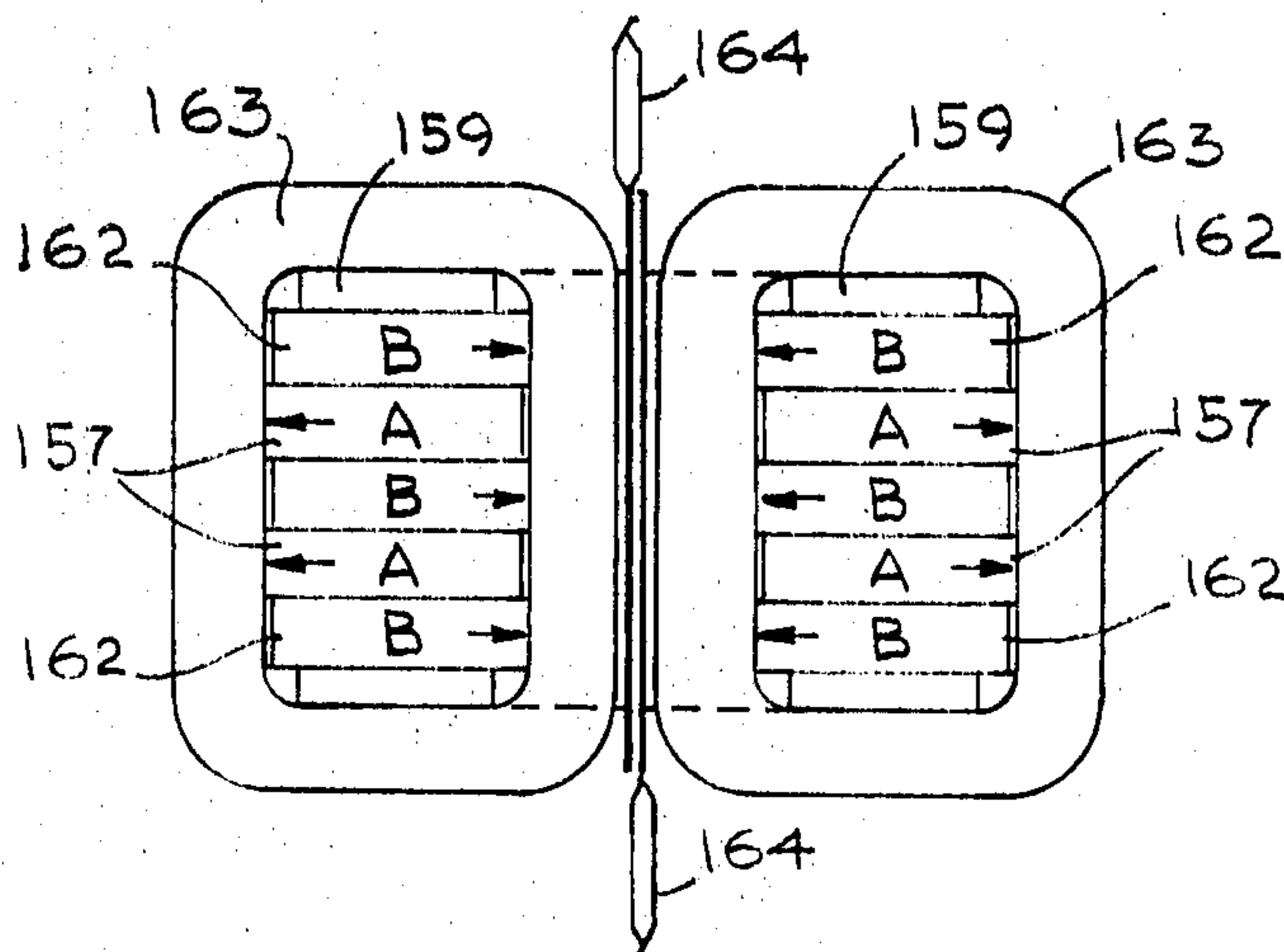


Fig. 34

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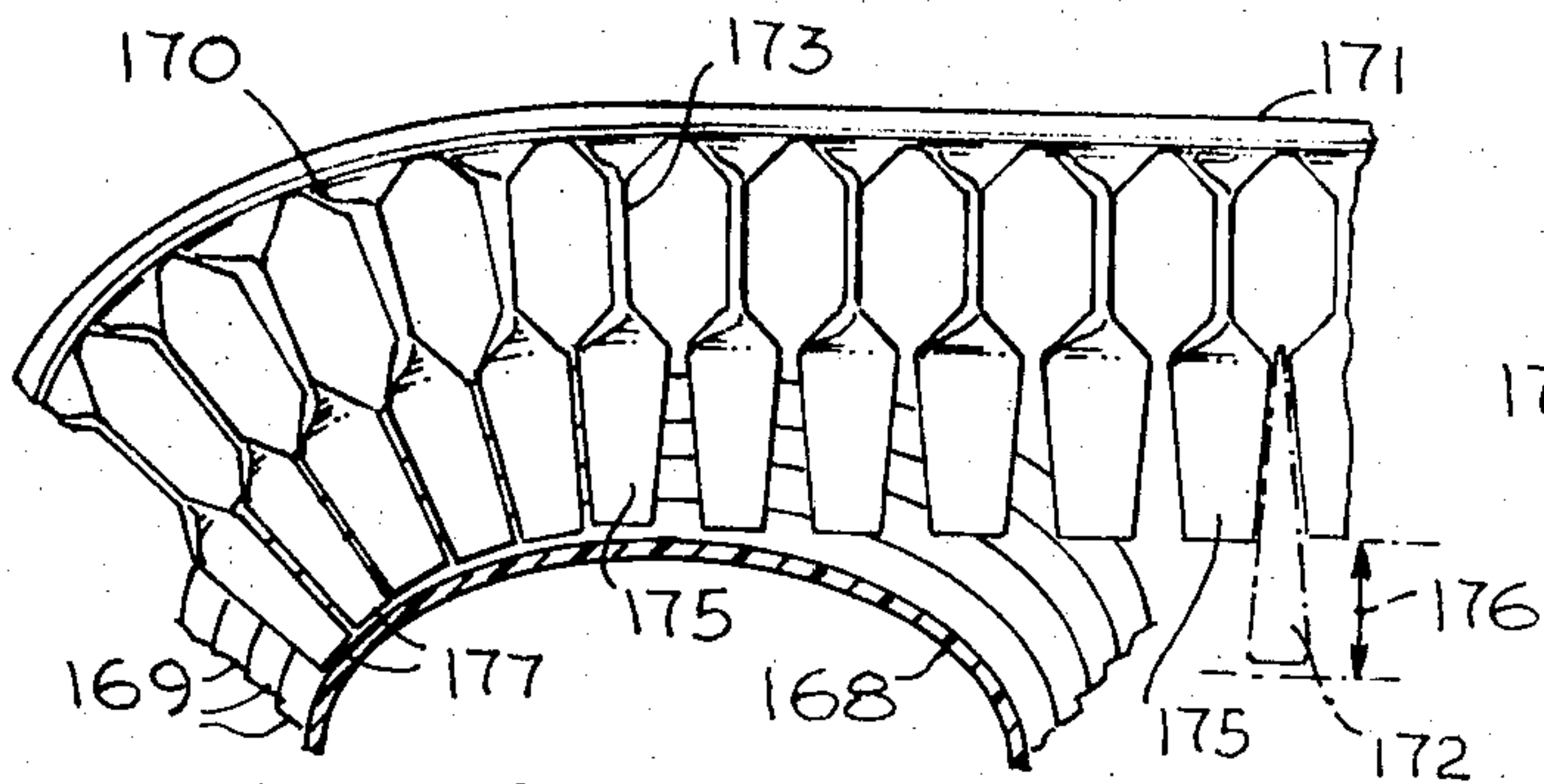


