July 13, 1965 A. U. WELCH 3,195,087

ELECTRICAL SHUNT REACTOR

Filed Feb. 27, 1963

2 Sheets-Sheet 1

Fig.1.

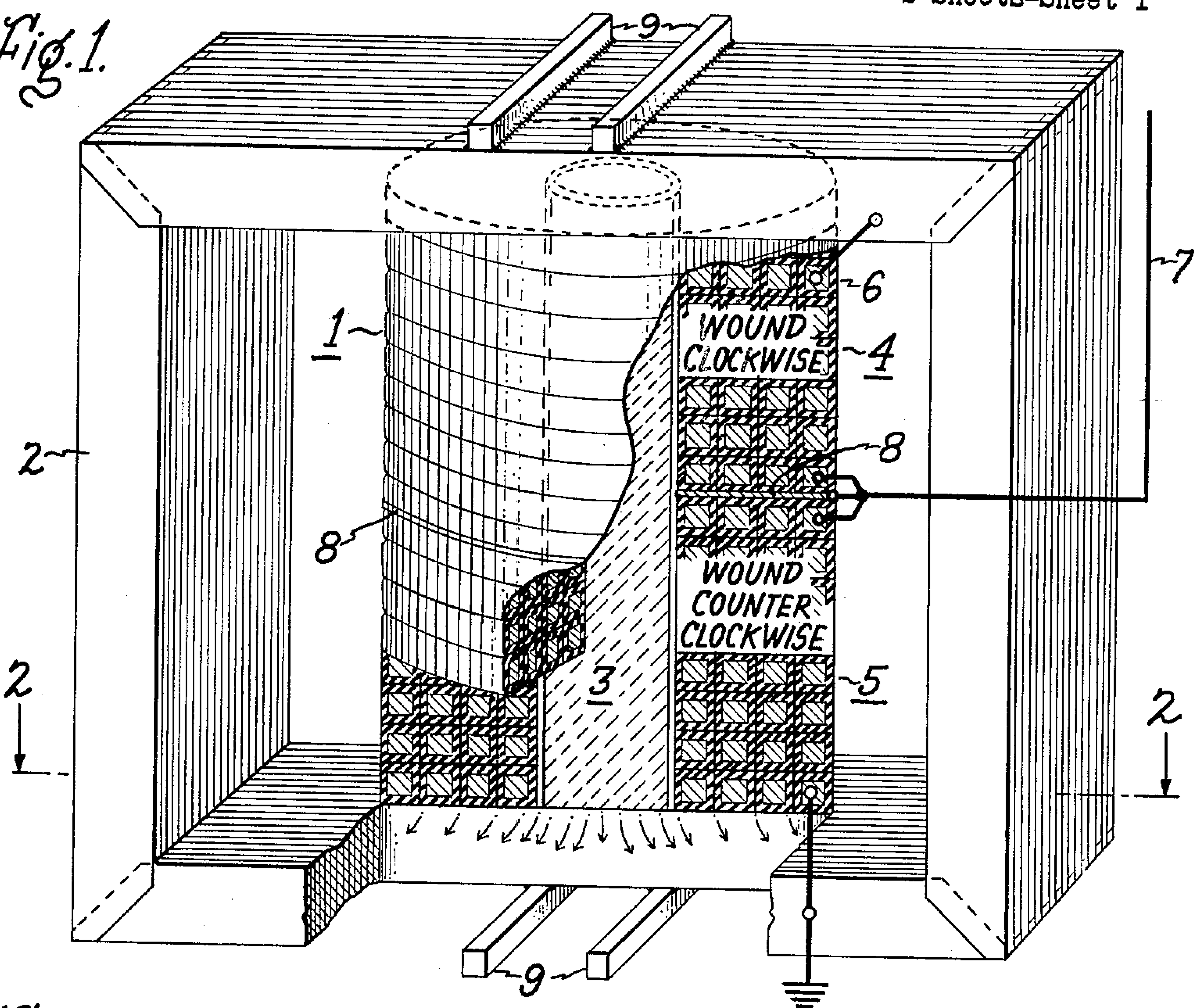

Fig.2.

