# United States Patent [19]

**Anderson**

[11] **3,761,752**

[45] **Sept. 25, 1973**


[54] **DYNAMOELECTRIC MACHINE WINDING SUPPORT**


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[52] **U.S. Cl.** .................. **310/179,** 310/194, 310/216

[51] **Int. Cl.** .............................................. **H02k 1/18**

[58] **Field of Search** ........... 310/179, 260, 254–259, 310/40, 52, 10, 216, 194, 43


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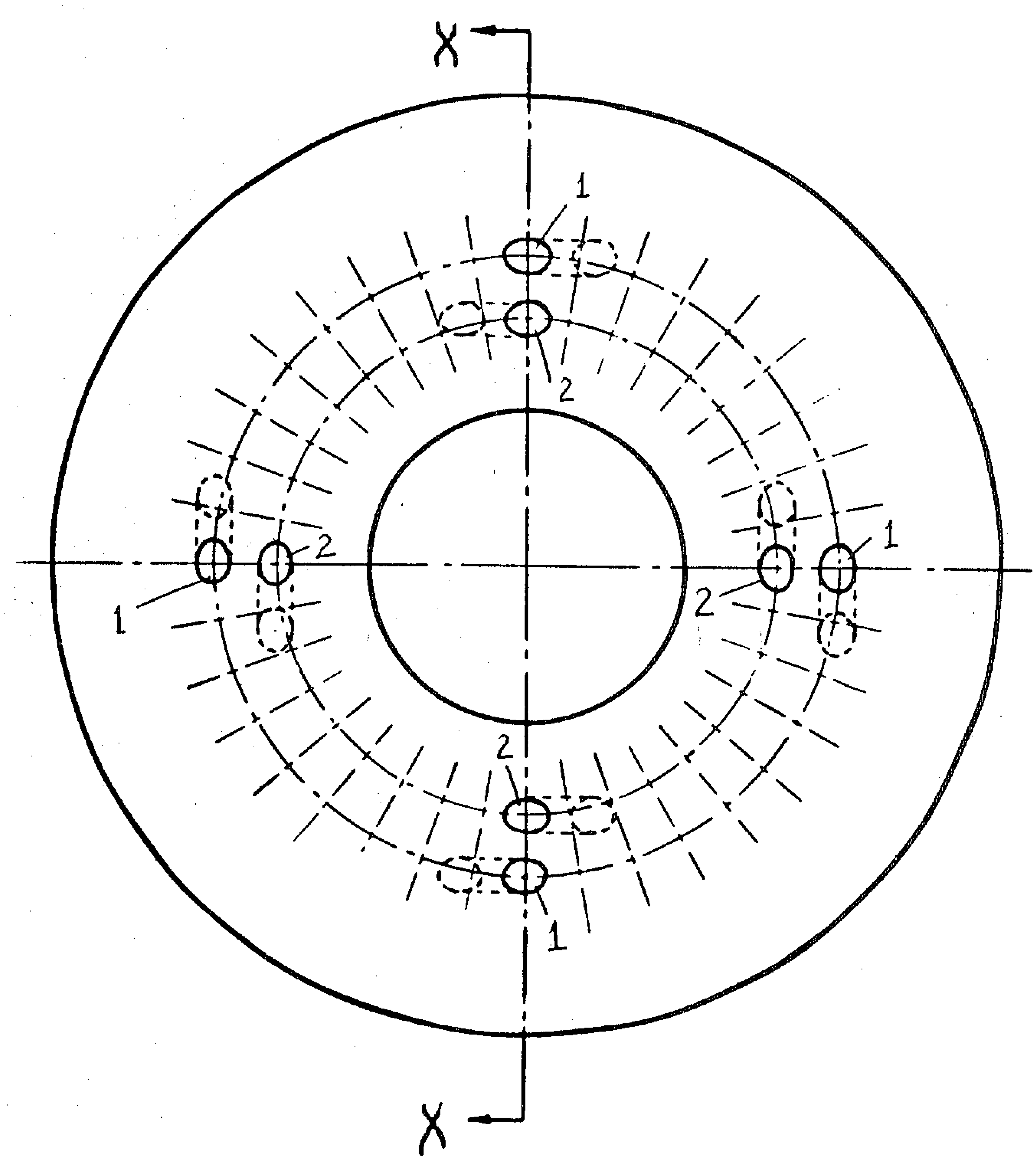
[57] **ABSTRACT**

A multi-phase stationary winding for an alternating current dynamo-electric machine, either of the type having a superconducting rotor winding or the air-gap winding iron-core type, is provided in which the conductors of the winding are helically disposed on a support structure so as to provide adequate mechanical support for the winding and reduce or obviate the problems of end winding support met in conventional alternating current machines of a similar nature.

