

[54] **HIGH VOLTAGE COIL ASSEMBLY FOR ELECTRIC INDUCTION APPARATUS**

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[51] Int. Cl. **H01f 15/04**

[58] Field of Search **336/69, 70, 84**

[56] **References Cited**

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[57] **ABSTRACT**

In a high voltage winding assembly of the balanced multi-layer type, axially juxtaposed winding sections each having a line terminal connected to its outermost coil layer are connected in series circuit relation at their innermost coil layers and wound upon a common supporting cylinder of wrapped insulating material. Interwound in the supporting cylinder are a plurality of radially spaced shielding sleeves of electrically conductive material, and at opposite ends of the winding each sleeve is flared radially outward and over opposite ends of the winding to connect with one of a series of axially spaced apart shielding rings. The radially innermost shielding sleeve is connected to ground and the radially outermost shielding sleeve is connected to the winding midpoint between the serially connected, balanced winding sections.

9 Claims, 8 Drawing Figures

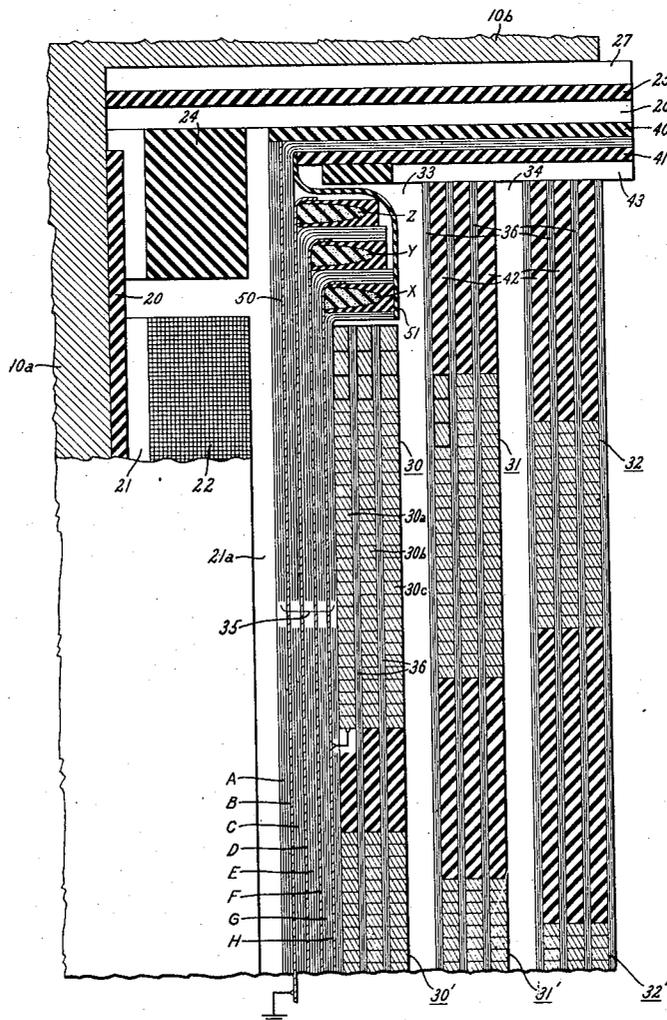


FIG. 1.

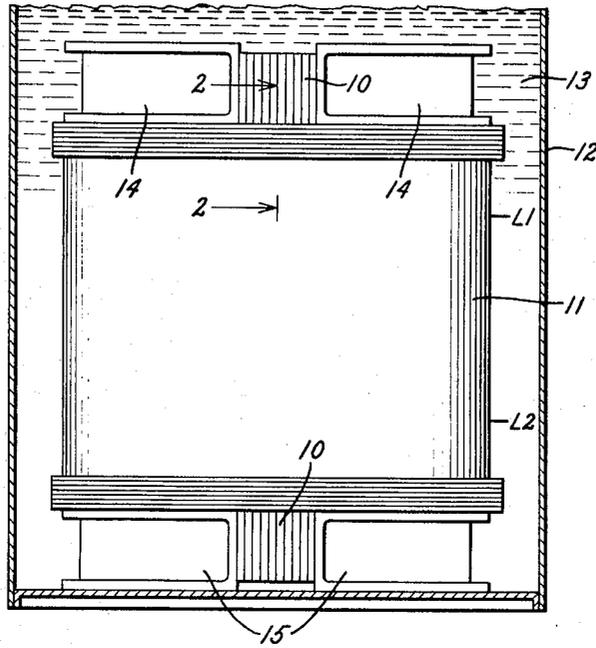


FIG. 3.