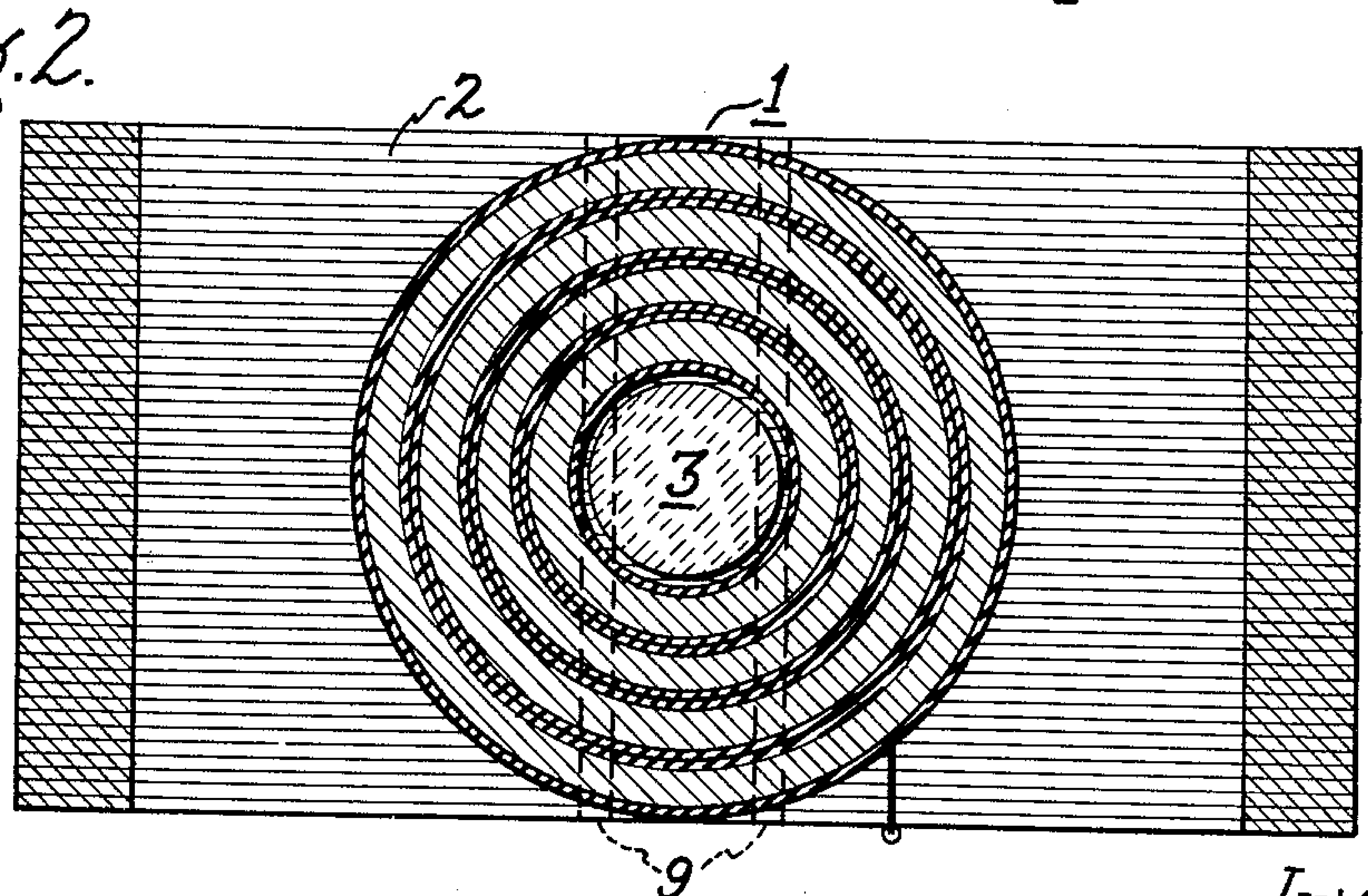

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Fig. 3.