**14 Claims, 11 Drawing Figures**

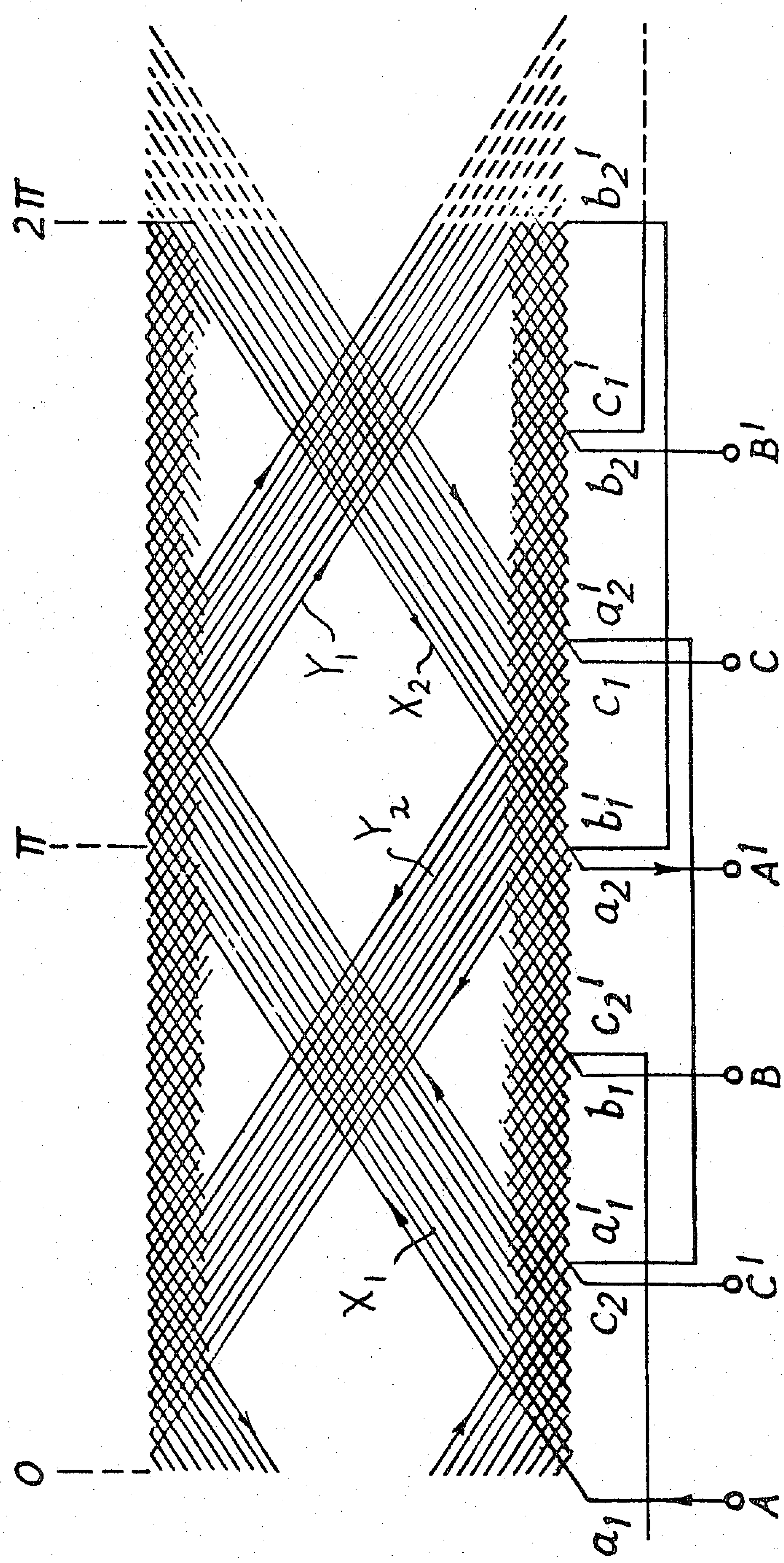



FIG. 1

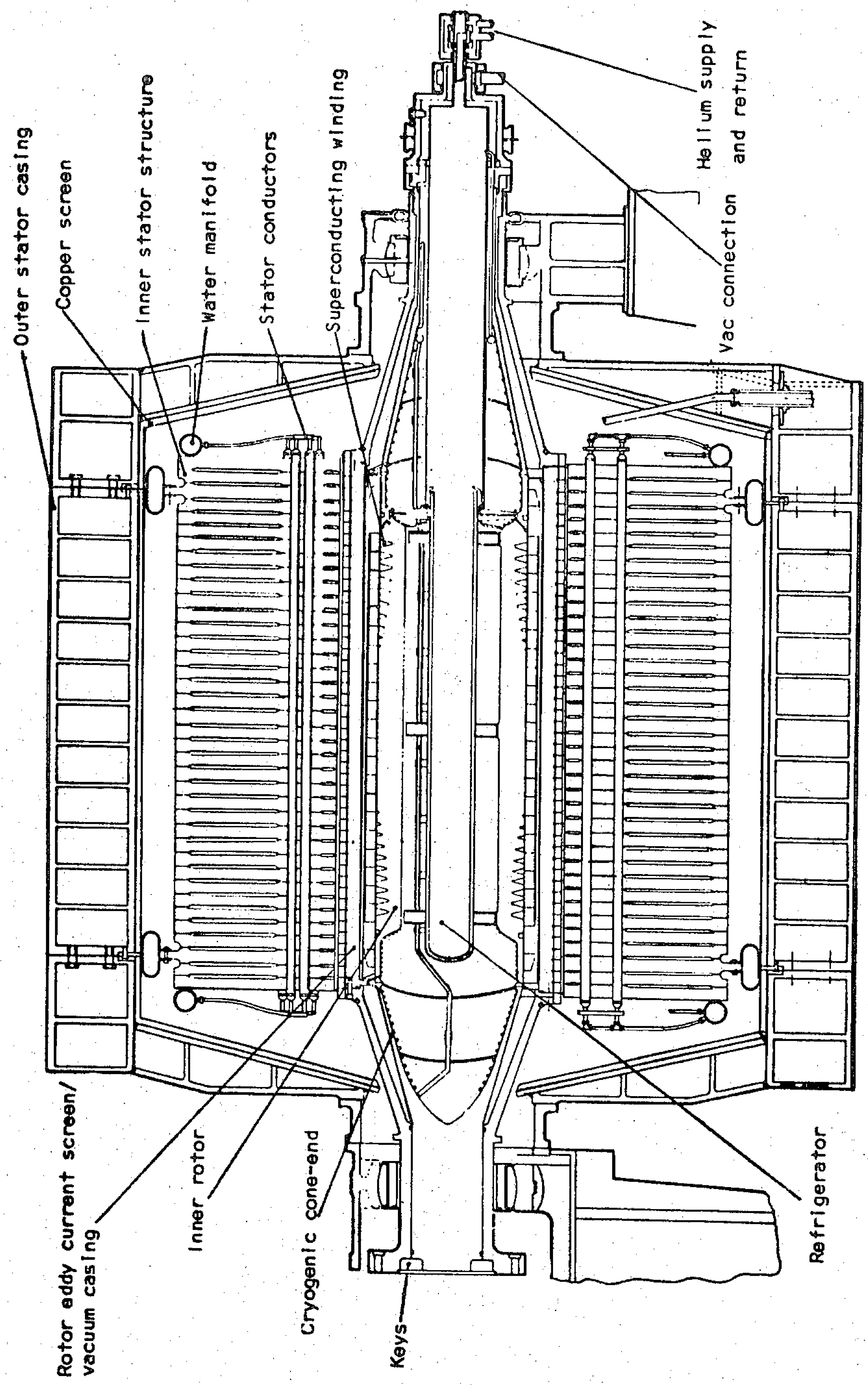

Outer stator casing
Copper screen
Inner stator structure
Water manifold
Stator conductors
Superconducting winding
Helium supply and return
Vac connection
Rotor eddy current screen/ vacuum casing
Inner rotor
Cryogenic cone-end
Keys
Refrigerator