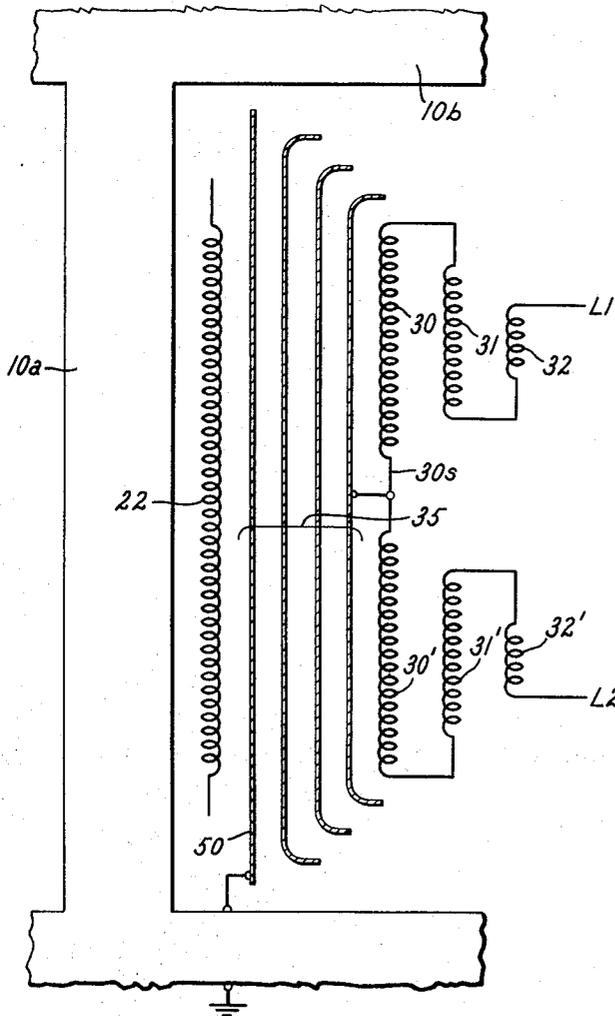


FIG. 4A.