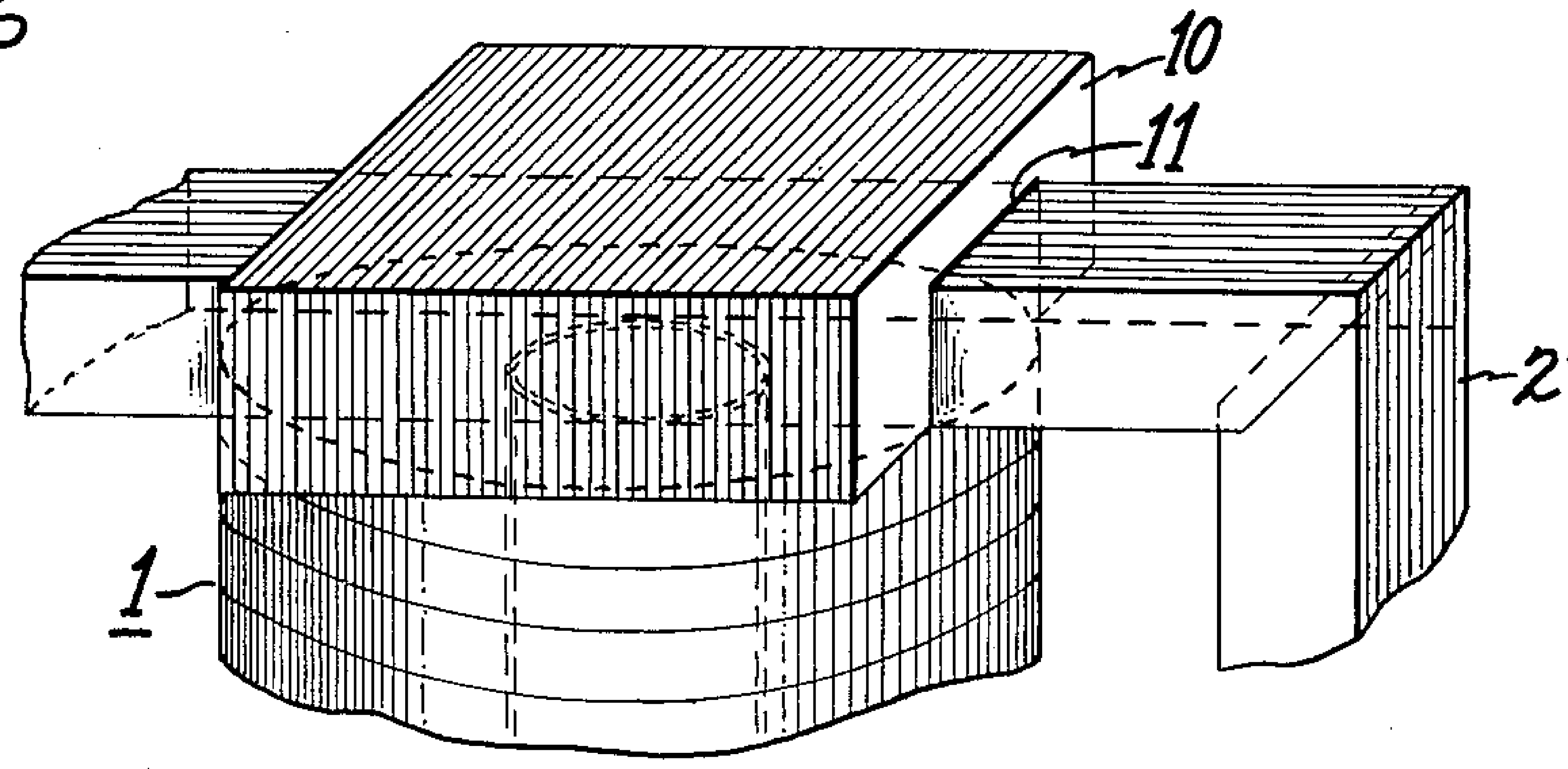