Fig. 35

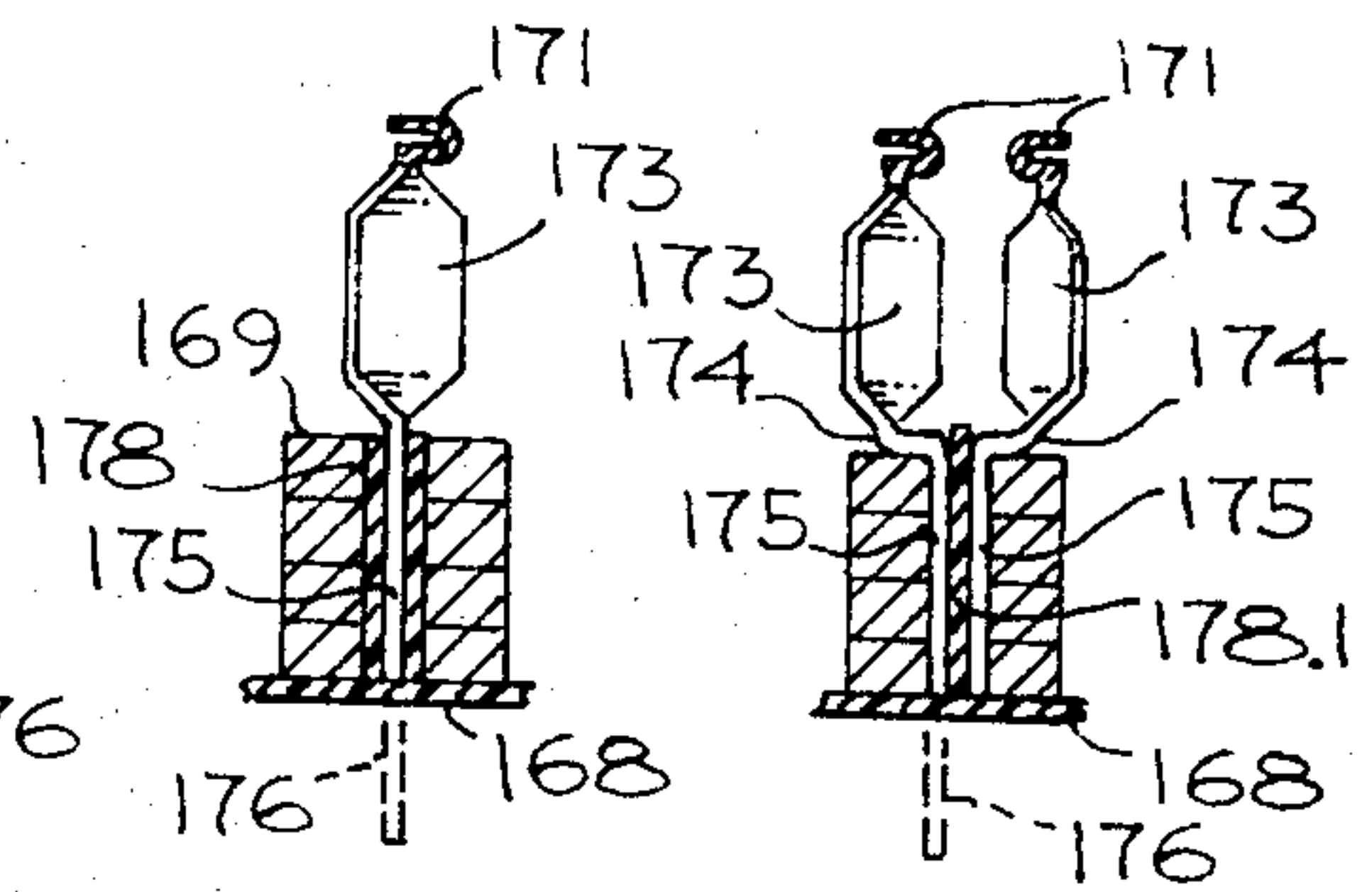


Fig. 36 Fig. 37

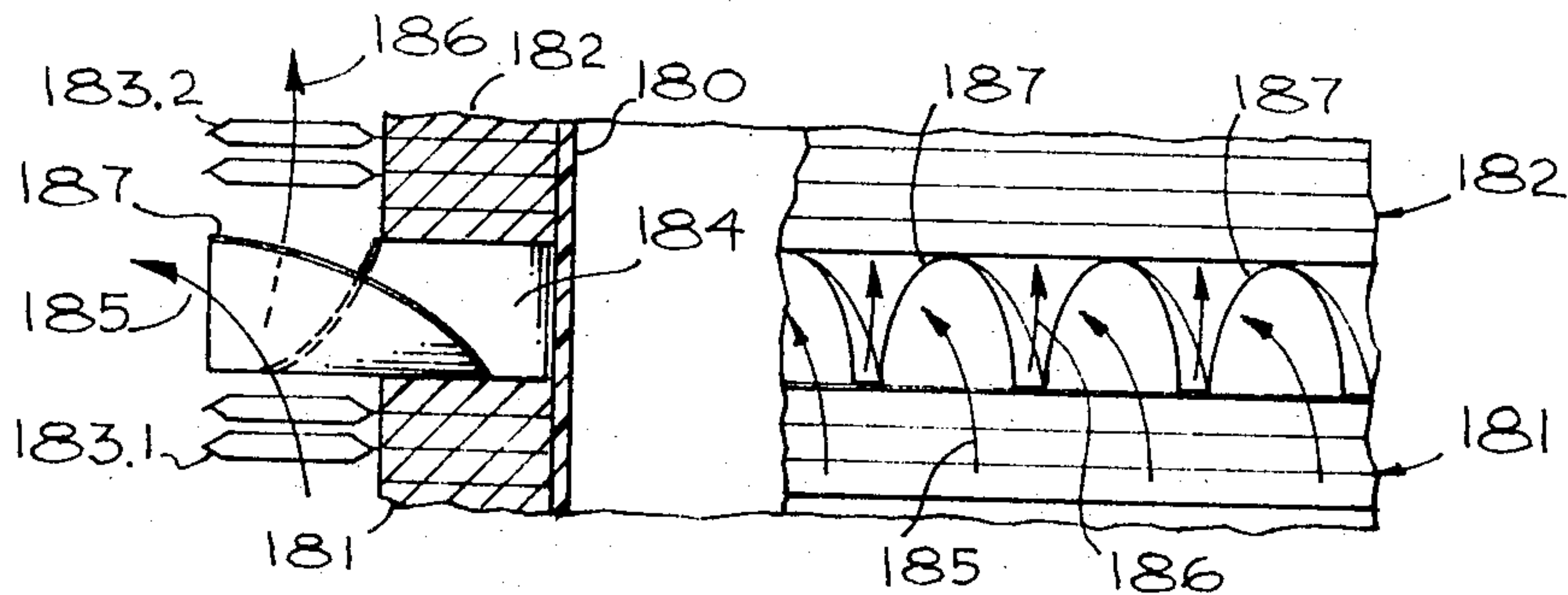


Fig. 38

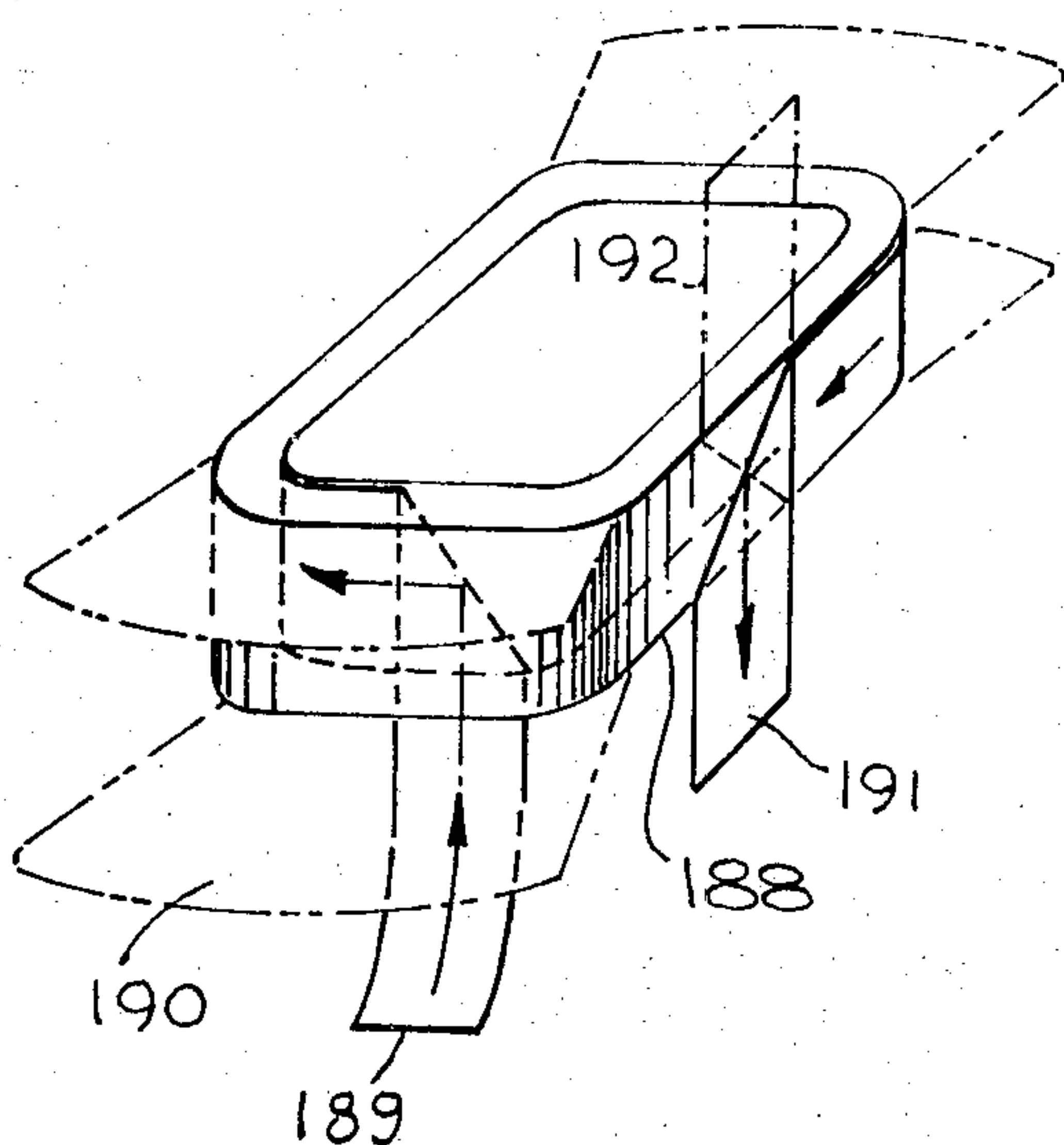


Fig. 39

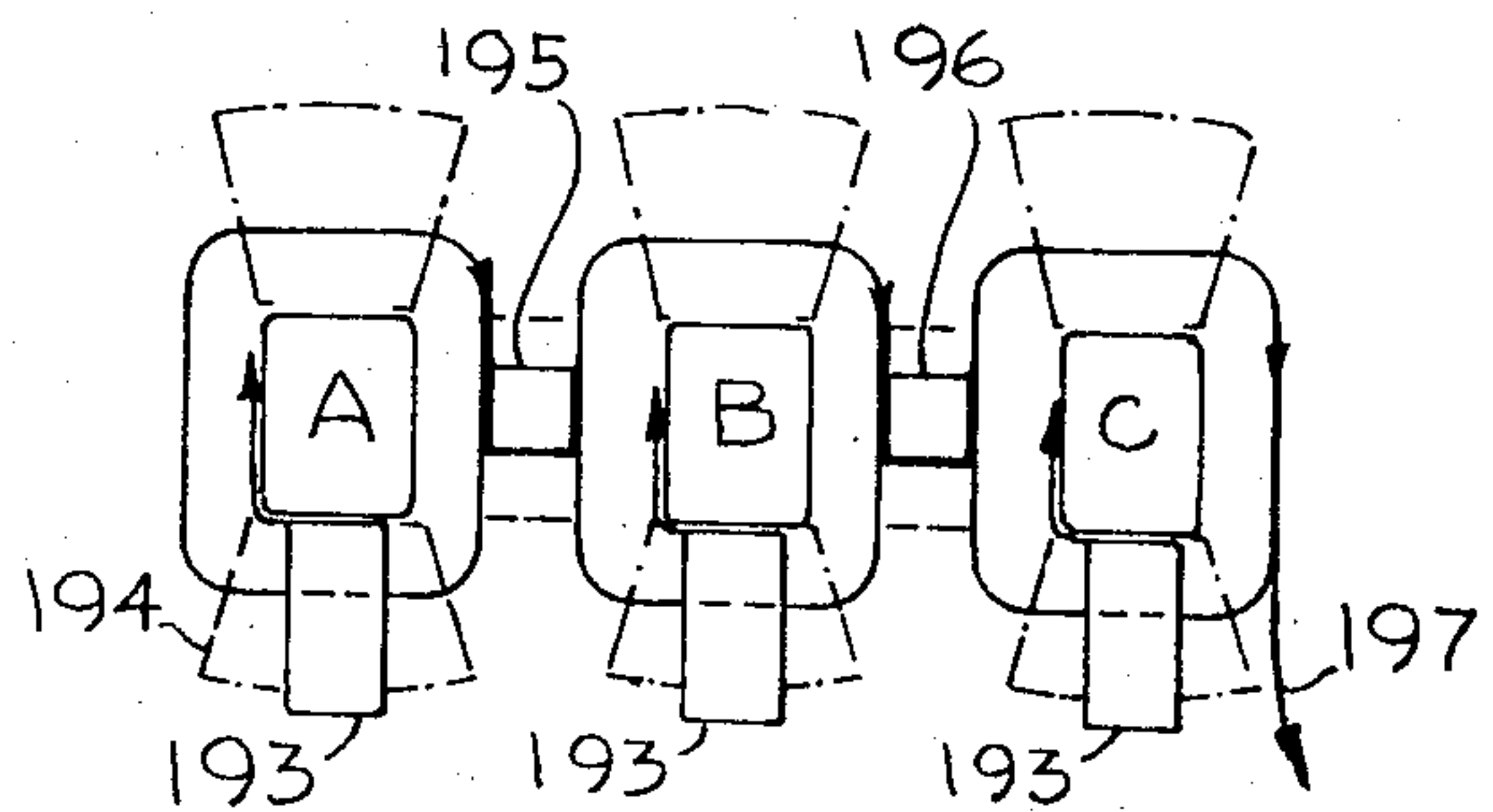


Fig. 40

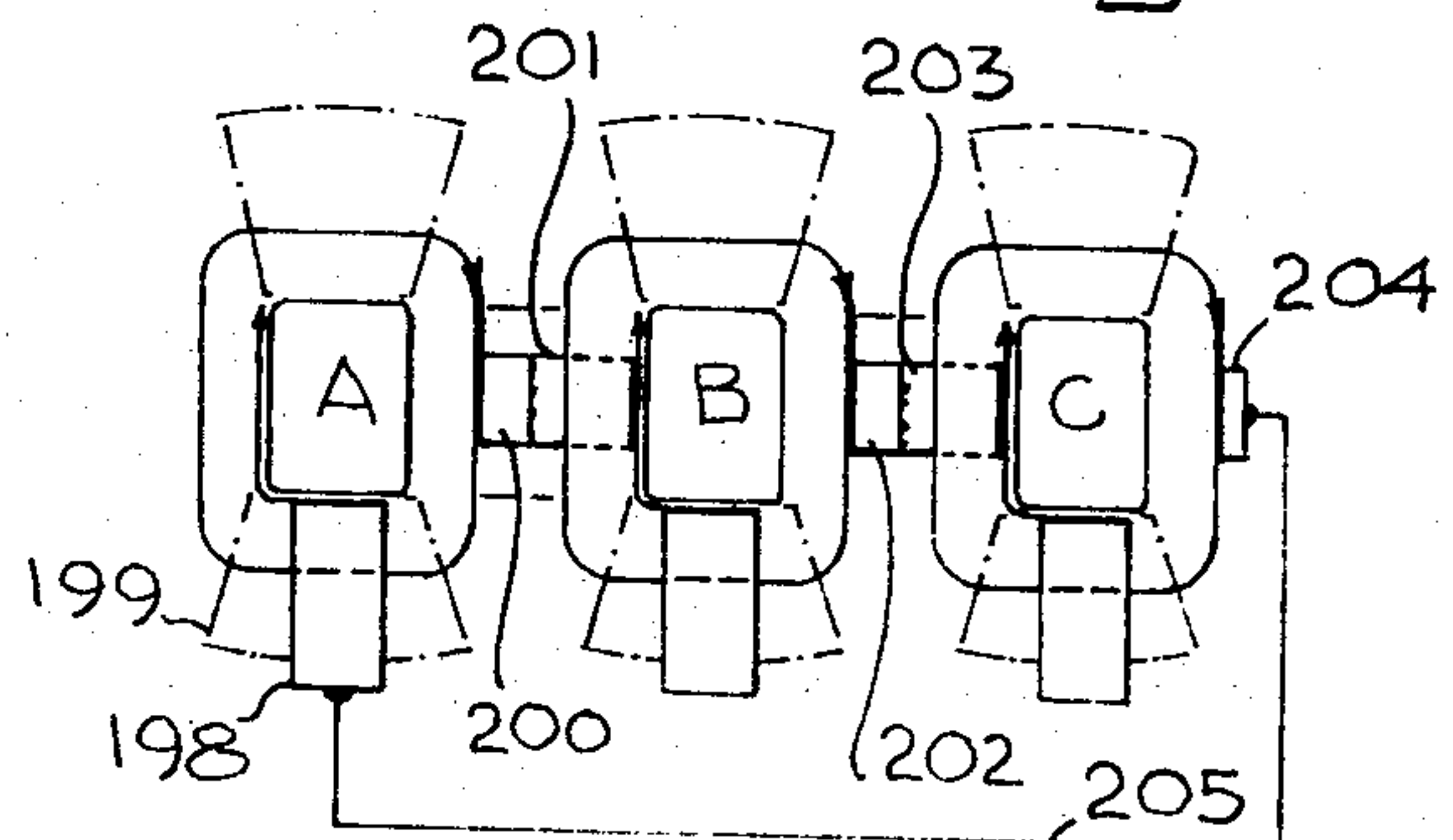


Fig. 41

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POWER TRANSFORMER INCORPORATING IMPROVED HEAT DISSIPATION MEANS

This application is a continuation-in-part of U.S. Pat. application, Ser. No. 718,972 now U.S. Pat. No. 3,551,863 filed Mar. 18, 1968.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to transformers equipped with heat dissipators and, more particularly, to improved and more efficient cooling arrangements for dissipating heat generated in the winding structure of power transformers.

2. Description of the Prior Art

In accordance with general design practices of conventional power transformers, in order to achieve a sufficient amount of cooling surface area, greater dimensions and amounts of material are utilized than would be necessary in the absence of heat dissipation requirements. It is common practice, for example, to use longer than optimum core leg lengths to achieve a greater cooling surface area and to space sections of a multi-section winding structure to incorporate cooling ducts. These practices lead to larger overall dimensions, longer mean turn lengths, increased core window area, and consequently, heavier design of both core and coil structure and thus, even larger power losses.

More particularly, in conventional power transformer design, each coil section is comprised of a winding wound on an insulating tube. The tubes are so dimensioned as to fit over a core leg or another coil section with considerable gap partly to facilitate assembly and partly to provide cooling ducts. Usually, wedges are driven into the gaps to tighten the overall structure and minimize noise. The necessity of providing these gaps is unfortunate because as a consequence, mean turn length is increased resulting in added copper costs as well as additional energy losses within the added length.

Moreover, the gap normally incorporated between the core and coil structure results in poor heat transfer therebetween. Consequently, the normally lower temperature of the core has little influence on the temperature of the coil structure. That is, two distinct thermal time constants can be observed in the temperature changes within a conventional power transformer. The coil structure exhibits a shorter thermal time constant and the core exhibits a considerably longer thermal time constant. Thus, such a conventional power transformer coil structure responds to a sudden load increase with a corresponding temperature increase with very little time delay. The core temperature, on the other hand, follows the increased coil temperature very slowly.

A further undesirable feature of the conventional transformer duct cooling is that the cooling medium temperature increases as the medium moves along the coil surface, especially in ducts, where no fresh cooling medium has access to the surfaces. The difference between the entering and exiting temperature of the medium might constitute a considerable part of the allowable temperature gradient between ambient and average coil temperature. This temperature differential between entering and exiting is most pronounced where wire-wound coil structures are utilized inasmuch as such coil structures do not have significant heat conductivity in an axial direction between turns since the barrier effect of the wire insulation is significant in that direction.

It is further pointed out that because of the spacing to accommodate cooling ducts between winding sections in a conventional transformer, there is normally insufficient internal capacitance to assure a non-resonating winding. As a consequence, excess voltage surges appearing between winding sections may cause damage when lightning strikes or a switching surge occurs.

Still further, the mechanical strength of coils of conventionally designed power transformers is somewhat limited as a consequence of the gaps or cooling ducts incorporated therein. When a short-circuit occurs, the winding conductors can experience tremendous magnetic forces which tend to

bend the mechanically unsupported portions of the conductors. For that reason, conductors with satisfactory conductivity such as aluminum, often cannot be used in the construction of large transformers because of their inferior mechanical capabilities.

OBJECTS AND SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the present invention to provide a transformer construction of minimum dimensions and material for a particular electrical rating.