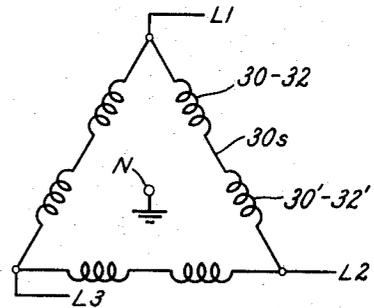
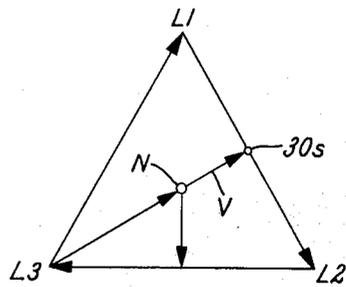
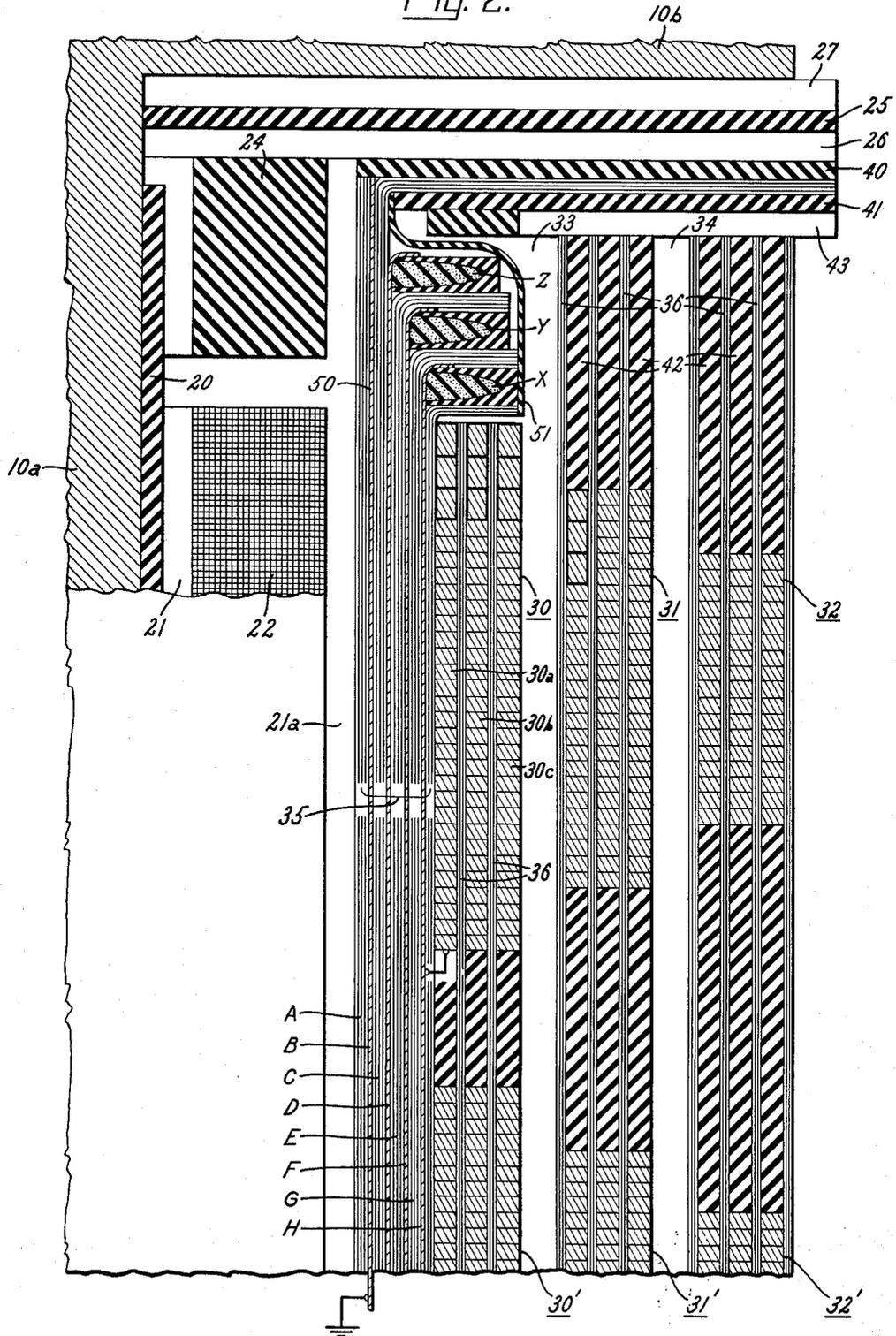


FIG. 4B.



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FIG. 2.



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FIG. 5A.

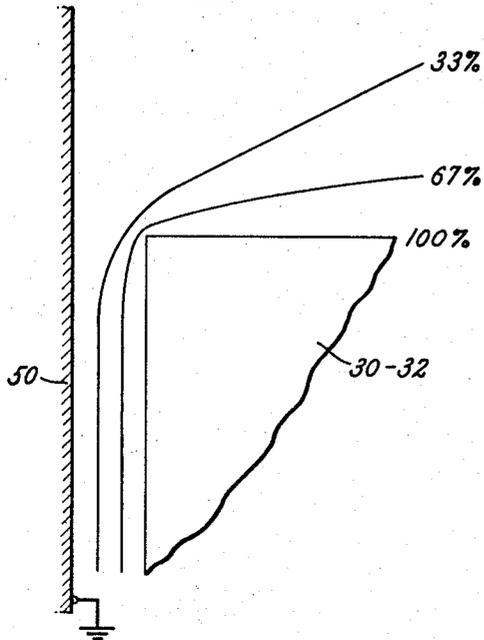


FIG. 5B.