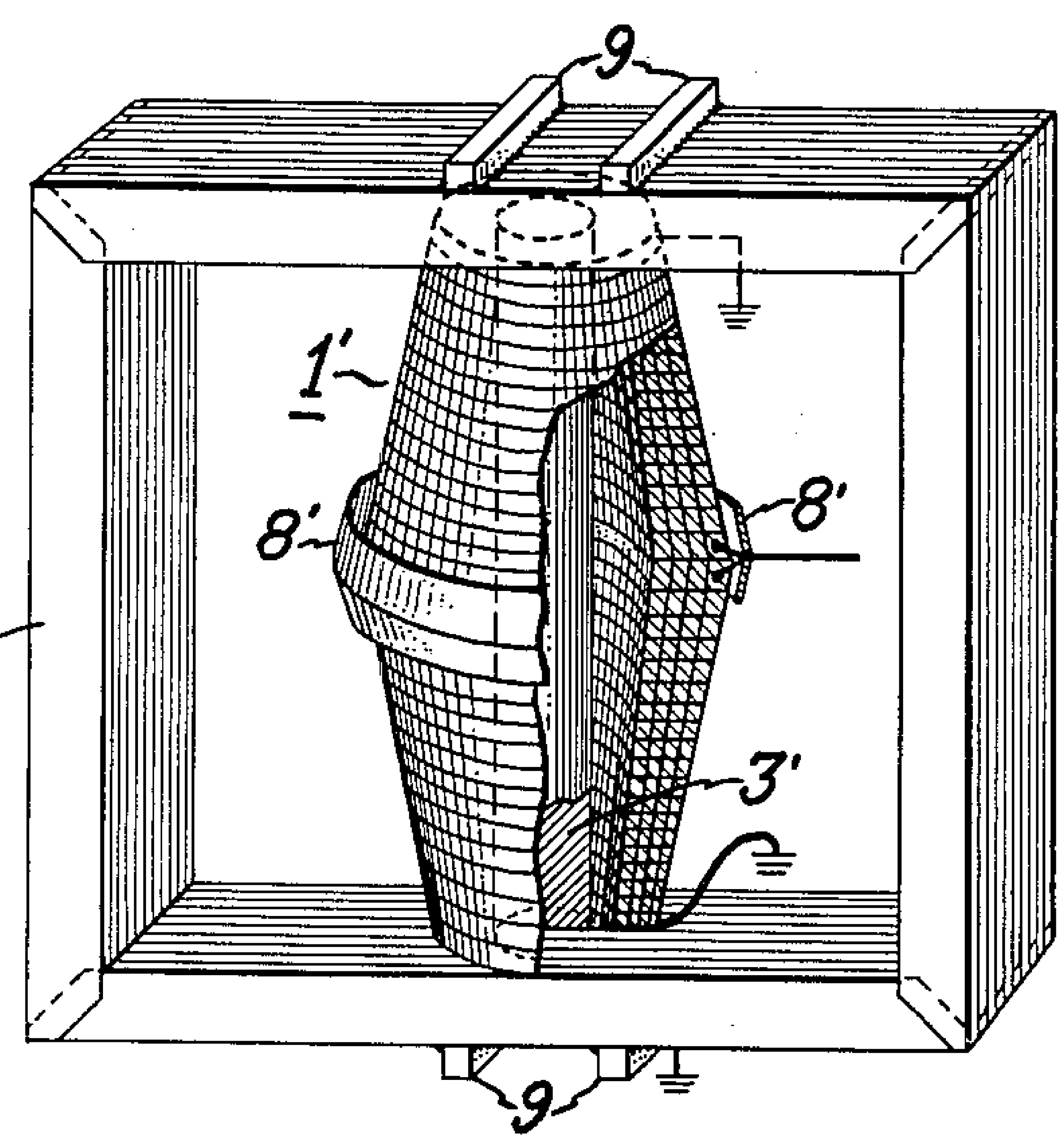