It is a further object of the present invention to provide a power transformer having improved heat dissipation means.

It is a still further object of the present invention to provide a power transformer having a coil structure of longer thermal time constant.

It is a still further object of the present invention to provide a power transformer construction which is mechanically more rugged than those heretofore known and which thus permits the utilization of winding materials, such as aluminum, having inferior mechanical capabilities than copper, for example.

Briefly, a transformer construction is provided in accordance with the present invention characterized by minimizing or eliminating gaps therein between the core and coil structure and between sections of the coil structure. More particularly, a substantially solid coil structure, closely mounted on a transformer core is provided with highly heat conductive dissipator layers mounted between adjacent coil sections and extending beyond the coil structure, terminating in fins arranged to assure maximum heat transfer to a cooling medium flowing therepast.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1-16 are directed to subject matter disclosed in the afore-cited parent application and FIGS. 17-43 are directed to subject matter not specifically disclosed in said parent application and wherein:

FIG. 1 is a plan view of one embodiment of a surface heat dissipator sheet;

FIG. 2 is a side elevation view of the heat dissipator sheet of FIG. 1;

FIG. 3 is a longitudinal section of an illustrative embodiment of a transformer equipped with heat dissipators in several different arrangements;

FIG. 4 is a partial longitudinal section of a further illustrative embodiment of a transformer equipped with various extended heat dissipators;

FIG. 5 is a partial plan view of the transformer shown in FIG. 4;

FIG. 6 is a partial sectional view of a disc-type transformer winding equipped with extended internal heat dissipators;

FIG. 7 is a partial sectional view taken along sectional plane A-A in FIG. 6 showing a dissipator sheet in plan view;

FIG. 8 is a partial sectional perspective view taken along section plane B-B in FIG. 6;

FIG. 9 is a partial sectional view of the cutting tool for the production of heat dissipators according to FIG. 8, shown in three consecutive phases of operation A, B, C;

FIG. 10 is a vertical longitudinal section of a transformer equipped with pancake type coils and extended surface dissipators;

FIG. 11 is a horizontal cross-section of the transformer taken along section plane C-C in FIG. 10;

FIG. 12 is an enlargement of the upper end of the transformer winding shown in FIG. 11;

FIG. 13 is a variation of FIG. 12;

FIG. 14 is a longitudinal section of an encased air-cooled transformer, with surface dissipators, illustrating arrangements for closed and open natural convection and forced air-cooling;

FIG. 15 is a partial side elevation view of a liquid cooled transformer with its enclosure and radiators equipped with surface heat dissipators;

FIG. 16 is a cross-section of a single radiator element equipped with surface heat dissipators on both sides;

FIG. 17 is a sectional view illustrating a portion of a coil structure incorporating heat dissipator means in accordance with the present invention;

FIG. 18 is a plan view of a single phase transformer constructed in accordance with the present invention;

FIG. 19 is a plan view of a three phase transformer constructed in accordance with the present invention;

FIG. 20 is a plan view of a single phase transformer with a butt-jointed shell-type core constructed in accordance with the present invention;

FIG. 21 is a sectional view illustrating a transformer in accordance with the present invention having a coil structure including a single section low voltage winding and a double section high voltage winding and equipped with a balanced temperature heat dissipator arrangement;

FIG. 22 is a sectional view of a sealed convection cooled embodiment of the present invention;

FIG. 23 is an edge view illustrating an alternative fin arrangement used in the sealed enclosure transformer embodiment of FIG. 22 and in FIG. 33;

FIG. 24 is a schematic diagram illustrating a fabrication technique for winding a coil section in accordance with the present invention;

FIG. 25 is a schematic illustration showing how a laminar core structure can be built up in accordance with the present invention;

FIG. 26 is a sectional view further illustrating how a laminar core structure can be built up in accordance with the present invention;

FIGS. 27-29 are schematic illustrations pointing out the relationship between core cross-section area and mean turn length of various core configurations;