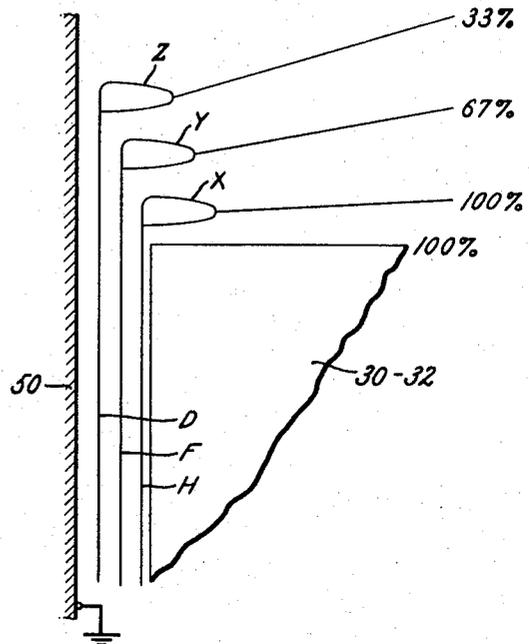
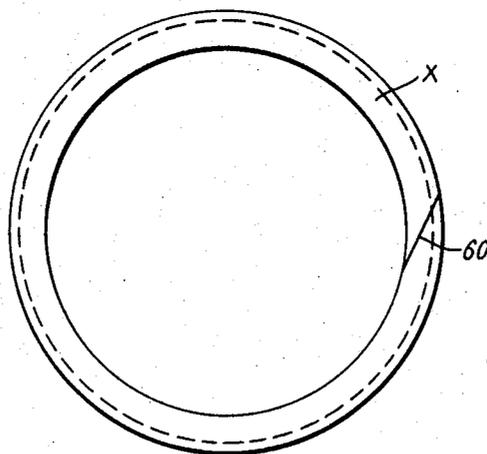


FIG. 6.



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HIGH VOLTAGE COIL ASSEMBLY FOR ELECTRIC INDUCTION APPARATUS

My invention relates to electric induction apparatus, such as transformers and reactors, and particularly to high voltage coil assemblies for such apparatus. The following U.S. patents are representative of published prior art presently known to applicant: No. 1585448-Weed; No. 1940840-Bellaschi; No. 1940864-Hodnette; No. 2288201-Meyerhans.

When high voltage power transformers or the like are connected in delta to a three phase transmission or distribution line it is known that voltage stress between the high voltage winding and adjacent grounded metal parts, such as core or ground shield, may be reduced by utilizing two axially juxtaposed multi-layer helical (i.e., concentric layer) winding sections. The two winding sections are connected in series circuit relation by joining the centrally positioned ends of their inner layers or coils. The axially remote terminal ends of the radially outer coils are connected to separate lines of the three phase circuit. As in single-ended helical layer windings, such a double-ended or "balanced" winding is possessed of relatively high series capacitance and is therefore useful in high voltage applications where impulse voltage distribution is critical in determining insulation requirements.

Under impulse or other high frequency surge conditions a balanced multiple layer winding has relatively low voltage stress between the core and axially remote ends of the inner layer of high voltage winding. This is because the radially outer coils or layers, relatively remote from grounded parts, absorb a disproportionately greater part of a steep wave voltage even though series capacitance does tend to distribute the voltage drop between line terminals. Such a winding therefore offers the possibility that somewhat less main gap insulation may be used than in single-ended helical windings. At relatively low power frequency, however, the outer winding coils absorb a lesser portion of total voltage from line to ground. Thus the limiting factor in respect to gap insulation may be voltage stress at the ends of the inner coil layer under power frequency or under applied potential test conditions.

In high voltage power transformers it is usual practice to provide a rigid and separately fabricated insulating cylinder to support each winding assembly, and the high voltage cylinder is thus positioned concentrically in the "main gap" between low voltage and high voltage windings. Such substantial and rigid insulation usually has the form of high quality dielectric pressboard. Pressboard cylinders are time consuming and expensive to make and it is therefore desirable, if possible, to provide less expensive main gap insulation, as by wrapping flexible and inexpensive insulating paper as a support for the high voltage winding.

Accordingly, it is a principal object of my invention to provide in electric induction apparatus having balanced high voltage windings, improved insulating means for the main gap between the high voltage winding, low voltage winding, and adjacent grounded metal parts.

It is another object of my invention to eliminate rigid, separately fabricated main gap insulation in certain high voltage power transformers designed for three phase delta connection.

It is a more specific object of my invention to provide an improved balanced coil assembly for high voltage induction apparatus wherein main gap insulation and stress control elements are built integrally into the coil assembly.

It is still another object of my invention to minimize the radial dimension of main gap insulation in high voltage electric induction apparatus having balanced multi-layer windings, thereby to reduce the main gap and to improve the space factor of the apparatus.