FIG. 2

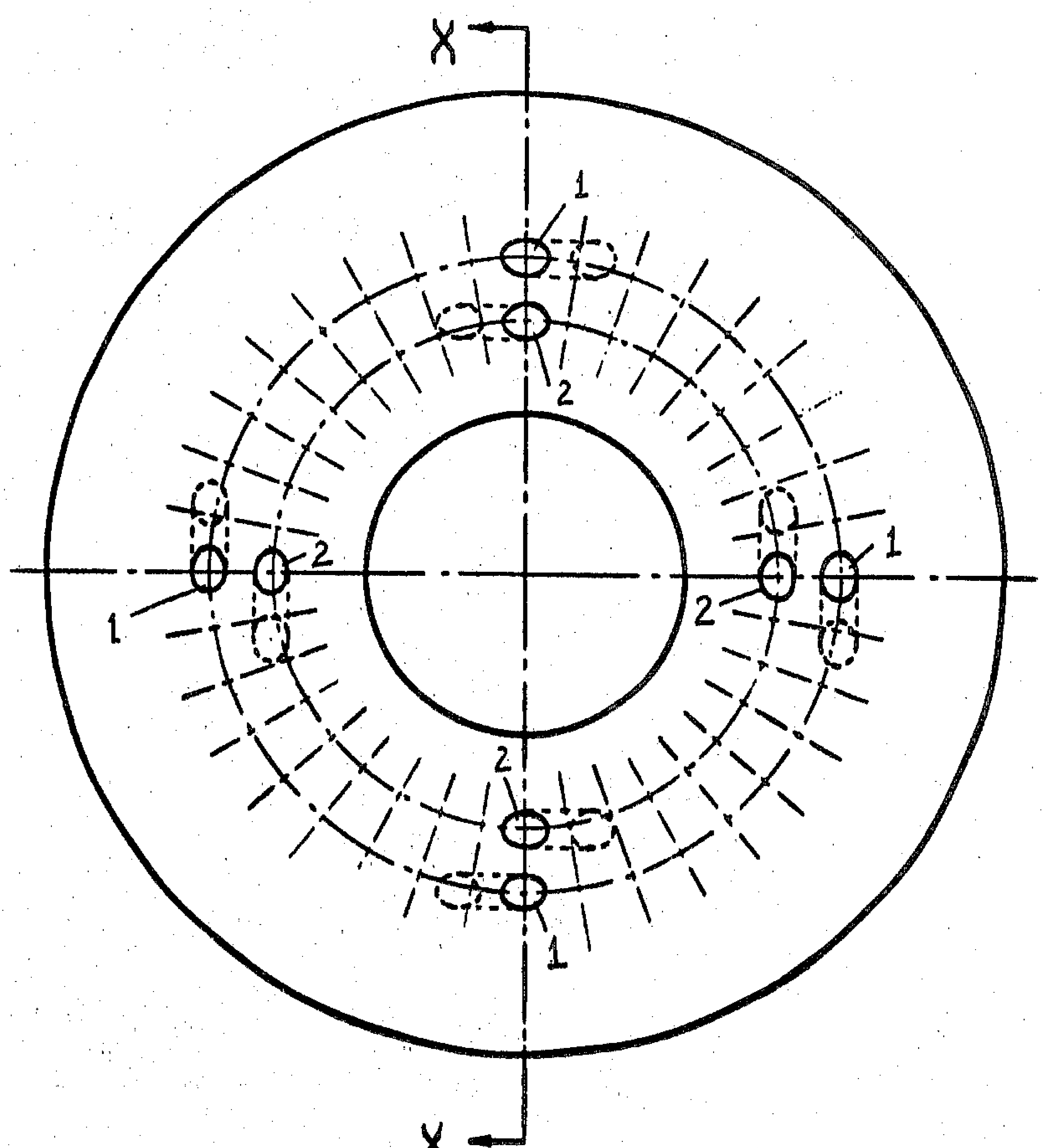



FIG. 3

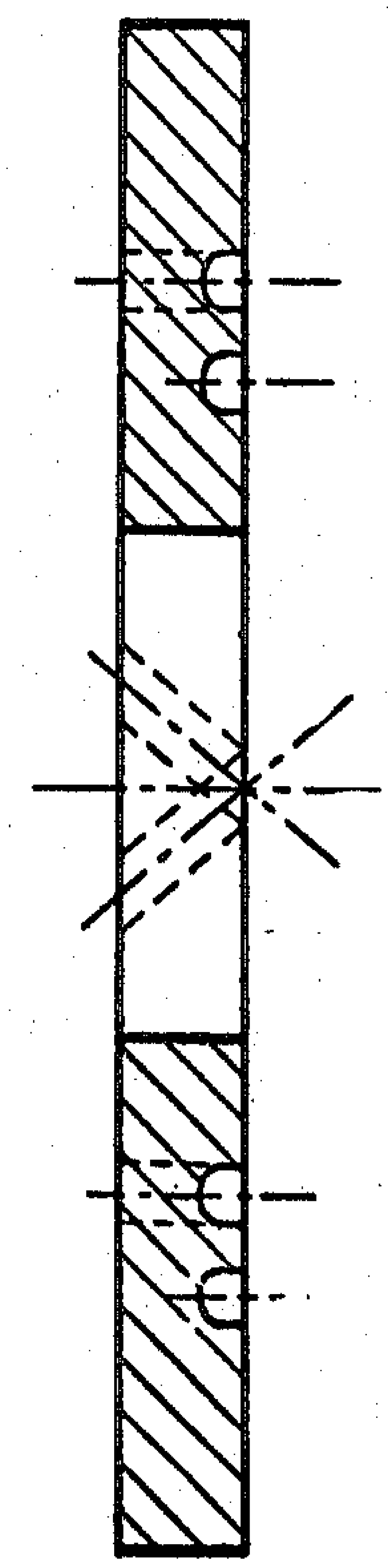


FIG. 4