Fig. 4.



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ELECTRICAL SHUNT REACTOR

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5 Claims. (Cl. 336—84)

This invention relates to electrical reactors and more particularly to improvements in EHV shunt reactors.

EHV is an abbreviation of extra high voltage which in the context of commercial frequency electric power transmission systems means voltages exceeding about 230 kilovolts. The upper limit of EHV is not as well defined as the lower limit between it and ordinary high voltage systems but EHV systems have been operated at voltages over 700 kilovolts and systems of 800 kilovolts will be operative in the near future.

A shunt reactor, as the term is used herein, is an inductive winding for connection across or in shunt with a high voltage or EHV transmission line. Its principal purpose is to supply or neutralize the charging current of such a transmission line which increases rapidly as the line voltage increases. In order that it will have a high magnetizing current it does not have a ferromagnetic core as with conventional stationary induction apparatus and consequently it is sometimes called a "coreless" reactor.

A problem with EHV (and even high voltage) shunt reactors, which are characterized by large size, is that the magnetic flux near the ends of the reactor winding or coil deviates from the axial direction and has a cross direction relative to the axis through the coil. This cross flux interacts with the current in the adjacent conductor turns of the coil to produce high axial mechanical compression of the coil structure and sets the structure into vibration of destructive amplitude. Such compressive force is also high enough to damage known forms of coil insulation.

In carrying out my invention in one preferred embodiment the compressive effect of cross flux upon the coil itself is eliminated or minimized by increasing the magnetic permeability or decreasing the magnetic reluctance of the magnetic circuit of the reactor external to its coil or winding window and particularly adjacent the end faces thereof so as to induce an axial direction of the flux within the coil. This is accomplished by means of an extra wide but relatively thin magnetic yoke member (or members) which not only functions as a magnetic shield for the coil as just described but also functions as an electrostatic shield for the winding under impulse conditions.

In order to prevent the wide and flat yoke members from applying crushing forces to the coil due to the magnetic attraction between the yoke parts at the ends of the coil a paramagnetic or nonmagnetic structural column of rigid material is provided in the coil window for resisting the attractive or compressive forces produced by the yoke parts.

An object of the invention is to provide a new and improved coreless electrical reactor having an external magnetic yoke.

Another object of the invention is to provide a new and improved EHV shunt reactor.

A further object of the invention is to minimize noise and vibration and substantially eliminate the compressive effect of cross flux upon the coil in a high voltage reactor winding.

The invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing,

FIG. 1 is an elevation view of an embodiment of the invention,

FIG. 2 is a sectional view taken on line 2—2 of FIG. 1,

FIG. 3 is a perspective view of a modified yoke construction, and

FIG. 4 is a view similar to FIG. 1 of a modification employing a conductive or semi-conductive central nonmagnetic supporting column and a tapering coil stack.

Referring now to the drawing, and more particularly to FIG. 1, the reactor comprises a winding **1**, a magnetic steel yoke **2** and a nonmagnetic insulator column **3** in the winding window. The winding **1** consists of upper and lower portions or coils **4** and **5** as viewed in the drawing, these being wound in opposite directions and electrically connected in parallel. As indicated, for example, the upper portion **4** is wound clockwise and the lower portion **5** is wound counterclockwise. Each portion is in turn divided into disc or pancake coil sections **6** which may be identical throughout the coils and winding. The adjacent ends of the portions **4** and **5** at the center of the winding **1** are interconnected to form a center tap or line lead **7** to which may be connected a conductive or metallic static plate or electrostatic shield **8** embedded in the winding **1** at the center for electrostatically shielding its line potential end and so as to grade the voltage stress distribution in its sections near the line end under impulse voltage conditions. Static plate **8** preferably has radial slits or is in the form of narrow slits to avoid excessive eddy currents. The sections **6** in each of the winding portions are serially connected. The outer ends of the portions **4** and **5** are connected to the magnetic steel yoke **2** which is grounded so as to form the other or ground terminal of the reactor.

It will thus be seen that the portions of coils **4** and **5** of the winding **1** constitute two electrically parallel conductive paths while at the same time these portions are magnetically in series in that their magnetomotive forces are additive in a common magnetic circuit.