In carrying out my invention in one preferred embodiment I utilize a high voltage power transformer having concentric low voltage and high voltage windings with a "main gap" therebetween. The radially outer high voltage winding is of the balanced multi-layer type, i.e., two axially juxtaposed sections of multi-layer helical winding serially connected between two

line or high voltage terminals. At its inner periphery this high voltage winding is wrapped upon an insulating cylinder formed of a plurality of layers of insulating paper having interwound therewith at least several radially spaced layers or sleeves of conductive material, as metal foil or conductive paint. The conductive sleeves are each interrupted circumferentially to preclude formation of short circuited turns and thus constitute a coaxial capacitive voltage divider for disposition in the main gap of the transformer. At their axial ends the cylindrical conductive sleeves are extended beyond and flared radially outward over the axial ends of at least the longest helical coils. Preferably the innermost conductive sleeve is grounded and the outermost is connected electrically to the series circuit juncture between balanced high voltage winding sections.

My invention will be more fully understood and its various objects and advantages further appreciated by referring now to the following detailed specification taken in conjunction with the accompanying drawing in which:

FIG. 1 is an end elevational view of a high voltage electric power transformer showing the enclosing casing in cross section;

FIG. 2 is a fragmentary cross sectional view of one core leg and winding assembly taken along the line 2—2 of FIG. 1;

FIG. 3 is a schematic circuit diagram of the low voltage and high voltage windings on a single leg of the transformer shown at FIGS. 1 and 2;

FIG. 4A is a schematic circuit diagram of typical delta-connected windings in a three-phase transformer; FIG. 4B is a vectorial representation of line-to-line and line-to-ground voltage characteristic of the circuit shown at FIG. 4A;

FIGS. 5A and 5B are graphical representations of dielectric stress conditions at the axial ends of the transformer main gap with and without certain shielding rings shown at FIG. 2; and

FIG. 6 is a plan view of a single shielding ring of a type shown at FIG. 2.

In the drawing I have shown at FIG. 1 in end elevational view a power transformer comprising a magnetizable core 10 and a winding assembly 11 disposed in an enclosing tank 12 and immersed in a dielectric fluid 13. In end elevation only one winding assembly of the transformer is visible, but it will be understood by those skilled in the art that in a three phase transformer three such winding assemblies are commonly disposed side by side on a core having vertical core legs in parallel spaced relation magnetically joined together by upper and lower horizontal yokes. Such a three phase power transformer is shown in U.S. Pat. No. 3,353,129-Leibinger. In FIG. 1 the core yokes are shown in end elevation and are disposed between upper and lower pairs of yoke clamps 14 and 15, respectively.

Referring now to FIG. 2, I have shown a partial cross-sectional view of the core and winding assembly in the axial plane of the core 10, the winding assembly being illustrated in one upper corner of a core window defined by the core leg 10a and the upper core yoke 10b. It will be understood by those skilled in the art that the fragmentary cross-sectional view of the winding assembly is shown at only one side of the core leg axis, and that the assembly is cylindrical and therefore symmetrical at the other side of the core leg axis.

In the winding assembly shown at FIG. 2 the magnetizable core leg 10a is surrounded by a close fitting cylinder 20 of insulating material, such as a rigid structure of cellulosic composition commonly known as pressboard or a bonded paper cylinder. Surrounding the insulating cylinder 20 and radially spaced therefrom to form an annular duct 21 for the passage of dielectric cooling fluid there is positioned a cylindrical low voltage winding 22. Preferably the low voltage winding 22, shown only schematically on the drawing, is wound as a single axial helix formed of multi-strand conductor, as is well known to those skilled in the art. At its axially remote ends the low voltage winding 22 is spaced from the core yokes and in the end spaces axially beyond the low voltage winding 22 I place annular end rings 24 of insulating material, one such end ring

being shown at FIG. 2. Beyond the insulating end ring 24 and between it and the core yoke 10b I provide a disk-shaped insulating collar 25, preferably formed of pressboard and spaced as shown from both the yoke 10b and the low voltage end ring 24 to provide annular ducts 26 and 27 for the flow of dielectric cooling fluid.

Radially outside the low voltage winding 22 and between the upper and lower pressboard disks or collars 25 I have shown an axially sectionalized high voltage winding of the multiple layer helical type, only the upper winding section being shown in full. In each winding section the individual helical coils or winding layers are disposed in three radially spaced groups, as the coil groups 30, 31, 32, in the upper section and groups 30', 31', 32' in the balanced lower section. The annular spaces between these concentric coil groups constitute ducts 33, 34 for the flow of dielectric cooling fluid. It will be understood by those skilled in the art that the radially spaced coil groups are supported one upon the other by spacers (not shown) in the ducts 33, 34. The entire high voltage winding is wound upon an insulating cylinder 35 which constitutes the principal solid insulation in the main gap and which will be more fully described hereinafter.