FIG. 30 is a plan view of a transformer coil in accordance with the present invention including an alternative core configuration to permit the accommodation of heat dissipators along longer portions of the coil structure circumference;

FIG. 31 is a front view of the core in FIG. 30 illustrating the manner in which a core structure can be modified to enable a greater number of heat dissipator layers to be accommodated within the window area;

FIG. 32 illustrates one manner of constructing a hybrid interleaved laminated core structure;

FIG. 33 is a sectional plan view illustrating a transformer utilizing a core structure constructed in accordance with FIG. 32 and incorporating heat dissipators between coil structures;

FIG. 34 is a schematic drawing illustrating an alternative core structure;

FIG. 35 illustrates a heat dissipator in accordance with the present invention utilized in conjunction with a disc-type coil structure;

FIG. 36 is a side view illustrating the manner in which the heat dissipators of FIG. 35 are contained between the disc coil sections of FIG. 35;

FIG. 37 illustrates an arrangement alternative to that shown in FIG. 36;

FIG. 38 illustrates a configuration of channel means used for temperature balancing in disc-type coil structures;

FIG. 39 is a perspective view partially broken away illustrating a convenient lead arrangement for foil type coils equipped with heat dissipators;

FIG. 40 is a plan view illustrating the manner in which a Y-connection can be realized in accordance with the present invention in a heat dissipator cooled three phase transformer when the leads are wide; and

FIG. 41 is a plan view illustrating how delta connection in accordance with the present invention can be realized in a three phase delta connected transformer equipped with heat dissipators, when wide leads are employed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Attention is initially called to FIGS. 1-16 which illustrate subject matter previously disclosed in the afore-cited parent application, Ser. No. 718,972. As pointed out therein, FIGS. 1 and 2 illustrate an embodiment of a prefabricated surface heat dissipator sheet for improving the heat transfer on any surface exposed to a stream of cooling medium. Said sheet is made by taking a continuous sheet of metal; and using a suitable tool, a three edged, substantially rectangular fin is punched out of the metal and bent up substantially at right angle along the intact fourth edge. These fins are all bent so that they protrude on the same side of the sheet; their major surfaces become substantially parallel to an axis of orientation (generally representing the direction of the stream of cooling medium local thereto with one exception detailed at the end of this paragraph) and substantially perpendicular to the closest area of said sheet. Although other forms of the dissipator sheets can be used (e.g. continuous sheets with welded on fins, or punched sheets with different patterns, etc.) according to the invention, the arrangement shown in FIG. 1 has certain particularly attractive characteristics such as low production costs and in some cases additional heat transfer capability, as will be pointed out later in connection with FIGS. 3 and 16. It will be seen from FIGS. 1 and 2 that the metal sheet 1 has substantially rectangular fins 2 in pairs of rows according to a regular pattern, each pair contained by a zone. In the first row, representing the upper part of the first zone, each fin has its holes (punched in the prefabrication process and referred to, hereafter, as "punched holes") to the left; in the second row, representing the lower part of the first zone, each fin has its holes to the right; in the third row, representing the upper part of the second zone, to the left; and so on, alternately. On sheets with a finless zone, the latter may have punched peep slots perpendicular to its edges to facilitate the alignment of the sheet in the winding operation. The holes and the fins can be tapered, symmetrically (A1 and A2) or unsymmetrically (B1, B2 and C1). In extreme cases, the holes can be tapered with a right angle at the top edge (B1) or at the lower edge (C1), the top edges for both remaining on zone border line 3. The distance d_A between borderlines 4' and 5 is slightly smaller than the distance d_B between zone border lines 3' and 6, while the surface areas of the fins remain the same. An increased distance d_B is more advantageous in practical application, offering more space for bandaging and for cutting the sheet while retaining a smooth bordering edge. A slightly tilted arrangement, as shown by hole C1, introduces a small angle α between the fin surface 7 and the direction of the flow 8 of the cooling medium. If a larger angle is preferred in order to improve the heat transfer in some cases (see details later in connection with FIG. 15), the top edges of hole C1 become slanted and penetrate the zone border line 3.

The cooling fins on the heat dissipator are preferably narrower than one-fourth of the dimension of the region occupied by the dissipator, both measured in the direction of the stream of the cooling medium. The fins are arranged in at least one of the zones defined by a subdividing of the region occupied by the heat dissipator into at least two zones along the axis of orientation. Larger fin dimensions in the direction of the stream allow an increasingly heavy boundary-layer to develop along the fin surface, resulting in a diminishing heat transfer toward the rear edge of the fin and an increasing resistance to the flow of the cooling medium (due to the longer friction area along the larger dimensions). On the other hand, if the stream passes along a number of narrow fins while crossing the subsequent zones, the resistance to the stream increases (especially in ducts); nevertheless, the heat transfer may still be improved due to smaller boundary-layer thickness on the narrower fins.

Surface heat dissipators, e.g., as shown in FIGS. 1 and 2, are utilized on transfer surfaces of active parts normally exposed to a stream of cooling medium. The dissipator sheets are con-

nected mechanically to the transfer surfaces with heat conductive means, and they can be extended beyond the dimensions of their transfer surface.

Referring to FIG. 3, a transformer is shown comprising a core 9 and a generally tubular winding structure 10 having extended heat dissipators, in several different versions. On the left side, two dissipator sheets are arranged on the outside surface over the top insulating layer 11 of the winding 10. Both of the sheets occupy a region longer than the axial length of the winding 10; the region of occupancy is subdivided into nine zones, each containing a multiplicity of fins on the external sheet; but only the first two and the last two zones are containing fins on the internal sheet. The internal sheet 12.1 is wrapped around the insulating layer 11 with its central area without fins. It has fins on its extensions only, oriented toward the center of the winding. Directly on top of the internal sheet 12.1 the external sheet 12.2, with fins all over its surface, is wrapped and placed with its punched holes in alignment with the punched holes on the sheet 12.1, so that air can pass through the holes of both top and bottom extensions along the path of arrows 13.1 and 13.2, respectively. The fins of the second sheet 12.2 are oriented away from the fins of the first sheet 12.1.

The heat transfer on the extended areas of the dissipator is higher per surface unit, since all the extended areas consist of narrow strips with practically boundary-layer free surfaces all around, including the sheet itself, between holes.

It is possible to improve the heat transfer even further, in the same arrangement, with no change in the surface areas, simply by cutting up the extended portions of the heat dissipators along the paths of the heat flow into strips and bending them apart.

The right hand side of FIG. 3 illustrates several versions of the heat dissipator created by this process. In order to maintain the clarity of the illustration, strips in the background are not shown. Over the upper area of insulating layer 11, dissipator sheet 12.11 is placed, having prefabricated extensions. Its top extension 12.11A has punched out fins 12.11B and is cut up into strips containing two or four vertical rows of fins. After the sheet is in place, the strips are bent outward to facilitate the movement of air between them involving more air in the convection process. The bottom extensions of sheet 12.11 are cut up into simple narrow parallel strips 12.11C, and twisted so that the planes of the strips become oriented substantially perpendicular to the original plane of sheet 12.11; after the sheet is wrapped around the winding, the twisted strips 12.11C can be bent up into a position, close to horizontal, as shown, with their helical transient area close to the main body of the sheet wrapped around the winding.

A second sheet 12.12 covers the bottom area of the same layer 11. The extension strips 12.12A of sheet 12.12 are bent upward in this illustrative embodiment for the purpose of being accommodated in the window of core 9. Sheet 12.21 is wrapped directly over sheet 12.11 and sheet 12.22 over sheet 12.12. Both have punched out fins covering their entire surface area; sheet 12.21 has a top extension 12.21A, which is cut up and bent as shown, to allow the air to flow along both sides of the strips.

Since the application of strips as extensions provides an increased mobility for the cooling air, additional extended dissipator sheets, such as sheet 14, can be wrapped around one or more internal layers of the winding. The extensions 14B, 14C of sheet 14 of this example are similar to those of sheet 12.11, respectively. The internal sheet 14 creates internal transfer surfaces for the winding on both of its sides without the usual increase in the mean turn (such as in the case of conventional cooling ducts), decreasing the internal gradient and the winding hot spot temperatures effectively. To facilitate the winding operation and handling, two thinner sheets can be used in close contact with each other, having a prefabricated extension area (one oriented to the top, the other to the bottom), and a wider finless area, which can be sheared according to the axial dimension of each winding. The two sheets may be

provided with an electrical insulating coating to prevent the flow of eddy currents between them, and with peep slots for alignment.

To allow the application of internal extended heat dissipators in larger transformers, the winding can be built up from sections, leaving enough space between them to accommodate bent out extensions such as 14C. There is a possibility of using extensions of this type also in long layer wound coils, by providing gaps periodically between turns to accommodate the bent up extensions.

An illustrative embodiment of a production tool for the prefabrication of sheets equipped with twisted strip extensions, such as 12.11C and 14C, will be discussed later in connection with FIG. 9.

If heat dissipators are used on the winding surfaces, the heat transfer through the layers of the winding is also multiplied. To avoid the development of large internal temperature gradients, care should be exercised to keep the thermal resistance in the coil as low as possible. To decrease the part of the resistance due to the layer insulation, special insulating sheets can be used with improved heat conductivity. This improvement can be achieved by embedding fin grains of solid, highly heat conductive insulating material (e.g., fine silica sand) into the base material of the sheet. Another way to improve the degree of heat conductivity in the internal heat transfer is by winding tightly, combined with void free vacuum impregnation. Heat dissipators should have means for good conduction with the surfaces where they receive heat; they should, therefore, be bent carefully to follow the curvature of the surface and tightened. The tightness can be improved in rectangular windings by using a mandrel with a slight outward arch on all sides and a corner radius of not less than twice the wire dimension, as shown in FIG. 5. Any tendency of the first insulating layer to buckle (during impregnation) can be eliminated by winding a temporary reinforcing metal sheet (e.g. cut out of core steel) under this layer and peeling it off after impregnation and oven treatment.

In coils, where pockets of impregnating material or air can be expected, the heat conductivity of these pockets can be drastically improved by filling up the pockets with silica sand composed of different sized very small grains. The silica filler, embedded in the impregnating material, is capable of effectively bridging any internal gaps. The best procedure for getting the silica into the gap is to mix the dry silica with a temporary liquid binder, obtaining a paste-like mixture which is then applied over each layer, as necessary, to fill up lower areas, and achieving even layer surfaces during the winding operation. After vacuum drying and vacuum impregnation, the liquid binder can be readily exchanged with the final liquid impregnating material. Where no vacuum impregnating equipment is available, fairly good results may be obtained by mixing the silica with the final impregnating material and applying this mixture to the layers as needed, and curing it in an oven.