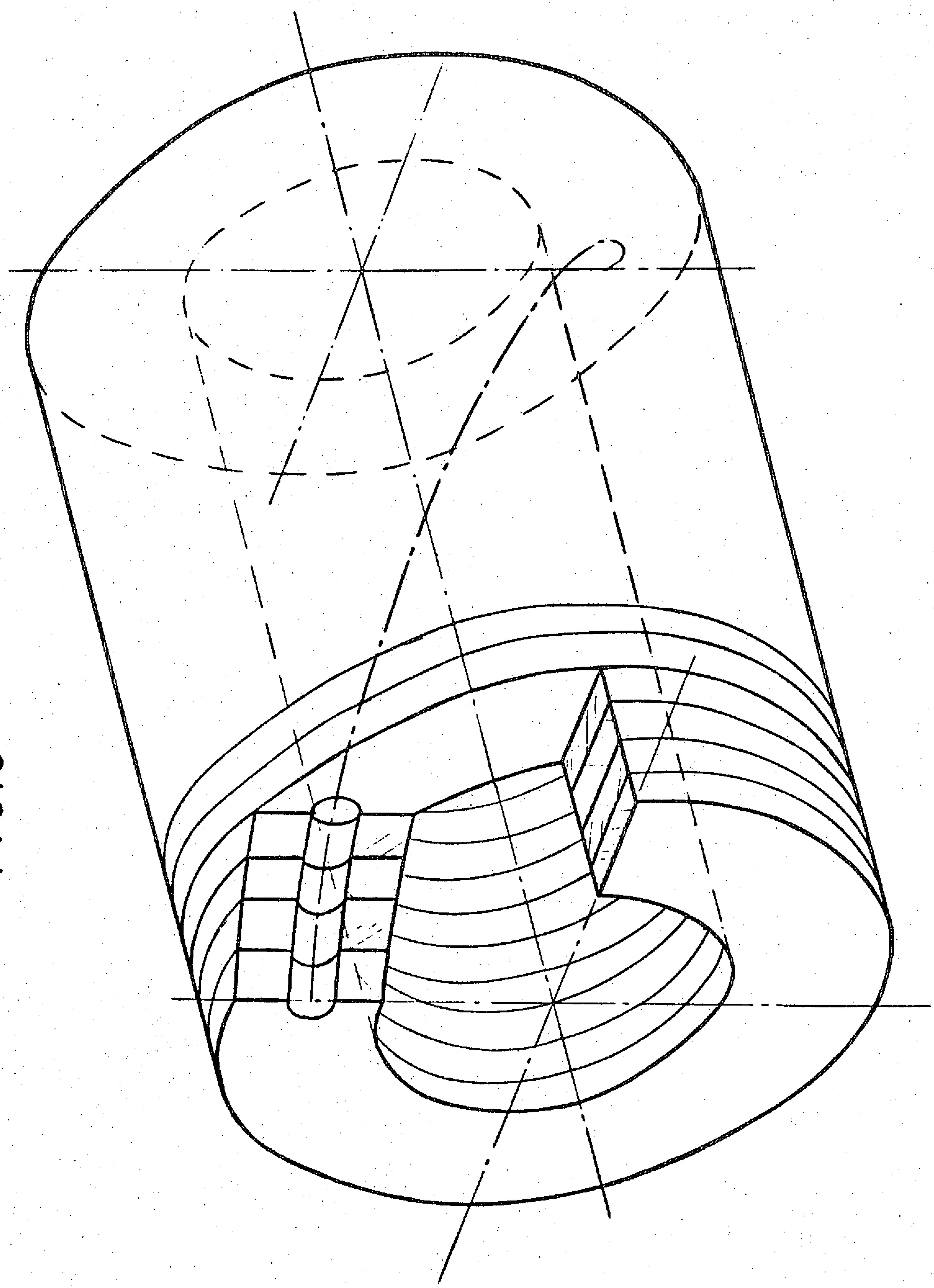


FIG.5

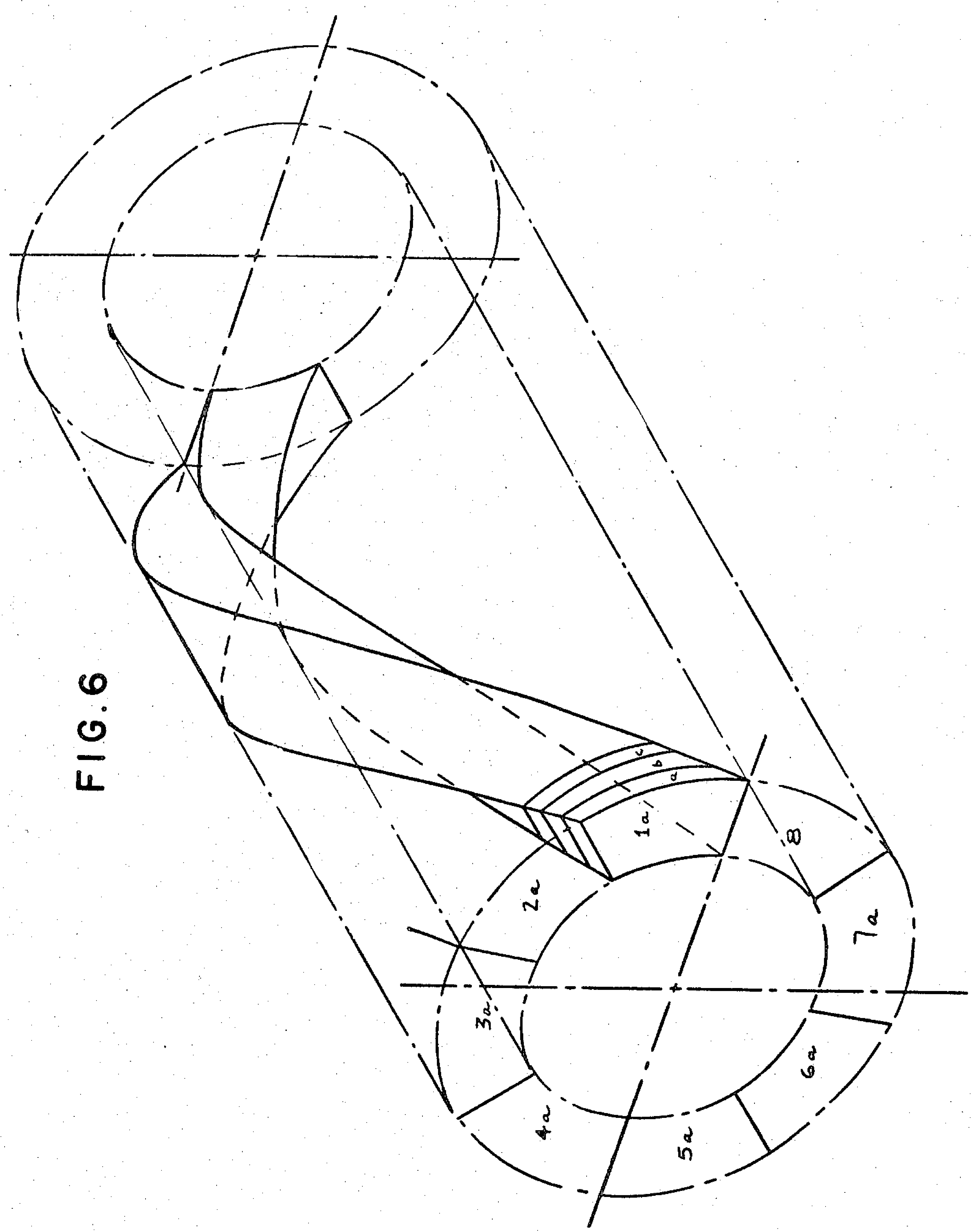
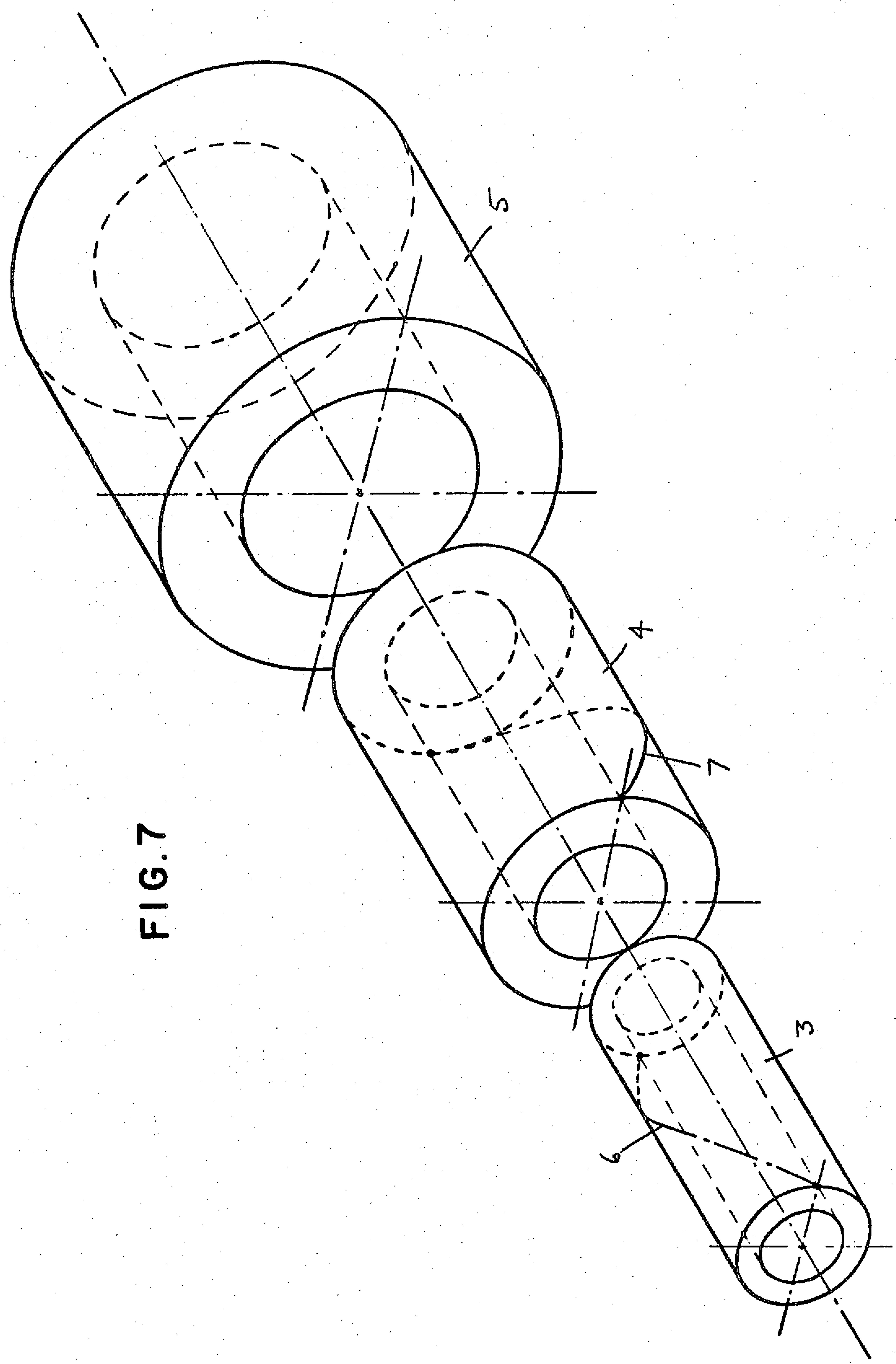