For the purpose of illustrating a typical axially balanced, multi-layer helical winding I have shown at FIG. 2 each coil group composed of three concentric helical coils, such as coils 30a, 30b, and 30c, in the coil group 30, the individual coils being separated by suitable layer insulation 36 which may be of paper. As indicated in the drawing, the several coil groups constituting the high voltage winding are of progressively less axial length as their radial distance from the core leg increases. Preferably the end turns of at least the several innermost coils of the high voltage winding are more heavily insulated than the intermediate turns, thereby to act as buffer turns in resisting breakdown to ground upon the imposition of steep wave front surge voltages, or low frequency dielectric tests. In the radially outer coil groups 31 and 32 the paper layer insulation 36 is extended axially beyond the end of the coils to a point near a pair of spaced apart end collars 40 and 41 formed of insulating pressboard. In these end regions and between the layer insulation 36 I provide end rings 42, preferably formed of insulating pressboard. Between these end rings and the end collar 41 there is provided an annular liquid passage 43.

To illustrate electrical connection of the two-section, balanced, multiple-layer, high voltage winding structurally illustrated at FIG. 2, I have shown at FIG. 3 a schematic circuit diagram of the low voltage and high voltage windings of FIG. 2 in their relation to the core window formed by the core leg 10a and core yoke 10b. At FIG. 3 the low voltage winding 22 is shown as a single helical coil, the main gap insulating cylinder 35 is shown schematically and the balanced high voltage winding sections 30-32 and 30'-32', are shown connected in series circuit relation between line terminals L1 and L2. The series circuit connection between the axially spaced apart high voltage winding sections (each comprising three groups of coils) is made between the juxtaposed ends of the innermost coils in groups 30 and 30', as by a connecting strap 30s. As schematically illustrated at FIG. 3 the radially outer coil groups (as 31, 32) are of progressively less axial length and in each section of the balanced winding these outer coils are serially interposed between the series-connected inner coils 30, 30' and the respective line terminals L1, L2.

The balanced high voltage winding assembly shown at FIGS. 2 and 3 is of a design ordinarily employed as one phase winding in a three phase transformer with delta connection as for example the windings of a three-legged transformer each winding assembly of which is constructed in the manner illustrated at FIG. 2. Such a typical delta connection is shown schematically at FIG. 4A wherein three similar transformer windings are shown connected in delta circuit relation between three-phase line conductors L1, L2 and L3. By reference numerals corresponding to those at FIG. 3 there is indicated correspondence of the winding between terminals

L1 and L2 in FIG. 4A to the same winding illustrated separately at FIG. 3. At FIG. 4A I have also indicated a grounded system neutral point N; at FIG. 4B I have shown diagrammatically the vectorial voltage relationship of the grounded neutral point N to the line terminals L1, L2 and L3 and to the winding midpoint, i.e., at the series circuit connector 30s in the winding between L1 and L2. It may be observed from FIG. 4B that in such a delta connected winding the voltage normally appearing between the system neutral (which may for example be represented by the grounded transformer core 10) and the delta winding midpoint at 30s may be represented by a voltage vector V substantially less in magnitude than the line-to-line voltage. Similarly the voltage difference in normal operation between the grounded neutral point N and any intermediate point in one of the balanced winding sections (as an intermediate point in winding section 30-32) is substantially less than full line-to-line voltage.

It will now be evident to those skilled in the art that in normal operation at power frequency the axially remote ends of the innermost high voltage winding layers (as the coil 30a and its counterpart in coil group 30') are the points of highest voltage on these innermost coils, but are substantially below the terminal voltages of the lines L1, L2 with respect to ground. In the high voltage winding it is these innermost coils which are most closely adjacent to grounded or relatively low voltage parts, such as the primary winding 22 and the transformer core 10. Also, it is common practice to interpose between the low voltage winding and the high voltage winding a cylindrical metallic or conductive sleeve 50 connected to ground as indicated at FIG. 2 and 3. The innermost helical coils of the balanced high voltage winding sections are concentric with this "ground shield" 50 and it is therefore the axially remote highest voltage ends of the innermost coils at which the critical voltage stress to ground occurs in normal power frequency operation. This high stress region exists adjacent the axially endmost conductors of the coil group 30, and for this reason the end or "buffer" conductors have additional turn-to-turn insulation. However even in this region at the core window corners with high stress on the dielectrics due to large voltage gradients, the turn-to-ground voltage is substantially less than line voltage in a balanced, delta-connected transformer. Such a transformer therefore offers the possibility of reduced cost and improved space factor by providing main gap insulation 35 of reduced radial thickness and of a construction which may be wound in a single operation with the high voltage winding.