For larger dry type transformers, over 100 kVA approximately in single phase, dissipator arrangements in accordance with FIGS. 4 and 5 offer some advantages, especially when an alternative possibility for operation with forced air cooling with increased kVA rating is also desired. On leg 15 of a magnetic core, multilayer winding 16 is accommodated. Six heat dissipator sheets extending beyond the length of the winding are attached to the winding on each of its end portions protruding horizontally beyond the longer contour lines of the core. Sheet 17 is placed on the internal end surfaces of the winding, with fins penetrating into a duct between the leg 15 and the winding 16. To dissipate the core losses, the heat dissipators 18 are accommodated in the same duct and joined to the core 15 at its laminated surfaces. Underneath the last layer of the first winding (e.g. primary), another duct 19 is formed on the end portions, by placing two dissipator sheets 20, 21 along the outer surface of the second last layer of the winding, and sheet 22 along the inner surface of the top layer of the first (e.g. primary) winding. Sheet 20, being closer to the winding

surface, has fins in zones on its extended area only, which are oriented toward the core; sheets 21 and 22 have fins all over their respective surfaces, the fins being oriented away from the core in the case of the former and toward the core in the case of the latter, and thus into the air stream flowing in duct 19. The punched holes of sheets 20 and 21 are in alignment to facilitate the movement of the cooling medium. layers interleaved

Where natural convection is the process for the heat transfer, the density of the fins in the ducts should be substantially reduced as compared to that on outside surfaces, in order to facilitate the movement of the cooling medium; e.g. with $\frac{1}{2}$ -inch ducts in air, when the duct is 6 inches long, $\frac{1}{2}$ -inch wide fins should not be closer vertically than 1.250 inch, while the vertical rows should be about one-half inch apart horizontally. The main insulation 23 is placed over the last layer of the first winding and has to withstand the full test voltage between primary and secondary windings. On the top of the secondary winding, dissipator sheets 24 and 25 are accommodated. All sheets are extended beyond the length of the winding. For sheets 24 and 25, as in the case of sheets 20 and 21, the fins are oriented away from one another and the punched holes are brought in alignment to facilitate the movement of the air.

The dissipator sheets are insulated from the next layer of the winding by the normal layer insulation, and can be connected to a point in the next layer where the voltage, due to the inductive voltage distribution, is closest to the voltage level of the dissipator sheet, due to capacitive voltage distribution. This arrangement allows the sheets to play a secondary role as surge shields, thus preventing high frequency oscillations on the winding if a sudden voltage change is generated by switching, lightning stroke, or any other surge source.

The best arrangement for internal heat dissipators is one where the heat does not have to flow through heavy electrical insulating layers. This flow pattern can be achieved in most cases by selecting for the internal heat dissipators layers that allow the peak internal temperature between two dissipators such as 22 and 24 to develop in the line of the heavy insulating layer (e.g. 23).

In three phase core type units, the center leg is always in an inferior position regarding heat transfer. This situation can be readily corrected by using additional heat dissipators, most advantageously on the surface of the winding, e.g. applying outside dissipator sheet 26 (in FIG. 5) all around the coil, while omitting the same in the window area of coils on the outer legs.

The extended portions of the dissipator sheets can be cut and bent apart with the same advantages as described in connection with FIG. 3.

In arrangements where two dissipator sheets are used in a winding in close contact with each other, sufficient electrical insulation should be applied, most conveniently in the form of film coating, to reduce the flow of eddy currents which may be generated by stray flux between the sheets.

For windings of larger transformers, made in the form of plane horizontal discs stacked up along the legs, plane disc-like extended heat dissipators with a louver-like fin structure can be used. In FIGS. 6-8, an illustrative embodiment of the disc-like heat dissipator is shown with a louver-like structure extending along the outside contour of the winding. On an insulating tube 27, between insulating rings 28 and discs 29, heat dissipators in the form of prefabricated segments of metal discs 30 are placed, stacked up between disc windings 31. On metal segments 30, a multiplicity of substantially rectangular fins 32 (arranged in a row along the contour line of the winding) are punched out along their two radial sides by a tool and twisted out of their plane close to a direction perpendicular to the plane of the dissipator sheet. This louver-like arrangement lets the cooling medium flow through, e.g. as shown along arrow 33, in FIG. 8, establishing very effective heat transfer on its relatively narrow, practically boundary-layer free fin surfaces.

In order to avoid excessive additional losses in the dissipator sheets due to eddy currents being generated by strong stray flux penetrating the sheets, the segments can be cut up, or narrow separating channels 34 can be punched out along the paths of the heat flow as close to one another as needed. If stray flux is expected to occur between fins 32, channels 34 should be extended out to the edge, as shown by channel 34A in FIG. 7.

FIG. 9 shows an illustrative embodiment of a cutting tool to prefabricate the louver-like fin structures 32, 12.11C, and 14C (the latter two shown in FIG. 3). A multiplicity of cutting blades are arranged in alignment to form multiple shears. The blades 32.1 of the lower, stationary part of the shears are oriented with cutting edges upward; the vertically movable upper blades 32.2 are oriented with cutting edges downward. The edges of both groups of blades are in horizontal alignment; on FIG. 9, however, to demonstrate the cutting and twisting operation, the three upper blades are shown in three consecutive phases of their downward movement, A, B and C. The metal sheet is introduced in position 32A between the cutting edges; the blades start cutting (phase A); then but further movement, the strips are twisted by the rounded rear edges of the blades (phase B), while the center line 32C of the strips moves down also, the jig supporting the sheet should follow this movement to produce a twisted fin with no bending at the base. At the lowest position of the upper blades (phase C), each fin is pressed between the vertical rear surfaces of the blades, acquiring its final shape, while the sheet itself moves to position 32B.

Two examples of the application of heat dissipators in plane form are presented in FIGS. 10-13. Referring to FIGS. 10-12, which show a shell-type transformer having a horizontal leg 35 and "pancake" type rectangular windings, primary coils 36 and secondary coils 37 are arranged in pairs with the solid main insulation 38 between them; heat dissipators are placed between two primary windings 36 and between two secondary windings 37, respectively, and at the end of the window, between the last winding and the core (39A in FIGS. 11 and 12), separated from the winding by layer insulation 38A only. In this arrangement, the ducts built up by the dissipators are placed between balanced leakage groups where no leakage flux develops. In an alternative arrangement, shown in FIG. 13, to achieve high internal impedance, greater distance is used between primary coils 40 and secondary coils 41. In the leakage duct, two heat dissipators 42 are therefore accommodated with the layer insulation 43 adjacent to the windings, separated by a stack, consisting of the main insulation 43A sandwiched between two metal sheets 44. Since the full leakage flux appears between the primary and secondary coils, tending to generate eddy currents in loops composed of fins short-circuited by sheets 44, to provide the necessary electrical insulation needed for the prevention of eddy currents between sheets 42 and 44, sheets 44 being coated with an insulating film.

The unit shown in FIG. 10 is equipped with a group of propeller fans 35.1, accommodated in circular venturi-tubes 35.2 which are connected to a casing 35.3, enveloping the lower part of the unit vertically. When the fans are not in operation, the unit can get cooling air through natural convection of the fan openings. When the fans are operating, at least four times as much heat can be removed and the kVA load increased to at least double its value.

Another arrangement is illustrated in FIG. 14 for air cooled transformers designed for operation with natural convection and alternative forced air cooling. A dry type transformer 45, with heat dissipators 46 on its windings, is equipped with fan 47 housed in a bypass-free envelope 48. Even when fan 47 is not in operation, the surface heat dissipators in the duct get cooling air through the fan opening, along arrows 49, while the external surface dissipators get their cooling air mostly along arrows 50, bypassing the envelope 48. The transformer-fan assembly is surrounded by enclosure 51, shown in two versions. On the right side of FIG. 14, the side wall 52 of the en-

closure has louver-like openings 52.1 both on the top and the bottom, serving as entrance and exit for the fresh cooling air. On the left side of FIG. 14, a version is shown with a completely sealed enclosure. The sealed inner wall 53 is equipped with heat dissipators 54A on their internal surface and dissipators 54B on their external surfaces. The sealed wall 53 is surrounded by an outer wall 55 having built-in fans 56 on the bottom and louver-like exit openings 57 on the top for the air drawn in by fan 56. Baffle 58, with its extension 58.1, confines the air flow along dissipator 54A. The sealed part of the enclosure may be filled with dry air or a special insulating gas (freon etc.).

The cooling process of the sealed version consists of two cycles: in the internal cycle, the cold internal cooling medium moves upward along heat dissipators 46, picking up the heat, then returns to its starting level. While passing along internal heat dissipator 54A, the cooling medium, guided by baffle 58, transfers its heat content to wall 53 through fins of dissipator 54A. In the external cycle, fresh air is blown by the fan 56 through the channel formed by the external wall 55 and wall 53 from which it receives the heat via external heat dissipators 54B and leaves the unit through louvers 57.

When the fan 47 is in operation, all the dissipators 46 get accelerated cooling air from fan 47. In the narrow passage, however, created by baffle extensions 58.1, the injector effect of the high speed air stream 49.1 along the external dissipators creates a pressure drop above the passage which accelerates the outside stream of air along arrow 50, preventing a downward flow along envelope 48.

Heat dissipators can be used also on sealed transformer enclosures, or any extensions thereof such as cooling tubes, radiators, etc., which contain insulating liquid. Since the largest gradient develops between the enclosure and the cooling air on the outside surfaces when liquid to air-cooling is used, the application of heat dissipators can be limited to the outside surfaces in most cases.

An illustrative embodiment is shown in FIGS. 15 and 16. To the outside surfaces of the sealed enclosure 59 of a liquid cooled transformer, heat dissipators 60 are connected mechanically. To obtain additional cooling surfaces, radiators 61 are connected to the enclosure by tubes 62 allowing the internal cooling liquid to circulate through the radiators. Heat dissipators 63 are connected to the outside surfaces of the radiators with heat conductive means.

The cooling air moves vertically up along the surfaces by natural convection, or is driven by fans 64. To allow more air to get involved in the cooling process, to shorten the average path length of the air along the radiator surface, and to provide fresh air also for the upper part of the radiators, the radiators can be built in pairs slightly tilted closer together at the top as shown by radiators 61.1 and 61.2 in FIG. 15. If the plane of the fins are tilted away from the closely arranged tops of the pair, as shown, the normally vertical path 65 of the cooling air can be deflected farther away from the center line along path 65.1. This results in a substantial shortening of the original path length of the air from P1-P2 to P1-P3. Tilted arrangements of radiators 61.1 and 61.2 are especially advantageous when they are used with alternative forced air operation and a common fan 64 as shown.

Attention is now called to FIGS. 17-41 which illustrate the further utilization of heat dissipator layers, generally disclosed in FIGS. 1-16, to achieve significantly improved transformer constructions characterized generally by considerable savings in weight and cost together with improvements in structural and electrical characteristics. More particularly, as discussed in the introduction to this specification, conventional power transformer designs intentionally incorporate gaps between the core and coil structure and between coil structure sections for establishing cooling ducts. As further pointed out, these gaps require increased dimensions for a particular transformer rating resulting in increased energy losses and increased material costs. In addition, the gaps result in structurally unsupported sections of the coil structure which are likely to be

damaged due to the tremendous magnetic forces which can be generated as a consequence of occasional short circuit currents. Further, the gaps adversely effect electrical characteristics in a manner so as to increase the likelihood of damage due to excess voltage surges between coil layers. In view of the foregoing considerations, heat dissipators of the type thus far discussed are utilized to achieve an essentially solid transformer structure in which such gaps have been substantially eliminated to thus avoid the related problems previously pointed out.