As shown most clearly in FIG. 1 the external magnetic steel yoke is essentially a rectangular frame surrounding the winding **1** and formed of end and side legs of wide and flat cross-sectional configuration. Unlike cores of conventional stationary induction apparatus, the four legs of the yoke **2** are relatively in a direction parallel to the laminations and substantially wider in a direction perpendicular to its laminations. This latter feature is shown most clearly in FIG. 2. Thus in the direction perpendicular to its laminations as shown in FIG. 2 the yoke is at least as wide and preferably somewhat wider than the outside diameter of the winding **1**. As a consequence of this construction, there is little or no tendency for the magnetic flux in the winding **1** either in its window or in the winding itself to assume a direction other than parallel to the axis of the winding which, of course, is parallel to the plane of the drawing and vertical in FIG. 1 and perpendicular to the plane of the drawing in FIG. 2. This is indicated by the direction of the light dashed lines representing the flux lines at the ends of the winding **1** as they enter and leave the yoke **2**. As will be appreciated by inspection of FIG. 2, this action is, of course, true in all radial directions at the end faces of the winding **1**.

The horizontal portions of the yoke **2** which lie across the ends of the winding being at opposite instantaneous magnetic polarity have a strong magnetic attraction which will tend to produce an axial crushing force on the winding **1** because the yoke parts being narrow parallel to the plane of their laminations are comparatively limber beams whose deflection is excessive under such force. This is prevented by the central structural column **3** of paramagnetic insulating material such, for example, as porcelain which is strong in compression and which extends through the length of the winding window and has a diameter substantially equal to the inner diameter of the winding and has its end faces substantially flush with the end faces of the winding 1.

The yoke member not only magnetically shields the winding 1 by preventing cross flux therein as indicated by the dashed lines representative of the direction of the flux lines, but it also acts as an electrostatic, or potential stress distribution grading, shield for the grounded ends of the winding 1 because of its substantial surface and because it is at the same potential as the opposite ends of the winding 1 by being directly electrically connected thereto. Inasmuch as there is no difference in potential between the ends of the winding 1 and the magnetic yoke little or no insulation is necessary between the ends of the winding and the yoke. This, of course, also contributes to the magnetic shielding action of the yoke because the closer the magnetic material in the yoke is to the ends of the winding the more it contributes to maintaining the desired axial direction of the magnetic flux in the winding.

When insulating material is used for the column 3, grounded metal is so far away from the disc coil stack that there is comparatively uniform transient voltage distribution along the stack and the stress between adjacent coil sections is comparatively small. Therefore, it is possible to use a rather high ratio of conductor to insulation (high space factor coil) and this leads to a coil design more economical than the layer windings conventionally used in power transformers.

Because the yoke members are of essentially the width of the outside diameter of the coil, as shown in FIG. 2, in order to pick up its entire magnetic field and avoid radial fluxes, this width is obviously larger than the diameter of the supporting column 3 and, therefore, it is necessary to transfer the force from the outer unsupported laminations over to the column 3. One way of accomplishing this is the use of very stiff steel beams 9 placed transversely across the laminations and welded continuously to the edges of all the laminations.

A modified yoke construction which also performs the function of the transverse beams 9 is shown in FIG. 3, where the main yoke 2′ is of narrower construction, its width perpendicular to the plane of the laminations being essentially the same as the diameter of the supporting column 3 of the inner diameter of the coil 1. This is combined with a subsidiary or auxiliary C-shaped yoke member 10 having similarly shaped laminations extending crosswise to the laminations of the main yoke member 2′. As shown the ends of the legs of the C-shaped part 10 cover the remaining otherwise uncovered end faces of the coil 1. However, magnetic forces on the C-shaped member 10 are transmitted to the main yoke part and thence to the central supporting column 3. In order to prevent short circuiting of the laminations electrical insulating material 11 is placed between the main yoke part 2′ and the C-shaped yoke part 10 where they cross. This is made thin enough so that the additional reluctance of the magnetic flux transfer is small.