High frequency or steep front impulse and surge voltages are not likely to create limiting dielectric stress conditions at the opposite axial ends of the innermost coils of a balanced multi-layer winding. Even though the ends of these inner coils lie quite near to the core of other grounded parts, and even though impulse voltage gradient is not unduly steep in a multilayer winding (due to inherent series capacitance), a major part of surge or impulse voltage drop is absorbed in the radially outer coils, as in coil groups 31, 32 at FIG. 2. Thus in a balanced layer winding the limiting voltage stress condition at the ends of the inner coils or layers usually occurs at normal operating voltage and frequency, or under applied potential test conditions. In such tests the axially remote ends of the coil groups 30, 30', are at substantially the same voltage as that imposed upon the line terminals. It is this consideration which renders it desirable to supplement a reduced main gap insulation with means to effect a favorable distribution of voltage stress in the main gap, particularly in the region of the winding layer ends and the core window corners.

At FIG. 2 I have shown main gap insulating cylinder 35 wound integrally with the balanced, sectional, high voltage winding sections 30-32 and 30'-32'. The cylinder 35 incorporates the ground shield 50 and capacitive means to influence favorably electrostatic voltage distribution between the high voltage winding and adjacent grounded parts, particularly at the axially remote ends of the radially innermost winding coils. Beginning at the radially innermost point, such

wrapped main gap insulation comprises first, several turns or layers A of insulating paper over which is wrapped the ground shield or sleeve 50. The ground shield 50 is of conducting material, and may be formed either of a sheet of metal foil or a layer of conductive paint sprayed upon the paper layer A. In any case the conducting sleeve 50 is divided or split axially to prevent the formation of a short circuited turn.

Between the cylindrical ground sleeve 50 and the innermost coils of the two section high voltage winding the main gap insulation 35 comprises alternate layers of wound paper insulation C, E, G and intermediate conducting sleeves D, F, H. Each of the paper insulation layers C, E, G is formed by wrapping several layers of dielectric paper, as in the formation of the layer A. Intermediate the paper layers are interposed cylindrical conducting sleeves D, F, and H which may comprise, as in the ground shield 50, an axially split cylinder of metal foil or coating of conductive paint applied to a layer of paper. The outermost conductive sleeve or cylinder H is electrically connected to the high voltage winding midpoint connection 30s and thus is maintained electrically at the potential of the high voltage winding midpoint. The intermediate conductive sleeves, as the sleeves D and F, are electrically isolated in the electrostatic field between the midpotential shield H and the ground potential shield 50. The conducting sleeves D and F therefore assume intermediate potentials and, with the terminal shielding sleeves 50 and H, constitute a capacitive voltage divider. In this manner dielectric stress in the main gap between the low voltage winding 22 and the innermost high voltage coils is substantially evenly distributed in the solid insulation portion of the main gap. It will be understood that the main gap ordinarily includes also a cylindrical liquid duct 21a radially outside the low voltage winding 22.

Relatively uniform radial distribution of dielectric stress in the main gap would be distorted at the axially remote ends of the innermost turn layer in the high voltage winding if the metallic capacitive surfaces D, F and H were omitted or terminated axially at or near the ends of the innermost coil groups 30, 30'. At FIG. 5A I have shown diagrammatically and by means of equipotential lines of electric field strength the corner effect which would be experienced adjacent the radially inner ends of the high voltage winding if the capacitive surfaces D, F and H do not extend beyond the end turns of the inner coils. As is well known to those skilled in the art, the crowding together of these equipotential surfaces as they turn the corner of the winding 30-32 indicates a steep voltage gradient in the dielectric field at this point. This is particularly undesirable in the core window corner location at the winding end where it characteristically occurs in induction apparatus.

In order to overcome the corner effect indicated at FIG. 5A I extend the main gap insulation and the interwound conducting sleeves D, F and H axially beyond the end turns of the innermost high voltage coil groups and connect the several shields, respectively, to a plurality of toroidal conductive end rings X, Y and Z as shown in FIG. 2. The end shielding rings X, Y, Z are positioned in axially juxtaposed relation between the end turns of coil group 30 and the insulating disk assembly 25, 40, 41 adjacent the core yoke 10b at the upper limit of the core window. It will be understood, of course, that a similar end ring assembly (not shown) is to be located beyond the end of layer group 30' at the bottom end of core leg 10a.