FIG. 6

FIG.7



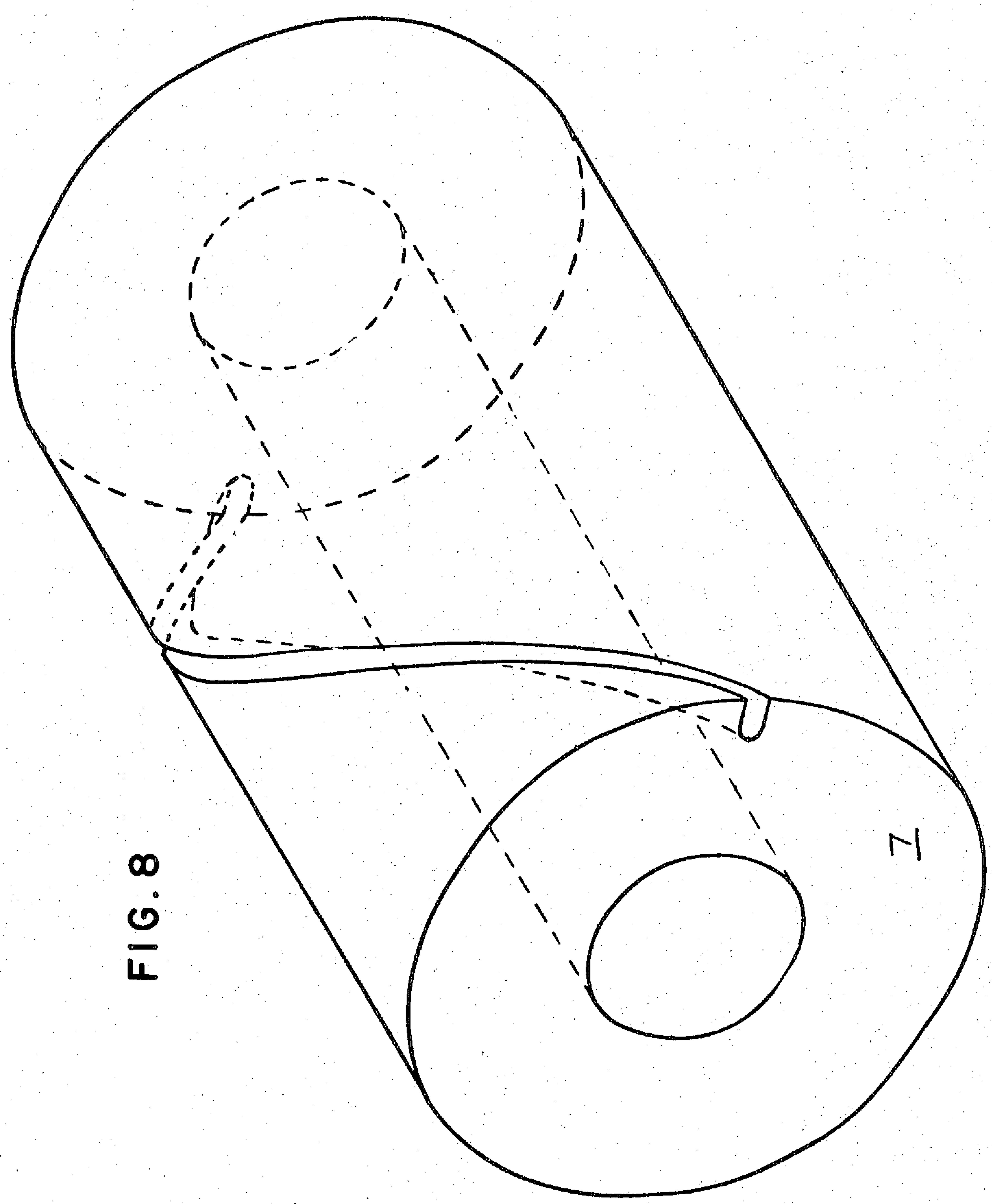



FIG. 8

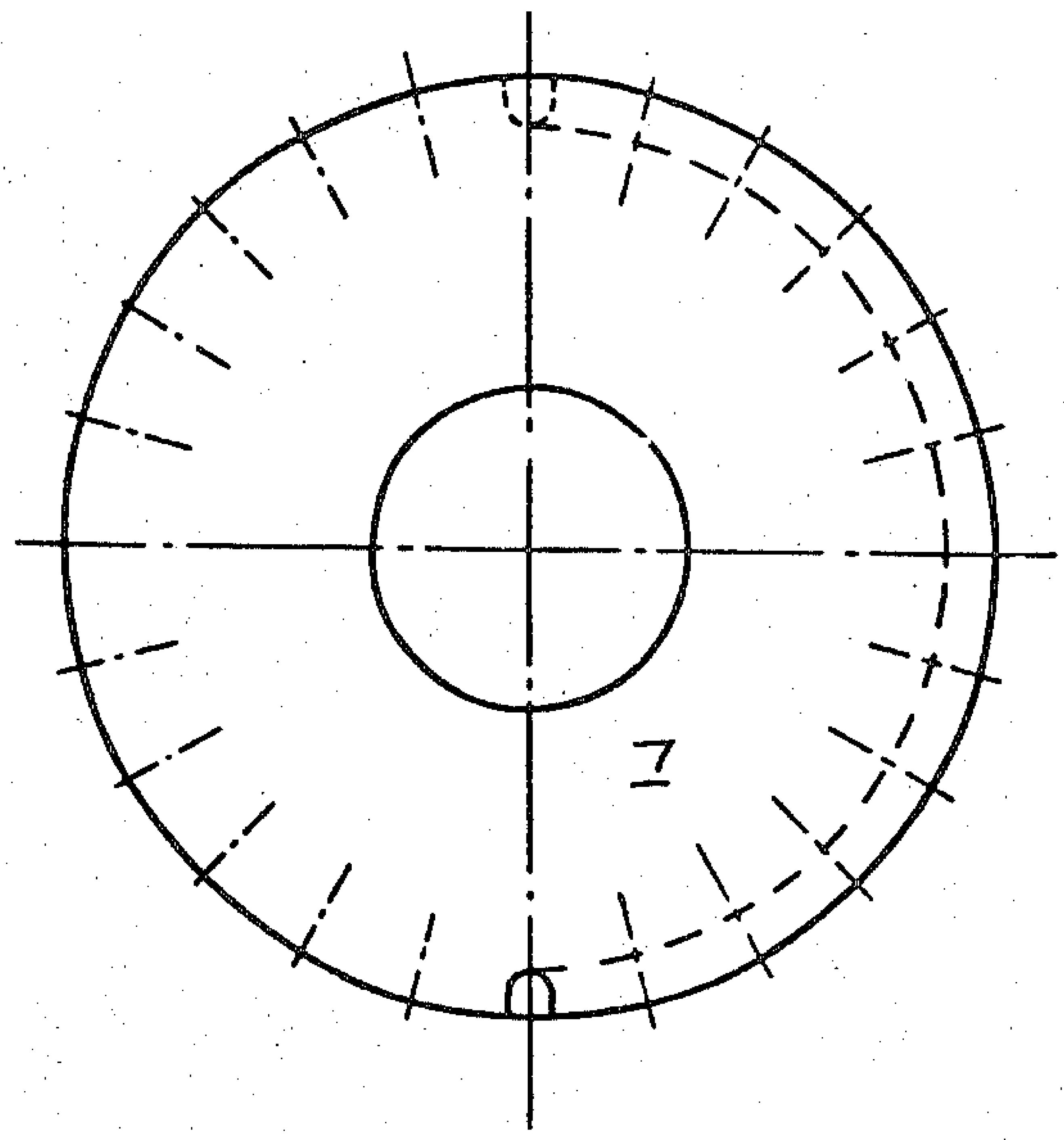



FIG. 9

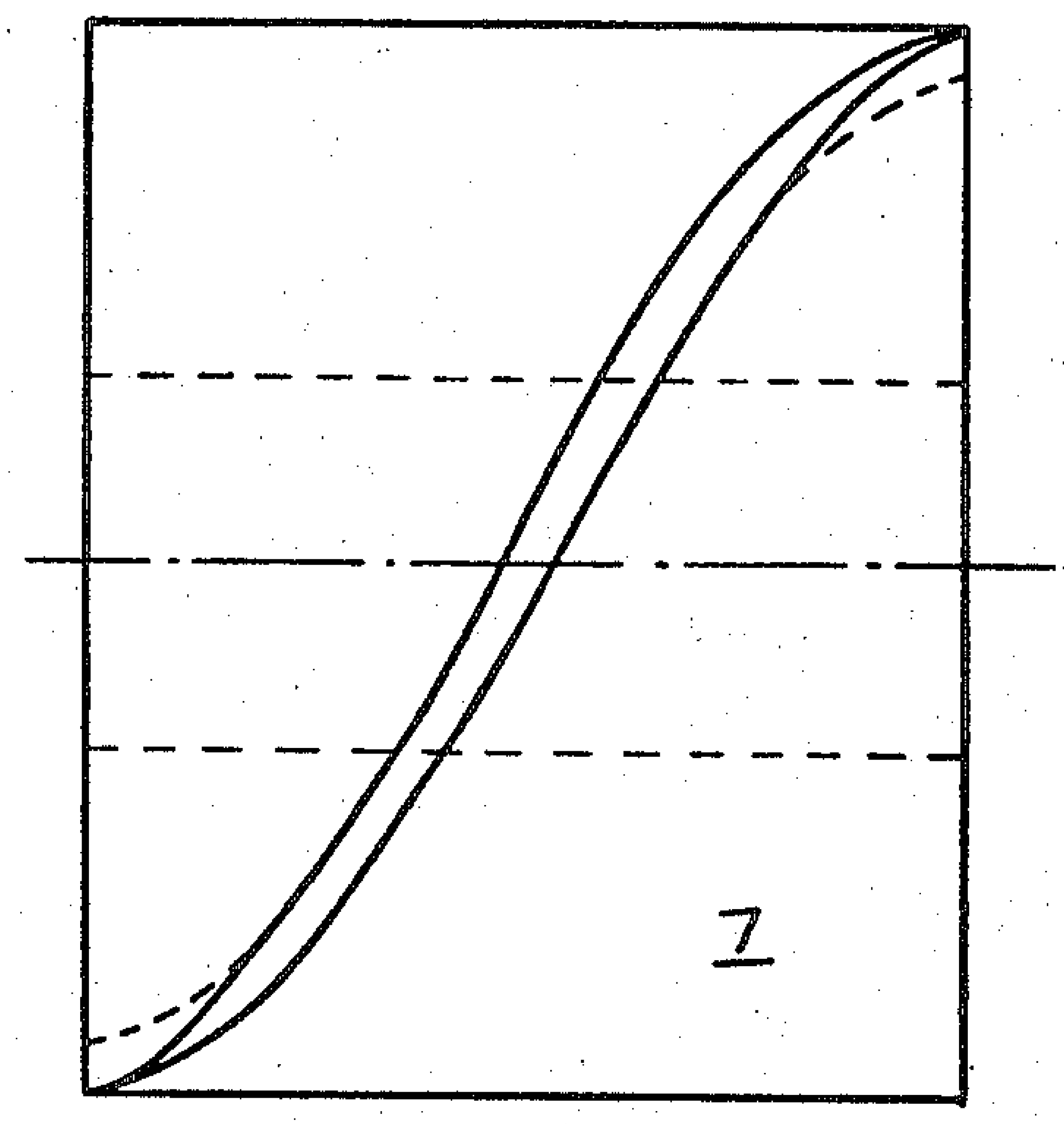



FIG. 10

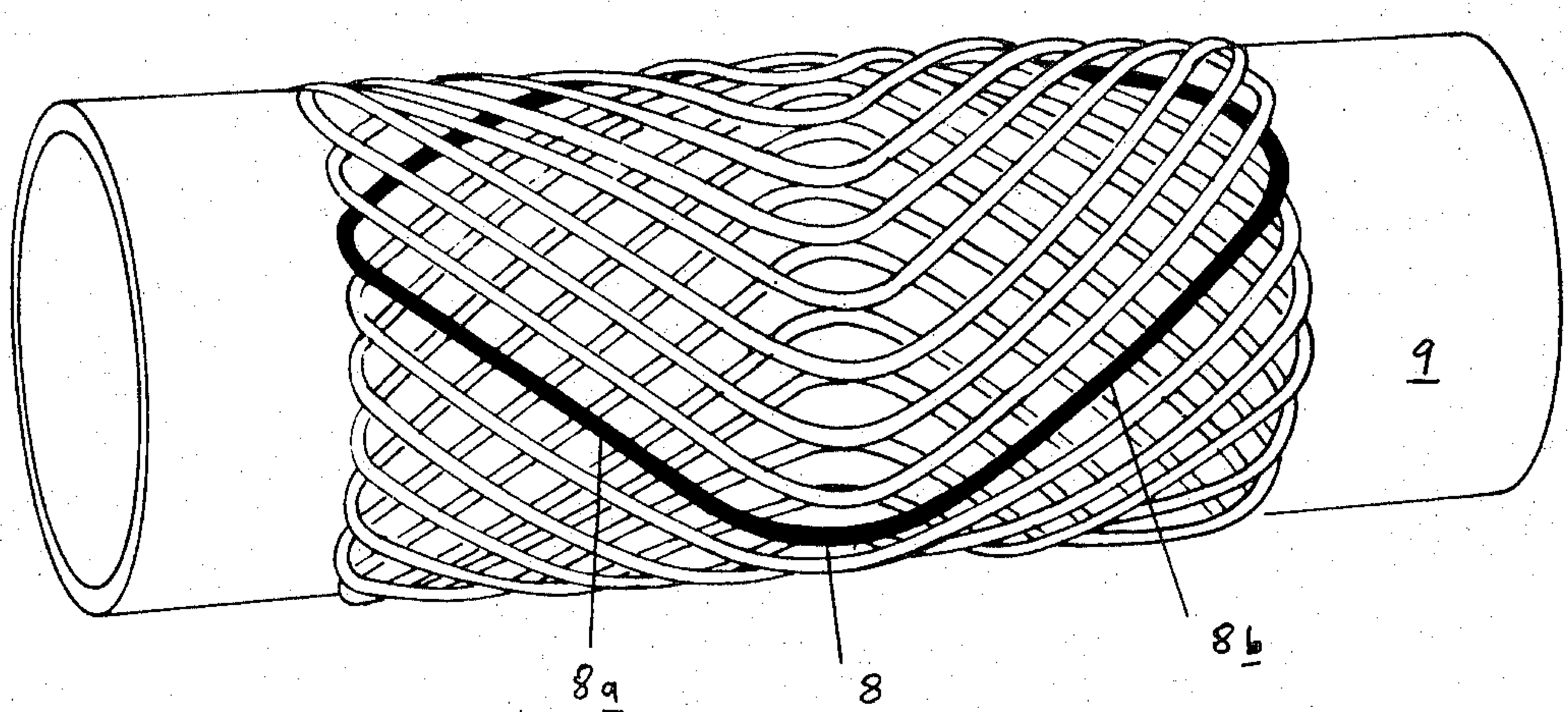



FIG. 11

## DYNAMOELECTRIC MACHINE WINDING SUPPORT

The present invention relates to multi-phase stationary windings for dynamo-electric machines, especially air-cored windings such as those employed in the stators of machines having a superconducting winding on the rotor (see our U.S. Patent application No. 043,693, allowed Sept. 13, 1971) and as air-gap windings in conventional iron-cored machines (see our U.S. Pat. No. 3,546,503).