FIG. 17 illustrates a sectional view of a coil structure in accordance with the present invention which has been designed without any gaps between coil sections to thus reduce energy losses, dimensions, and material costs. Elimination of the gaps, however, which normally function as cooling ducts, requires the inclusion of other heat dissipation means. The coil structure of FIG. 17 constitutes a multilayer layerwound structure wherein an insulating wrap 101 is wrapped around a core leg (not shown) with the first winding layer 102 wound about the wrap 101. An insulating layer 103.1 is wrapped around winding layer 102. As shown, a first heat dissipator layer 104 is placed against layer 103.1 and a second layer 105 is placed against layer 104. Each of the layers 104 and 105 terminates in fins, generally of the type shown at 14C in FIG. 3, extending beyond the coil structure dimension. During the winding stage of fabrication, the fins preferably extend in the dotted line orientation shown in FIG. 17 at 104.1 and 105.1. After the completion of the winding stage of fabrication, the fins are bent over to the positions 104.2 and 105.2.

A normal insulating layer 103.2 is wrapped around the heat dissipator layer 105 followed by a second winding layer 106. Another insulating layer is wound around the winding layer 106 followed by heat dissipator layers 109 and 110. Additional winding layers 107, 108, insulating layers and heat dissipator layers 111, 112 are placed in appropriate succession as shown in FIG. 1 as the coil structure is built up.

The heat dissipator layers are preferably formed of relatively heavy sheets, of approximately 0.040 inch thickness, of some highly heat conductive non-magnetic material such as aluminum. It is, of course, desirable to incorporate a maximum amount of heat dissipator layer area into the coil structure and thus, as shown in FIG. 18, the heat dissipator layers preferably surround the coil structure along its entire free surface (outside of the core window area). In the case of a three phase transformer as shown in FIG. 19, it may be necessary to limit the heat dissipator layers to the free end portions of each coil structure.

Regardless of the amount of coil structure circumference which can be utilized to contain a heat dissipator layer, in any event after the winding operation has been completed and the coil structure has been removed from the winding machine, the continuous strips, e.g. 105.3 of the heat dissipator layer connecting the outer ends of the fins is cut up so as to create groups of fins containing, for example, from three to 20 fins. A lesser number of fins is contained in a group where the radius of curvature of the heat dissipator layers is smaller. Simultaneously with the cutting up of the fins into groups, the groups of unbent fins 104.1, 105.1, 110.1 (FIG. 17) are bent into close horizontal position 104.2, 105.2, 109.2, 110.2, 111.2 and 112.2 as shown. The fins extend beyond the coil structure; and spread out, e.g. alternately as groups 104.2 and 111.2, as shown in FIGS. 18 and 19, so as to assure the maximum amount of heat transfer to a cooling medium flowing therepast, and so that the fins offer a minimum resistance to the cooling medium flow.

Note well that the coil structure of FIG. 17 has been formed without the inclusion of any gaps or cooling ducts therein. Thus, the coil structure forms a solid integral unit having significantly more inherent mechanical strength than conventional coil structures incorporating cooling ducts. Note also, as will be again mentioned hereinafter, that as a consequence of eliminating internal cooling ducts, the means turn length of the windings is reduced to thus reduce the material cost of the

coil structure as well as reducing the energy losses within the coil structure.

Attention is now called to FIG. 20 which illustrates a single phase transformer having a butt-jointed shell-type core 113 having multiple steps in the cross-section to fill the round coil structure 114. The finned heat dissipators 115.1 and 115.2 spread over the major part of the circumference of the coil structure 114 reducing the temperature of the hottest spot 114.1 and 114.2 close to the average temperature of the winding measurable on the basis of the resistance change of its conductor. Brackets 116 are equipped with a movable pressure plate 116.1 and a fixed pressure plate 116.2 for exerting pressure to the butt-jointed legs and yoke parts of the core structure.

Attention is now called to FIG. 21 which illustrates a coil structure having a low voltage, high current winding wound in a single section with foil-type conductor, and a high voltage low current winding wound in two sections, both windings are equipped with balanced temperature heat dissipator arrangements to be discussed in greater detail hereinafter.

More particularly, in FIG. 21 a first insulating layer 117 is wrapped about the core structure (not shown). A full width foil layer 118 is wound about the insulating layer 117. Heat dissipator layers 119, similar to those discussed in conjunction with FIG. 17, are then placed in the coil structure during fabrication adjacent to but insulated from the foil layer. The "start" foil lead 118.1 is shown in FIG. 21 as emerging from the coil structure beneath the heat dissipator fins 119.1. The "finish" foil lead 118.2 is illustrated as emerging from the coil structure in the window area.

The two sections 121 and 122 of the high voltage winding are wound with relatively short axial dimensions and with stepped down layer lengths toward their top layer. The interconnection of the two sections is the first layer of the high voltage winding, as illustrated in FIG. 21, and this constitutes the "start" of both sections, wound in opposite directions. Thus, both "finish" leads 123 and 124 of the two high voltage windings, are on the shortest top layer together with two taps 125. This arrangement facilitates the insulation of the high voltage leads connected to these terminals and taps.

The heat dissipator arrangement of FIG. 21 utilizes the balanced temperature cooling principle. More particularly, in convection cooling with a relatively limited quantity of cooling medium passing along the cooling surfaces such as are provided in FIG. 21 by fins 119.1 and 119.2 for the foil wound low voltage winding and fins 126.1 and 126.2 for high voltage section 121 and fins 127.1 and 127.2 for high voltage section 122, the top fin surfaces 119.2, 127.1 and 127.2 are cooled with cooling medium already preheated by the bottom dissipator surfaces 119.1 and 126.1 and 126.2. Recognizing this preheating, and in order to achieve uniform temperatures for both top and bottom sections of the coil structure, a greater amount of heat dissipator surface area is incorporated for the top of the coil structure to compensate for the preheating of the cooling medium resulting from contact with the fin surfaces toward the bottom of the coil structure. That is, in order to assure balanced temperatures, note in FIG. 21, that two rows of top dissipator fins 119.2 are utilized while only one row of bottom dissipator fins 119.1 are used for cooling the low voltage winding. Similarly, for the top high voltage section 122, dissipator fins 127.1 and 127.2 are each comprised of two rows of fins while the bottom section 121 employs dissipators 126.1 and 126.2 each comprised of one row of fins.

It is pointed out that the full width foil-wound characteristic of the low voltage winding also functions to equalize the uneven temperatures in the coil. That is, the foil, being a bridge for heat transfer in an axial direction, prevents the build-up of substantial internal hot spots. In wire-wound coils, the hottest spot develops slightly over the center horizontal plane because the axial mobility for the heat is limited by the relatively small cross-sectional area of the heat dissipator embedded in the wire-wound coil.

In high voltage coils, such as sections 121 and 122 of FIG. 21, each heat dissipator sheet can be connected most advantageously to the connecting turn between the surrounding two layers, as a surge shield. This connection increases the internal capacitance between the winding layers so that a voltage surge passes through the winding easily without creating too high a voltage gradient or oscillation. In this arrangement a safe distance 128 should be maintained between fin rows connected to different voltages in the winding, which can be achieved by using a comb-like insulating structure 129.1 attached to the ends of the fin rows. This should preferably also be used on the fins rows 119.1 and 119.2 of the low voltage winding, where all dissipators 119.1 and 119.2 can be connected together to the neutral or other terminal of the low voltage system. The role of the comb-like structure 129.2 is to keep the fins away from their high voltage neighbor by maintaining the necessary gap 130 between the fin rows associated with the high and low voltage windings respectively.

It is pointed out that a full width foil-wound low voltage winding combined with a slightly shorter wire-wound high voltage winding can withstand heavy short circuit currents without damage, even if they are constructed of aluminum conductor normally having inferior mechanical characteristics. As previously mentioned, the reason as to why heavier short circuit currents can be withstood without damage is because in the absence of cooling ducts within the coil structure, the entire coil structure is solid leaving no portion unsupported which would be susceptible to bending. The stretching force which develops within the foil-wound low voltage winding portion of the coil structure of FIG. 21 is well within the mechanical capabilities of the foil-wound winding. The compression force developed in the wire-wound coil can easily be withstood because of the solid nature of the coil which prevents bending.

Attention is now called to FIG. 22 which illustrates an exemplary embodiment of a sealed enclosure convection cooled transformer utilizing a pair of coil structures as shown in FIG. 33. Only one of the coil structures can be seen mounted on core 131 in FIG. 22. The coil structure that is visible includes vertical heat dissipator layers incorporated between winding layers and having horizontally oriented fins 132 extending beyond the coil structure. The transformer of FIG. 22 utilizes a vertical heat dissipator sheet 133 inserted between the coil structures in a manner better illustrated in FIG. 33. As is further shown in FIG. 22, heat dissipators 134.1, 134.2 of the type previously explained in connection with FIG. 17 are attached to the adjacent inner and outer walls of the sealed enclosure 135. Baffle 136 separates the transformer from the enclosure wall and defines a convection flow path for the cooling medium. The cooling process associated with the operation of the transformer of FIG. 22 is comprised of an internal and external cycle. The internal cycle is closed loop. That is, when the transformer warms up, cooling medium starts to circulate along arrows 137, passing along dissipators 132, 133, warming up while removing the heat. The flow path continues through dissipator 134.1 where the heat content will be transferred to the external heat dissipators 134.2 through the wall 135. The cooling medium returns to the transformer behind baffle 136 along arrows 137.1. The external cooling cycle is open and is defined by the flow of ambient air through dissipators 134.2 to remove the heat content therefrom. It is pointed out that the vertical heat dissipator 133 of FIG. 22 may be constructed in the same manner as the dissipators (e.g. 132, 134.1 etc.) used internal to the coil structure, except that the dissipator 133 used between coil structures preferably has less twist on the fins thereof to exhibit an approximate 45° angle to the vertical. A still further fin arrangement is illustrated in FIG. 23 wherein the vertical dissipator sheet 133 is split up on its outside portion into vertical strips 133.1 and 133.2 by an appropriate shearing tool.

As previously pointed out, power transformers constructed in accordance with the present invention are preferably constructed with internal extended heat dissipators and without

internal cooling ducts. The resulting solid structure lends itself to achieve a substantial improvement in the thermal characteristics of the transformer. It is well known that power transformers are often subjected to a highly variable load presenting a peak which lasts several hours in each day. Most of the transformers operate under a fraction of peak load most of the day, keeping the temperature of the coil structure and core far below their limits. When the peak load occurs, the temperature of the coil structure starts to rise in accordance with its thermal time constant. The value of the time constant is substantially proportional to the mass involved in the warming up process and substantially inversely related to the specific heat transfer of the warming up mass. Therefore, coil structures built with ducts between coil sections and the core, the coil structures have fairly short time constants because they have little mass and large specific heat transfer. The temperature of the coil structure in conventional transformers therefore follows the load changes very rapidly. Thus, exposed to sudden overload, the coil structures in conventional transformers are prone to burning up.