The shielding rings X, Y and Z may, if desired, be made of metal suitably insulated on all except their inner peripheral surfaces where contact is made with the associated cylindrical shield or sleeve. I prefer, however, to form the shielding rings X, Y and Z of electrically conducting rubber, such as graphite-filled rubber, or of wound paper insulation covered with conducting paint. In any event each shielding ring X, Y and Z is shaped with a rounded outer surface to provide a desirable dielectric field distribution and is electrically open circuited peripherally, as indicated at 60 on the ring X shown at FIG. 6.

The toroidal conductive end rings X, Y and Z are electrically connected in consecutive order to the cylindrical conductive shields H, F, and D, the lowest potential ring Z being

most closely adjacent the core yoke 10b and the highest potential ring X being most closely adjacent the end turns of the winding portion 30. In making such electrical connection to the end shielding rings X, Y, Z the cylindrical conducting shields D, F and H are preferably flared outwardly, as indicated at FIG. 2, over the respective shielding rings. Such end flaring is readily accomplished if the shielding sleeves D, F, H are formed of conductive rubber sheeting. Alternatively, annular rings of conductive rubber may be drawn over the axial ends of each shielding sleeve and flared radially outward to connect to or to form one of the end rings X, Y, Z.

Intermediate the end shielding rings X, Y and Z the paper insulation layers E and G, respectively, are flared radially outward between the shielding rings. The axially endmost paper layer C is shown turned radially outward as a full end collar between the pressboard collars 40, 41. It is desirable to complete the main gap insulating structure upon which the balanced high-voltage winding sections 30-32 and 30'-32' are wound by wrapping the outer peripheral surface of the end rings X, Y, Z in an outer sheath 51 of flexible insulating material, one such end ring assembly being formed at each end of the main gap insulating cylinder 35. The capacitive main gap cylinder 35 is thus constructed as a supporting base upon which the balanced, sectional, multi-layer, high voltage winding is formed.

While I have described a preferred embodiment of my invention by way of illustration, many modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

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

1. In a high voltage winding assembly for electric induction apparatus, a supporting cylinder of insulating material including at least three shielding sleeves of electric conducting material in radially spaced apart relation, said sleeves being split axially to form capacitively coupled electrostatic shields between inner and outer surfaces of said insulating cylinder, a two-section multiple layer helical winding on said cylinder, each winding section comprising a plurality of concentric helical coils connected in series circuit relation, said winding sections having a series circuit connection between the juxtaposed ends of their radially innermost coils and each section having a high voltage line terminal at its other end, said shielding sleeves extending axially beyond and being radially flared outwardly over opposite ends of said innermost coils, and means electrically connecting said series circuit connection to the radially outermost shielded sleeve.

2. A winding assembly according to claim 1 including in combination, a plurality of split shielding rings of electrically conductive material disposed in axial spaced relation on said insulating cylinder adjacent the axially remote ends of said winding sections, said shielding rings at each axial end of said winding being electrically connected to said shielding sleeves in consecutive order with the radially outermost sleeve being connected to the rings immediately adjacent opposite ends of said winding.

3. In combination with the winding assembly of claim 1, a grounded magnetizable core disposed within said supporting cylinder, and means electrically connecting the radially innermost shielding sleeve to said core.

4. In a winding assembly according to claim 1, the combination of means electrically connecting the radially innermost shielding sleeve to ground potential.

5. A winding assembly according to claim 2 in which said shielding sleeves are of progressively less axial length in radially outer positions and said shielding rings are formed as annular lips at opposite ends of each said sleeve.

6. The winding assembly according to claim 5 in which said shielding rings are individually insulated on all external peripheral surfaces.

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7. A winding assembly according to claim 5 in which said shielding rings are formed of electrically conducting elastomeric material and encircle opposite ends of each said shielding sleeve in resilient contacting engagement.

8. A winding assembly according to claim 1 wherein said supporting cylinder is formed of wound insulating sheet material and said shielding sleeves are formed as interwound

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layers of conducting sheet material in concentric radially spaced relation.

9. A winding assembly according to claim 8 wherein each said shielding sleeve comprises a single peripheral layer of electrical conducting paint applied to said insulating sheet material.

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