In a conventional machine such as an A.C. generator the stator winding is composed of conductor bars disposed in slots in an iron core and extending parallel to the axis of the machine. The ends of the conductors are connected by end windings which like together conductors spaced around the rotor in order to form the turns of the winding. The end windings are usually of involute form and lie on a frusto-conical surface. In such a machine the field is concentrated around the conductor bars by the iron core and the influence of the field on the end windings, which project beyond the core, is further reduced by the frusto-conical formation which takes the end windings away from the region of high field strength generated by the rotor winding.

In a superconducting machine the field ampere turns obtainable are so great that it becomes possible to dispense with the expensive and cumbersome iron core of the stator winding whilst maintaining an effective flux density equal to or greater than that of a conventional machine. The magnetic forces in an a.c. machine having armature conductors retained in slots in an iron core largely appear on the iron, however, whereas in an air-gap winding or superconducting machine the forces appear on the conductors themselves. A conventional form of armature winding employed in the type of machine to which the present invention relates would thus suffer the disadvantage that it would be exposed to high field strengths, and hence high mechanical forces, throughout its length, including the end windings, and the problem of providing adequate mechanical support for the frusto-conical end windings is presented.

In accordance with the present invention there is provided a multi-phase stationary winding for an alternating current dynamo-electric machine comprising a non-magnetic, hollow cylindrical, support structure and at least two co-axial cylindrical layers of conductors carried by the support structure, each conductor extending between opposite ends of the cylindrical layer in which it is confined along a path at least the greater part of which comprises one or more substantially helically disposed lengths, end connections being provided between the adjacent ends of conductors of the two layers to form turns of the winding in which at least one conductor of one layer is connected in series with at least one conductor of the other layer, the circumferential extent of each of the said end connections being substantially zero and each conductor bearing the same spatial relationship to the remaining conductors of the winding.

In a winding of this configuration the arrangement of the conductors in cylindrical layers at a constant radius facilitates the provision of a strong mechanical support throughout the length of the winding. The displacement of the ends of the conductors allows the end connections to be made directly and reduces the requirement for end windings to connect conductors lying at spaced positions around the winding.

In a preferred construction the conductors are of helical formation each comprising a single helically disposed length between the ends of the winding and extending through a helical passage in the support structure. The support structure is composed of a plurality of rings each of which has for each layer of conductors a circle of inclined holes, the rings being assembled so that these holes are aligned to form the helical passages. All the rings are of the same form and they provide a uniform support for the conductors over substantially the whole length of the winding.

In alternative embodiments the path of each conductor from end to end of the winding may comprise two helically disposed lengths of opposite hand, there being a substantially abrupt change of direction of the conductor intermediate the ends of the winding. The two lengths of each helical conductor are preferably equal, but need not necessarily be so.

where the winding forms the stator winding of a machine having a superconducting rotor field winding it preferably extends beyond the ends of the rotor winding so that the end connections lie in a region of lower field strength than the central parts of the conductors to reduce eddy current losses. Such a distribution may also be adopted with an air-gap armature winding for an iron-cored machine.

As in conventional windings, several turns can be connected in series to form a coil in windings according to the invention, successive turns being made of conductors lying adjacent to one another in the winding. A second coil whose conductors are displaced from those of the first coil around the axis of the cylindrical layers may be electrically connected in series or in parallel with the first coil. In a preferred construction the first and second coils are connected in series and in such a way that the current flows through the conductors of the two layers in opposite orders in the two coils.

In one embodiment the displacement between the ends of each conductor in each layer is approximately 180°, each turn consists of a single conductor of each layer, and the first and second coils are displaced 180° from each other. In this embodiment the first and second coils form a coil set for one phase and similar coil sets are provided for two other phases each coil set being displaced 120° around the rotor. The conductors of each layer are spaced uniformly around the winding.

To enable the nature of the invention to be more readily understood various embodiments thereof will now be described by way of example with reference to the accompanying drawings, of which:

FIG. 1 shows a developed diagram of a three-phase stator winding for an A.C. generator in accordance with the present invention,

FIG. 2 shows a cross-sectional view inside elevation of an alternator of a type in which a stator winding in accordance with the present invention may be employed,

FIG. 3 shows an elemental ring of a stator winding structure in accordance with the present invention,

FIG. 4 is a cross-section through the ring shown in FIG. 3 taken on the line x—x,

FIG. 5 is a diagrammatic, partially cut-away, perspective view of a portion of a stator winding support structure formed of rings of a similar type to that shown in FIG. 3,

FIG. 6 is a similar view of FIG. 5 of an alternative stator winding support structure in which the elemental rings are composed of a plurality of segments,

FIG. 7 is a diagrammatic exploded view of a stator winding structure according to the invention comprising three concentric hollow cylinders,

FIG. 8 is a diagrammatic perspective view of one of the cylinders forming the support structure shown in FIG. 7,

FIG. 9 is an end elevation of the cylinder shown in FIG. 8,

FIG. 10 is a side elevation of the cylinder shown in FIGS. 8 and 9, and,

FIG. 11 is a perspective view of a stator winding showing the principle of an alternative form of winding to that shown in FIG. 1.

Referring first to FIG. 1, the winding diagram shown includes the complete coil set for one phase extending between the terminals A and A', but for the sake of clarity only shows the ends of the conductors for the other two phases B—B' and C—C'.

The coil set A—A' is made up of coils $a_1$—$a_1'$ and $a_2'$—$a_2$. The coil $a_1$–$a_1'$ is composed of 10 turns each of which consists of a conductor $X_1$ of one layer and a conductor $Y_1$ of the other layer. The coil $a_2'$—$a_2$ is composed of 10 turns each of which consists of a conductor $Y_2$ of the —layer and a conductor $X_2$ of the first layer. The two coils are connected in series by an end connection between $a_1'$ and $a_2'$ such that whereas the current in coil $a_1$—$a_1'$ flows first through a conductor $X_1$ and then through a conductor $Y_1$, that in the coil $a_2'$—$a_2$ flows first through a conductor $Y_2$ and then through a conductor $X_2$. The directions of current flow shown on the conductors are of course those for a particular instant of time since they will change as the rotor rotates and the rotor field cuts the conductors of the winding.

It will be noted that all the conductors $X_1$ and $X_2$ of the first layer, together with the corresponding conductors for the other two phases have their ends displaced from one another around the stator in one sense, while all the conductors $Y_1$ and $Y_2$ of the second layer, with the conductors of the other phases, have their ends displaced in the opposite sense. Each of the conductors of the first layer follows a helical path comprising a single helically disposed length of the same positive helix angle and each of the conductors of the second layer follows a helical path of the same negative helix angle. In this particular embodiment the helix angle is the same for both layers and the conductors in each layer are uniformly spaced around the stator.

It will further be noted that the interconnection of the coils $a_1$—$a_1'$ and $a_2'$—$a_2$ is such that the radial components of fluxes which they generate assist one another. This can conveniently be seen by considering the two diamond shapes which the conductors form at diametrically opposite points on the stator. Whereas the currents circulate clockwise about one diamond, they circulate anti-clockwise around the opposite diamond and hence the flux entering at one side of the stator leaves at the opposite side.

The individual conductors are each finely subdivided and twisted to minimise eddy current losses. The end connections, which may be solid, but might also be subdivided, are located in a region of lower field strength. For this purpose the length: diameter ratio of the winding is preferably greater than 1.5.