In the modification shown in FIG. 4, the central supporting column 3′ is made of conducting material or semiconducting material. Thus it can be made of laminated high resistivity nonmagnetic steel, for example Type 302 stainless steel, or it can be made of concrete. It is, however, essential that like the insulating column 3 of FIG. 1 it be nonmagnetic or paramagnetic. In this figure the coil or winding 1′ is made of tapering construction so as to maintain or provide large radial clearance between the central portion of the winding which is at line potential and the conducting column 3′ which is at ground potential. However, such a construction is substantially more expensive than the construction shown in FIG. 1 where the coil or winding is cylindrical and the central supporting column is a nonconductor. Because the supporting column 3′ is a conductor at ground potential it is preferable to use a rib type electrostatic shield 8′ surrounding the line end of the winding instead of a static plate embedded in the winding as in FIG. 1.

While single phase embodiments of the invention have been shown and described it will, of course, be obvious that they can be any phase of a polyphase reactor.

While there have been shown and described particular embodiments of the invention, it will be obvious to those skilled in the art that changes and modifications may be made without departing from the invention, and therefore it is intended by the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A shunt reactor having a voltage rating of the order of at least 200 kilovolts comprising, in combination, a conductive winding having a pair of oppositely wound coils axially juxtaposed on a common core and having a common external magnetic circuit, said core being formed of a high reluctance structurally strong electrical insulating material and said common external magnetic circuit being formed of a low reluctance electrical conducting material, means electrically connecting juxtaposed ends of said coils together and opposite end points of said coils to said low reluctance conducting material thereby to connect said coils electrically in parallel and magnetically in series, said low resistance electrical conducting material acting as both magnetic and electrostatic shielding means for said coils, said high reluctance insulating core acting as a structural column for preventing said low reluctance external magnetic circuit from applying magnetically produced mechanically compressive force to said coils.

2. A reactor as in claim 1 including in addition an electrically conductive electrostatic shield in the region of the juxtaposed ends of said coils and electrically connected to said ends.

3. A high voltage coreless shunt reactor having a conductive winding, a structurally strong column of paramagnetic material inside said winding and having opposite end faces substantially flush with opposite end faces of said winding, laminated magnetic main yoke members extending transversely and diametrically across said column and winding end faces with the laminations thereof edgewise of said column and winding end faces, said main yoke members being as thick in a direction perpendicular to their laminations as the diameter of said column, auxiliary laminated C-shaped yoke members fitted over said main yoke members opposite the end faces of said winding, the laminations of the auxiliary yoke members extending edgewise to said end faces and crosswise of the laminations of said main yoke members, the width of said auxiliary yoke members in a direction perpendicular to their laminations being at least equal to the outside diameter of said winding, and electrical insulation between said main and auxiliary yoke members.

4. A high voltage shunt reactor comprising, in combination, a circular cross section conductive winding having inner and outer diameters tapering between maximums at its center at high potential and minimums at its ends at ground potential, magnetic yoke members extending transversely across its ends and a conductive paramagnetic column of a diameter substantially equal to the minimum inner diameter of said winding extending through said winding between said yoke members.

5. An EHV shunt reactor comprising, in combination, a rectangular magnetic yoke frame of flat stacked laminations of silicon steel, a porcelain column extending across the window of said frame perpendicular to and in contact with edges of the laminations of two of its opposite sides and midway between and parallel to its other two sides, said porcelain column having a circular cross section whose diameter is substantially less than the thickness of said frame perpendicular to the plane of its laminations, a conductive winding comprising duplicate portions mounted coaxially end to end on said porcelain column, adjacent ends of said portions being electrically connected together to constitute a line terminal at the center of said

winding, opposite ends of said portions being closely adjacent to and electrically connected to said steel frame so as to constitute a grounded line terminal for said winding, said portions being reversely wound so that they are magnetically in series although electrically in parallel, the thickness of said frame perpendicular to the plane of said laminations being at least as great as the outside diameter of said winding whereby said frame magnetically shields said winding by preventing cross axial direction magnetic flux through it and electrically shielding said winding under impulse voltage conditions, and a conductive electrostatic shield encircling said core at the center of said winding and electrically connected to said line terminal.

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