If the solid ductless coil structure according to the present invention is built to fit closely to the core with negligible gaps therebetween which can be filled up with impregnating varnish, the temperature change of the coil structure for the same overload becomes significantly slower than in conventional coil structures. The heat dissipator cooled solid coil structure in accordance with the invention lends itself to be integrated thermally with the core especially when a rectangular coil shape is used. In this case, the coil structure can be brought into good heat conductive relationship with the core, bringing the cut surfaces of the core laminations close to the coil. The core has much higher heat conductivity parallel to the lamination than perpendicular thereto. Consequently, when the coil structure touches the core on the cut surfaces, the core and coil structure becomes thermally integrated so that when the coil structure starts to warm up, its heat content escapes into the core which has a specific heat storage capacity four to six times that of the coil structure.

To achieve a thermally integrated core and coil structure, the coil should be wound with precise dimension on its inside surface. FIG. 24 shows a simple approach to achieve the required precision. To jaws 138.1 and 138.2 having a width equal to one of the standard core steel laminations are fitted into a standard lathe chuck fastened to the spindle of the winding machine. Both jaws are adjustable with an operating screw. The jaws have rounded corners and can be extended with a flat supporting member 139 on the side areas of the coil structure. At the start of the winding operation, the distance between outside end surfaces 140.1 and 140.2 of the jaws should be adjusted slightly below the stack height of the core given in the design. After wrapping on the necessary inside insulating layers, the first layer 141 of the winding can be wound on. Then the jaws 138.1 and 138.2 should be pulled apart in accordance with arrows 138.3, 138.4 respectively, to get the correct stack height, stretching the first layer in the process. The rest of the winding should be wound with adequate tension to assure tight structure also on the sides.

Coils wound with inside opening equal to the outside dimensions of the core lamination cannot be slipped over the leg of a preassembled core in the conventional manner; therefore new methods are needed to assemble the thermally integrated core and coils. FIG. 25 illustrates a method which is fast and economical. In the horizontally placed coil 142, after introducing the narrower stack 143, convenient smaller stacks 144.1 of the leg steel 144 are inserted in a slightly tilted position as shown, until the opening becomes filled up with the main stack 144 close to the limiting line 144.2. The last laminations of the main stack 144 can be inserted by bending them around a convenient size dowel 145 placed in the center in axial direction. The last to be forced in along arrow 146.2 as a "steel wedge" as shown in FIG. 26 is the lower half 146.1 of the upper narrower stack 146, to which several extra sheets can be added to reach the necessary tightness.

By eliminating the gaps between core and coils usually present in conventional power transformers, a reduction in the mean turn length can be achieved, leading to copper weight reduction. A further reduction can be achieved by using the optimum dimensional proportions in the rectangular core cross-sections. In cores built from strips having two different widths W_{L1} and W_{L2} and one step on their corners, as shown in FIG. 27, a minimum of the circumferential length around the core is obtained when the magnitude of the step is about one-tenth of the dimension W_{L1} of the wider core steel width, assuming radii R on corners equal to the steps. The width W_{L2} of the narrower core steel is in that case equal to $0.80 W_{L1}$. The length of the circumference is 97.7 percent compared to a square core having the same cross-sectional area.

Using three different strip width and two steps in the core leg, as in FIG. 28, the optimum radii R on the corner is equal to $0.215 W_{L1}$, resulting in a reduction of the length of the circumference to 95.25 percent of that of the square core. The strip widths for that pattern are: $W_{L2}=0.874 W_{L1}$, $W_{L3}=0.57 W_{L1}$; this means also the reduction of the heat transfer area between core and coil to 71 percent compared to the one step core.

Using four different strip widths, as shown in FIG. 29 $W_{L4}=0.45 W_{L1}$ with a comparable reduction in the heat transfer. The circumference is 93.8 percent of that of the square core with the same area, with a corner radius of $0.275 W_{L1}$. Considering the small gain in copper weight reduction compared to the inconvenience of the many different strip widths and reduced heat transfer, it is probable that in most applications by increasing the number of steps in the core lamination beyond two is not justified. (The smallest circumference is 88.6 percent with round cross-section.)

In larger three phase transformers the need arises to accommodate internal heat dissipators in longer portions of the circumference of the coils. This extension of the heat dissipator area can be achieved by extending the core leg cross-section with narrower stacks on both end areas of the leg, as shown in FIGS. 30 and 31. The main part of the core 147 is built from strips having width A , supplemented with extension stacks 148, 149 and 150 on both ends with strip widths B , C and D as shown in the lower part of FIG. 30. To wind the coil to fit the extended core, jaws 151 can be assembled with jaws 152 and 153 (as shown in top part of FIG. 30) on the same lathe chuck described in connection with FIG. 24. Heat dissipator layers 154, 155 and 156 can be accommodated over the coil in the window area by placing the narrower yoke steel stacks 148.1, 149.1 and 150.1 away from the window in alignment with the outside top or bottom surfaces of the core respectively, as shown in FIG. 31. If necessary, the stack 148.1 can be displaced even further, to provide even more clearance to the window area for dissipator fins. Displacement of stack 148.1 of course, requires a commensurate extension of the length of stack 148 in the leg, until heat dissipator 154 has the necessary clearance b' from stack 148.1' in the window area, to obtain necessary circulation of the cooling medium.

Core structures built to fit tightly in precision wound coils described in connection with FIGS. 24, 25 and 26 do not lend themselves easily for the conventional interleaved core lamination process using the same patterns alternately as shown in FIG. 34. Furthermore, economical and technical advantages can be achieved by using butt-jointed, or hybrid butt-jointed interleaved cores. FIG. 32 part A illustrates an exemplary embodiment. Between two full width leg steel stacks 157, two short stacks of yoke steel 158 are placed with butt joints. Narrower leg steel stacks 159 are interconnected with adequately dimensioned narrower yoke steel stack 160. The core can be built entirely with butt joints, assembled most conveniently with horizontally positioned legs as shown in FIG. 25 and 26. After the assembly is completed, to eliminate the gaps in the butt joints, the best procedure is to turn the unit with legs horizontally but with yoke steel vertical, then excite the core to the highest flux, then let the magnetic forces close the gaps by loosening up the brackets and applying some

mechanical shocks by hammer or vibrator. When the exiting current reaches its minimum, that indicates that the gaps are already closed and the brackets can be bolted tight. To secure the legs in that position, holes 161 can be drilled through brackets into the core and tightly fitting pins can then be driven into the holes. Another way to secure the legs in position is to provide the brackets with movable pressure plates 116.1 and fixed plates 116.2 as described in connection with FIG. 20.

Another way to keep the leg steel in place is by interleaving steel pattern A with pattern B in FIG. 32. The interleaving can be unsymmetrical e.g. after placing uniform stacks of 1.5 to 2 cm. all around from pattern A, single sheets or several sheets can be placed according to pattern B, and so on. According to another version, equally large stacks of butt-jointed core parts can be placed alternately from pattern A and B repeatedly.

The latter version offers a special advantage: when flux is excited in the loose core, leg steel stacks 157 from pattern A cannot move closer, since yoke steel stacks 158 keep them apart. Interleaved alternate leg steel stacks 162 from pattern B can and will move toward each other horizontally under the influence of magnetic forces, as shown in FIG. 33. This movement is limited by the clearance in the opening of coils 163 resulting in a situation, in which leg steel stacks 157 from pattern A are pressed against outward sides of the coils 163 while members 162 of pattern B are pressed against the window sides of coils 163, as the arrows indicate. The same freedom of movement exists in vertical direction for yoke steel parts 158 and 160 of pattern A; these parts of the yoke steel tend to move into the window area and grab the coil both from the top and bottom firmly. This phenomenon eliminates any loose contact between coils and core automatically, with no wedges to force in; the tightness of the unit has a noise dampening effect on the magnetic vibrations generated in the core by the flux.

When vertical plane heat dissipators 164 are used between coils 163 (used also in FIG. 22) as item 133, and shown in detail in FIG. 23), it is necessary to press the coils together to ensure a good heat transfer path toward the flat part of coils 163. The conventionally cut core pattern 165.1, 165.2 shown in FIG. 34 when stacked up in fairly large stacks alternately, (e.g. first 1.5 to 2 cm. stacks of pattern A from FIG. 34, then similar size stacks from pattern B and so on, all with butt joints within stacks) the core can tighten itself up toward the window 166 from all four directions when the loosely stacked core 165.1, 165.2 receives the full flux after applying the necessary voltage over the terminals of its coils. Both A and B part of the core has the freedom to slide in the directions indicated by arrows under the influence of the flux, shrinking both window dimensions, until the coils are firmly under pressure, including dissipator 164 between them. This situation can be maintained by simply tightening up the core bolts between brackets while the flux is still on.

FIGS. 35, 36 and 37 illustrate a "disc" or "pancake" type winding used in larger power transformers, and is equipped with a heat dissipator embodiment in accordance with the present invention. Over a solid insulating tube 168, the turns 169 of a disc-type winding is arranged. Between two adjacent discs, a prefabricated strip of heat dissipator 170 is wound in. Two versions are illustrated: the first shown in FIG. 35 and FIG. 36, the second in FIGS. 35 and 37.

Both versions of the dissipator strip 170 are prefabricated in a progressive die, bending up a continuous strip 171 on the outside contour of the strip 170, punching out a tapered narrow portion 172 of the aluminum sheet and shearing and twisting up fins 173. The wedge-shaped elements of the dissipator strip according to the second version in FIG. 37 has a double bend 174 between its flat portion 175 and its fins 173. Both versions of the dissipator strips 170 are preferably coated with insulating film. Their flat portions 175 are narrow enough to prevent excessive eddy currents. The lower portion 176 of the strip 170 is subsequently cut off leaving wedge-shaped flat portions 175 with a proper radial dimension to fit to the radial dimension of the winding.

When the dissipator strip is inserted between two discs, it can follow the curvature of the disc winding up to a maximum curvature as shown in FIG. 35 at portions 177, when there is no more clearance between the flat portions 175. If more curved discs are also in use, wider tapered portions 172 should be removed by the die. With two or three different tapered cutouts 172, the whole range of the used curvatures can be covered. When strips with wider cutouts 172 used in less curved discs, the heat transfer of the lower part of the discs suffers slightly, having only partial contact with the heat dissipator.

The best procedure is to connect the coated heat dissipators electrically to the first turn of the disc and leave sufficient gap between the two ends not to create a shorted turn. The necessary electric insulation 178, 178.1 can be cut out of solid insulating material, or it may be applied as sufficiently heavy coating on the flat portion 175 of the dissipator. In the exemplary embodiment in FIG. 37 where twin dissipators are used between two discs, the heavy insulating layer 178.1 should be between the two heat dissipators, keeping the heat transfer possibly unobstructed between disc winding 169 and dissipator portions 175. The start of the two strips should both be connected to the start turn of the disc winding. In this arrangement, the presence of the connected heat dissipator strips increases the internal capacitance between discs substantially. Consequently, any high voltage surge entering the coil on its terminals, finds an easy bypass through the internal capacitances. Consequently, the coil displays a non-oscillating characteristic due to the extensive surge shielding provided by the dissipators.