Referring to FIG. 2, the superconducting alternator shown comprises a superconducting rotor field winding and a non-superconducting stator winding, and illustrates the preferred type of machine in which stationary windings according to the present invention may be employed.

Whilst the stator conductors are shown as straight conductor bars in FIG. 2, for convenience, they would follow helical paths in windings according to the invention. As shown, the stator conductor bars may be directly fluid cooled. This view also makes clear the substantial amount by which the stator winding overlaps the rotor winding at both ends of the machine.

FIGS. 3 and 4 illustrate an elemental ring from a number of which a winding support structure according to the invention may be produced. The ring includes two circles of inclined holes, only four holes in each circle being shown for clarity. Rings of the type shown in FIGS. 3 and 4 may be assembled as shown in FIG. 5 to provide helical passages through the structure. Only one such passage is shown in FIG. 5, passing centrally through the wall of the resultant hollow cylinder produced by the ring assembly, but in an assembly of rings as shown in FIGS. 3 and 4, the radially outer holes 1 would form helices winding in one around the stator bore, whilst the radially inner holes 2 would form helices of opposite hand. Holes 1 are thus arranged to receive conductors of an outer layer of a helical winding of the type shown in FIG. 1, whilst holes 2 receive conductors of a radially inner layer. Conductors which have been preformed to a helical shape can be threaded through the helical passages, and short radial end connections may be made at the ends of the passages to form the turns.

The material of which the support structure is composed is non-magnetic and preferably non-conducting, a suitable example being densified hardwood.

In the construction shown in FIG. 6, each elemental ring may be composed of segments, such as segments 1*a*–8*a* of the end ring *a* shown. With this arrangement, the segments may be threaded over conductors one at a time (the conductors passing through holes in the segments, not shown) which may in some cases facilitate assembly.

An alternative winding support structure is shown in FIGS. 7–10, in which the resultant hollow cylindrical structure is composed of three cylinders 3, 4 and 5 juxtaposed about each other, but shown exploded in FIG. 7. This form of construction permits the conductors to be disposed in grooves on the outer surface of either or both inner cylinders. The path 6 of a helical groove for an inner layer conductor is indicated on cylinder 3, whilst the path 7 of a helical groove of opposite hand is shown on cylinder 4. One of the grooves in cylinder 7 is shown in more detail in FIG. 8–10, by way of example.

FIG. 11 exemplifies a form of winding according to the invention in which each conductor in a layer such as conductor 8 say, follows a path from end to end of the cylinder in two lengths, 8*a* and 8*b*. Length 8*a* follows a helical path of one hand whilst length 8*b* follows a helical path of opposite hand. Over each axial half of the winding, however, the conductor portions in the upper layer follow helices of opposite hand to the conductor portions of the lower layer.

Whilst the winding in FIG. 11 is shown as lying on the outside surface of a support cylinder 9, the drawing is primarily inteOded to indicate a possible alternative conductor arrangement to that shown in FIG. 1 for embodiments in accordance with the invention which are not specifically represented. The winding shown in FIG. 11 does in fact constitute an electrical and magnetic equivalent to that shown in FIG. 1, and could be mounted on a support structure of the type outlined in FIG. 7, for example.

In windings of either the form shown in FIG. 1 or FIG. 11, it should be noted that each conductor or conductor portion bears the same spatial relationship to the remaining conductors of the winding. The self-inductance of the coils formed, and the mutual inductances between coils, may thus be made equal, thus enabling symmetrically balanced windings to be produced.

The embodiment described with respect to FIG. 1 is a simple two-pole, three-phase winding, but it will be apparent that windings having any combination of the number of pole pairs, the number of phases and the supply frequency, fall within the scope of the invention. In all such possible arrangements, it is simply required that the pitch of the conductors in the various layers be arranged so that the ends of the conductors to be joined come to lie as far as possible adjacent one another.

I claim:

**1.** In an alternating current dynamo-electric machine having a rotor and a stationary alternating current winding, the improvement comprising: a non-magnetic hollow cylindrical support structure for said winding coaxial with said rotor, said winding including at least one pair of coaxial cylindrical layers of conductors carried by said support structure, each conductor having at least one section of helical formation, each conductor of a layer having the same spatial relationship to the other conductors of the winding and all the conductors of each layer being at the same radius from the axis of the rotor substantially throughout the lengths of the conductors, and end connections between the ends of the conductors of a first layer of the pair and the ends of the conductors of the second layer of the pair forming turns of the winding each of which turns comprises at least one conductor of the first layer connected in series with at least one conductor of the second layer, each end connection extending substantially radially between a conductor end of the first layer and an adjacent conductor end of the second layer.

**2.** In a machine as claimed in claim 1, each conductor comprising a single helical section extending from end to end of the winding, the helical sections of the first layer being of opposite sense to the helical sections of the second layer.

**3.** In a machine as claimed in claim 1, each conductor of each layer comprising a first and second helical section of equal length and opposite sense, the first and second sections of the conductors of the second layer overlying and being of opposite sense to the first and second sections, respectively, of the conductors of the first layer.

**4.** In a machine as claimed in claim 1, the rotor having a magnetic field with an integral number of pole pairs, the stationary winding being a multi-phase winding having a set of two electrically-connected coils for each phase, each turn of each coil of a set comprising a conductor of the first layer in series with a conductor of the second layer, the conductors of the two layers having equal helix angles, and the center of each conductor being circumferentially displaced from the end of the said conductor by approximately $\pi/2$ electrical radians in respect of the said rotor field.

**5.** In a machine as claimed in claim 1 the rotor having a magnetic field with an integral number of pole pairs, the stationary winding being a multiphase winding having two-electrically-connected phase bands displaced relative to each other around the circumference of the winding by approximately $\pi$ radians in respect of the rotor field.

**6.** In a machine as claimed in claim 1, the hollow cylindrical support structure is provided with helical passages through the wall of the structure in which passages the conductors are retained.

**7.** In a machine as claimed in claim 1, the hollow cylindrical support structure being composed of a plurality of elemental rings, each of which has, for each layer of conductors, a circle of inclined holes, the holes in successive rings being in alignment whereby helical passages are formed through the assembly.

**8.** In a machine as claimed in claim 1, the hollow cylindrical support structure being composed of at least two concentric hollow cylinders juxtapose one about the other.

**9.** In a machine as claimed in claim 1, the hollow cylindrical support structure being composed of at least two concentric hollow cylinders juxtaposed one about the other, at least one of the cylinders having helical passages through its wall.

**10.** In a machine as claimed in claim 1, the hollow cylindrical support structure being composed of at least two concentric hollow cylinders juxtaposed one about the other, at least one of the cylinders comprising a plurality of elemental rings and each ring comprising a plurality of segments, adjacent segments in the axial direction of adjoining rings being staggered circumferentially whereby a helically extending stack of segments extends from each segment of an end ring of the assembly.

**11.** In a machine as claimed in claim 1, the hollow cylindrical support structure being composed of at least two concentric hollow cylinders juxtaposed one about the other, the curved surface of at least one cylinder having helically disposed grooves whereby helical passages through the structure are formed, the surrounding walls of which passages are formed by the wall, or walls, of each groove in combination with the adjacent curve surface of a cylinder adjoining the groove surface.

**12.** In a machine as claimed in claim 1, said rotor carrying a superconducting rotor field winding.

**13.** In a machine as claimed in claim 12, the axial length of the stationary winding being substantially greater than that of the rotor winding and the stationary winding extending beyond both ends of the rotor winding.

**14.** In a machine as claimed in claim 1, said rotor having an iron core, a stator of magnetic material surrounding said rotor, and a cylindrical air-gap region between said stator and said rotor, said stationary winding being located in said air-gap region.

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