When large numbers of disc windings are built up with dissipators along the leg, the cooling medium warms up and the upper regions of the winding have much higher temperature rise. To compensate for this, i.e., balance the temperatures, it is usually desirable to use more dissipators on coil sections located in higher regions, as previously described in connection with FIG. 21. This principle can be adapted to disc-type windings by, e.g., using the single arrangement illustrated in FIG. 36 on lower regions of the winding, while using the twin dissipators according to FIG. 37, on central regions, and triple dissipators on the higher regions, combining FIG. 36 with FIG. 37.

Another way to equalize the temperatures between higher and lower regions is to prevent substantial warming up of the cooling medium by channeling it off and allow fresh cooling medium access to higher regions. An exemplary embodiment for channel means serving that purpose in connection with disc-type windings is illustrated in FIG. 38 wherein two stacks of disc-type windings 181, 182 are built up over insulating tube 180. A lower stack 181 and an upper stack 182 are both interleaved with dissipator strips 183.1 and 183.2 respectively. Between the upper and lower stacks, a gap 184 is provided to accommodate a special baffle which is designed to channel the warm cooling medium rising through lower dissipators 183.1 along arrow 185 away from the coil while allowing the fresh cooling medium 186 to enter between channel members 187. Similar baffles can be used also with other arrangements, e.g. between heat dissipators 127.1 and 127.2 in FIG. 21, etc.

Larger transformers have heavy currents in their low voltage windings and when the finish lead of such a winding is brought out on the end portion of a layer wound winding in the conventional manner, a considerable part of the otherwise useful fin area is lost. To avoid that difficulty, finish leads can be brought out on the sides in the window where no fins are present; such an approach is particularly easy when a foil conductor is used on the low voltage side as shown in FIG. 39. On winding 188, "start" foil lead 189 is accommodated as a folded out extension of the first layer of the coil, entering beyond all heat dissipators 190. Finish lead 191 of the same winding can be brought out on the side, folding the foil downwards, or upwards (192) as needed. Winding 188 can be the whole low voltage winding, or only a part of it; other parts may be arranged on the same leg, above or below the winding 188, connected to it in the window, before the leg steel is

stacked into the windings. In multi-legged designs, the other parts of the winding are on the next leg, as shown in FIGS. 40 and 41. Either delta and Y-connection in three phase units, or series and parallel connection in single phase units are feasible in the window without the interference with the heat dissipators on the ends of the windings. In FIG. 40, three windings A, B and C start with start leads 193 brought out under dissipators 194; finish lead 195 on leg A is brought out in the window and connected to the last turn of coil B, which has its finish lead 196 in turn connected to coil C in the other window; the finish lead 197 of coil C can be brought to the terminal board easily as a neutral lead for the three phase Y-connection. In single phase units, having legs A and B only, the connection leads to a series connection with center tap 195 available if needed. Nevertheless, series parallel connection is also feasible bringing all four leads to the terminal board.

In FIG. 41, a delta connection is illustrated. Start leads such as 198 on leg A, are brought out beyond the heat dissipators 199. Finish lead 200 of coil A is brought out in the window; similarly, a foil tap lead 201 on the first turn of coil B is brought out adjacently to lead 200; they can be connected together conveniently in the window area. Similarly, finish lead 202 of coil B can be brought out in the other window and connected conveniently with tap 203 brought out from the first turn of coil C. Finish lead 204 of coil C can be connected with an outside jumper lead 205 to start lead 198 of coil A, completing the delta connection, with no interference between leads and heat dissipators. Similarly, in single phase units, having coils A and B only, a parallel connection can be established connecting leads 200 to 201 and 202 to 198.

Various additional modifications of the above-described embodiments of the invention will occur to those skilled in the art, and therefore the invention should be broadly construed in accordance with its full spirit and scope.

What is claimed is:

1. In a power transformer having improved heat dissipation characteristics and comprising at least one core leg and a generally tubular winding structure having an axis and including a plurality of layers defining tubular surfaces, the winding structure generating heat through electric and magnetic energy losses, the improvement comprising:

heat dissipator means including at least one layer of non-magnetizable highly heat conductive material in heat conductive contact with at least one of said tubular surfaces, said layer including portions extending axially beyond at least one end of said tubular surface, said extended portions connected to a louver-like structure disposed in a plane substantially perpendicular to said axis of said tubular structure and including fins, the fins of said louver-like structure being disposed substantially in planes parallel to said axis of said tubular structure whereby proper flow of cooling medium is maintained for the dissipation of heat by convection.

2. A transformer according to claim 1 characterized by said dissipator means comprising at least two layers arranged over the same transfer surface of said winding structure.

3. A transformer according to claim 1 wherein said heat conductive layer is disposed between two different windings of said transfer each having electrical insulation for the required test voltages on both sides of said heat conductive layer and being connected to ground, thus playing a secondary role as ground shield.

4. A transformer according to claim 1 characterized by the application of insulating layers with improved heat conductivity to said heat transfer surfaces, said insulating layers comprising fine grains of solid, highly heat conductive insulating material embedded in the base material of the insulating layers.

5. The transformer according to claim 1 characterized by a plurality of layers of said heat dissipator means each extending beyond at least one dimension of said winding structure, said extending portions each comprised of cooling fins projecting therefrom and arranged in separate rows along said axis, and

including a greater number of rows toward one end of said axis than toward the other end thereof.

6. The improvement of claim 1 wherein said louver-like structure comprises groups of fins having gaps between the outer ends thereof.

7. The improvement of claim 6 wherein continuous strips interconnect the outer ends of the fins in each group.

8. The improvement of claim 7 wherein said heat dissipator means includes at least a second layer of non-magnetizable highly heat conductive material in heat conductive contact with one of said tubular surfaces, said layer including a portion extending axially beyond the same end of said tubular surface as said first layer, said extended portion connected to a louver-like structure disposed in a plane substantially perpendicular to said axis of said tubular winding structure and comprises groups of fins, at least one of said groups of fins on said second layer being in substantially axial alignment with one of said gaps in said first layer.

9. The improvement of claim 1 wherein said generally tubular winding structure includes two tubular coil sections of winding layers disposed in axially spaced apart relation, each of said sections including heat dissipator means, and at least one of said means having louver-like structure disposed in the space between adjacent tubular winding sections.

10. The improvement of claim 1 wherein one of said internal layers of said winding structure includes a start lead disposed at one end of said tubular winding structure and passing beneath said louver-like structure and a finish lead emerging in the window portion of said tubular winding structure.

11. The improvement of claim 10 wherein said transformer includes at least one adjacent winding structure and the leads between adjacent structures are interconnected in the window.

12. In a transformer having improved heat dissipation characteristics and comprising at least one core leg and a winding structure comprised of discs each having an outer marginal edge and an axis, the coil discs being stacked in axial relation along the leg of the core, the winding structure generating heat through electric and magnetic energy losses, the improvement comprising:

heat dissipator means of generally disc-like construction disposed between said winding discs, a louver-like structure connected to said disc-like construction closely adjacent the outer marginal edge of said disc construction and extending beyond said edge, said louver-like structure including fins disposed substantially in planes perpendicular to the plane of said disc construction whereby proper flow of cooling medium is maintained for the dissipation of heat by convection.

13. The improvement of claim 12 wherein said disc is divided by separating channels along selected paths of the heat flow to reduce eddy currents generated by stray flux.

14. The improvement of claim 13 wherein said separating channels extend to the inner marginal edge of said disc and said louver-like structure includes a continuous strip mechanically interconnecting the outer ends of said fins.

15. The improvement of claim 14 wherein dissipator flat portions are defined by said separating channels and are tapered inwardly so as to have closely adjacent edges when said disc is wrapped between adjacent disc windings.

16. The power transformer of claim 1 having a physical construction for reducing the peripheral surface about the coil winding structure so as to reduce the amount of copper required in the transformer and to thermally integrate the core and coil comprising:

said core leg having a substantially rectangular cross section with corners each having at least one step at each corner; said tubular winding structure including an inner winding layer wound about said core leg with substantially no gap therebetween to thus thermally integrate said core and inner winding layer, at least one additional coil winding layer wound about said inner layer with substantially no

gap therebetween to thus thermally integrate said core structure and said additional coil winding layer; and said heat dissipator layers interleaved between adjacent coil winding layers of said coil structure.

17. The transformer of claim 16 wherein the leg of said substantially rectangular core comprises a stack of steel lamination of two different widths, the narrower stack being accommodated further away from the center plane of said leg, and the proportion between the widest and the narrowest steel stack width being between 1:0.75 and 1:0.85 for cores having two different stack widths to achieve substantially minimum circumference for said core leg and minimum mean turn length for the surrounding winding at any given cross-sectional area of said leg.

18. The transformer of claim 16 wherein the leg of said substantially rectangular core comprises a stack of steel lamination of three different widths, each narrower stack being positioned further away from the center plane of said leg, and the proportion between the widest and the narrowest steel stack widths being between 1:0.5 and 1:0.65 for cores having three different stack widths, to achieve substantially minimum circumference for said core leg and minimum mean turn length for the surrounding winding at any given cross-sectional area of said leg.

19. In a transformer having at least one active part in which heat is generated by electric and magnetic energy losses, heat dissipator means including at least one exterior layer of highly conductive material mechanically connected to a heat transfer surface on the active part, the improvement comprising:

an enclosure entirely surrounding said transformer;

a fan positioned substantially below said transformer for forcing a cooling medium through said heat dissipator means;

a venturi tube disposed about the periphery of said fan,

an envelope extending upward from said venturi tube adjacent the lower edge of said heat dissipator means, and said envelope and said enclosure defining a bypass duct through which a cooling medium is moved along the exterior layer of said heat dissipator means by convection or by induction when said fan is operating.

20. The improvement of claim 9 wherein the tubular coil

section at one end of said core leg has a larger number of dissipator means than the dissipator means on those sections closer to the opposite end of said core leg.

21. A transformer having improved heat dissipation characteristics comprising:

a generally tubular winding structure in which heat is generated by electric and magnetic energy losses and including first and second tubular winding layers each having a heat transfer surface spaced from and opposed to the other of said winding layers;

heat dissipator means defining a region of occupancy and including within said region at least one portion having an axis of orientation, said portion being subdivided along said axis into a plurality of zones, said heat dissipator means including at least one layer of non-magnetic highly heat conductive material, means mechanically connecting said heat conductive layer to at least one of said winding heat transfer surfaces, and a plurality of cooling fins each extending out of said at least one heat conductive layer and connected in heat conductive relation thereto within at least one of said zones of said region, said fins including major surfaces bordered by free leading and trailing edges and a side edge substantially coincident with said heat conductive layer, said major surfaces being spaced from said transfer surface and being oriented substantially parallel to the axis of orientation and having a dimension between the leading and trailing edges thereof in the direction of said winding axis which is less than one-fourth of the dimension of said region of occupancy measured in the same direction; and

said winding structure includes a low voltage winding formed by a foil having heat dissipator layer sinterleaved therewith and a high voltage winding wound around said low voltage winding and insulated therefrom, said high voltage winding formed of a plurality of layers of wire with the layers decreasing in axial dimension with increasing distance from said low voltage winding.

22. The transformer according to claim 21 including a comb-like insulating member fixed to the outer ends of fins in different zones to maintain them in spaced relationship.

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