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U. A. PEURON

3,173,115

HIGH VOLTAGE POTENTIAL TRANSFORMER

Filed Oct. 26, 1962

2 Sheets-Sheet 1

Fig. 1

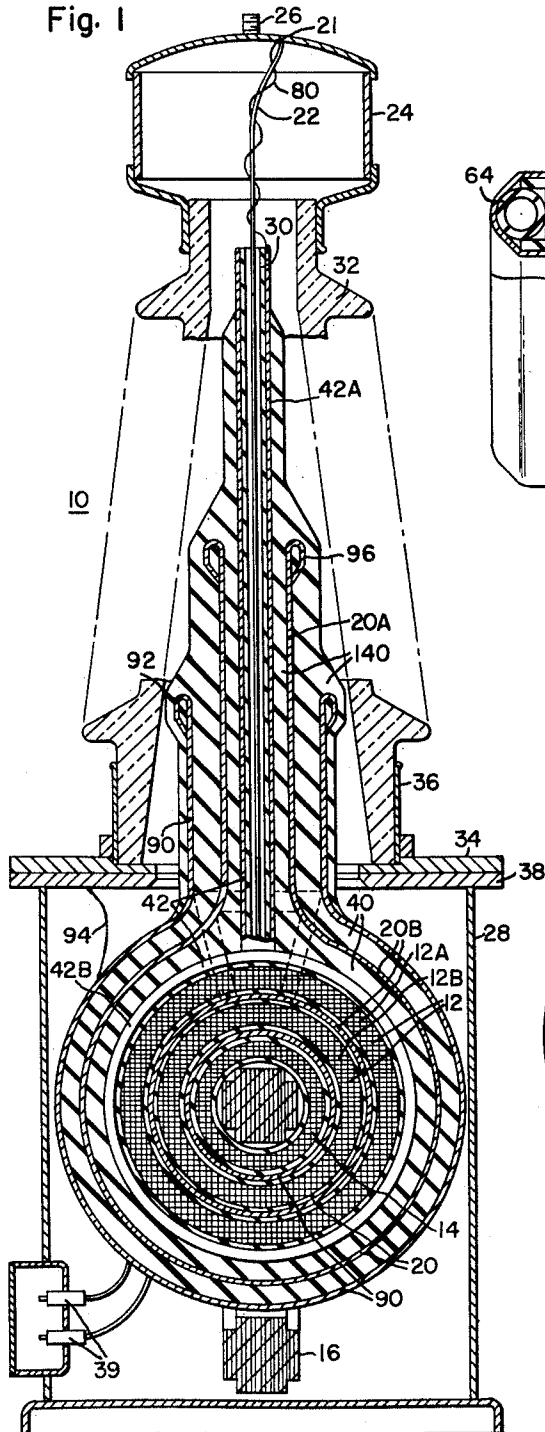


Fig. 3

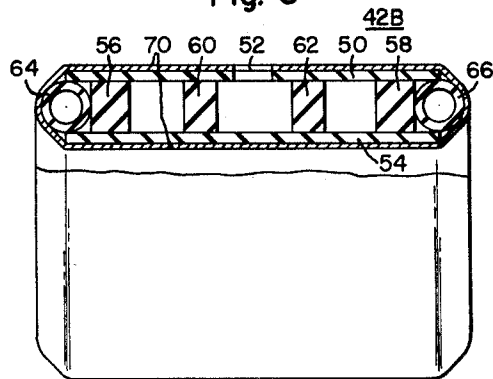
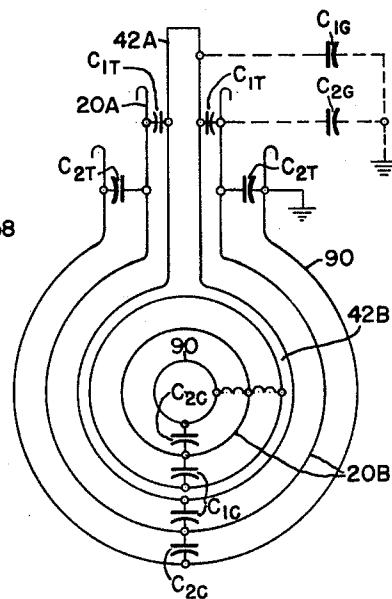


Fig. 4



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3,173,115

HIGH VOLTAGE POTENTIAL TRANSFORMER
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6 Claims. (Cl. 336-84)

This invention relates in general to electrical inductive apparatus, such as transformers, and more particularly to winding and insulation structures for such apparatus.

The physical size of high voltage electrical inductive apparatus, such as instrument transformers, is determined largely by insulation requirements rather than the volt-ampere rating of the apparatus. Considerable size reduction in instrument transformers immersed in a dielectric fluid, such as oil, has been accomplished by using a solid insulation comprising fibrous insulating material, such as crepe paper. The barrier action of the fibrous insulating material allows a substantial reduction in the major insulation. Further advantages are obtained when high voltage inductive apparatus, such as potential transformers, utilize the solid insulation and are constructed with a single pyramidal type high voltage coil. Surge voltage distribution in a pyramidal type primary coil with continuously narrowing width of winding layers is excellent. The initial and final voltage distributions across a pyramidal type coil nearly coincide, indicating an absence of harmful oscillations and making it possible to reduce insulating material necessary in other types of coil designs to meet special surge voltage characteristics.

However, even with the above reductions in major insulations, still further reductions of major insulation could be made if the potential stress surrounding the high voltage coil could be reduced. Still further reductions in major insulation could be achieved if the initial and final voltage distributions for the transformer as a whole would coincide. Also, a large portion of the weight and cost in a high voltage inductive apparatus is in the weather casing or bushing for the primary lead. Condenser type bushings produce linear voltage distribution along their outer surfaces, but for reasons of excessive length and high cost, it is highly advantageous to use simple bulk type bushings and utilize other means for obtaining longitudinal stress control along the high voltage bushing. Some prior art designs use a potential grading system similar to that of a condenser bushing, except the step-located concentric shields are incorporated in the primary lead insulation rather than in the bushing itself. This method, however, has disadvantages in that considerable skill and accuracy is required on the part of the manufacturing personnel who insulate the leads. In addition, the primary lead insulation has to be made relatively thick and with a large plurality of shields in order to reduce the voltage steps and edge effect on shield ends. Too great a voltage between adjacent shields results in corona on the sharp edges of the shields. It is, therefore, desirable to provide an improved winding and insulation arrangement that will provide favorable initial and final voltage distribution and stress control along the high voltage bushing, as well as radial stress control on coil corners, without the disadvantages of the hereinbefore mentioned systems of voltage distribution. It is also desirable that the improved winding and insulation arrangement incorporate pyramidal type primary coils and bulk type bushings, thus resulting in electrical inductive apparatus having not only reduced insulation thickness but reduced critical voltage gradients as well.

Accordingly, it is the general object of this invention to provide a new and improved winding and insulation structure for electrical inductive apparatus, such as transformers.

Another object is to provide a new and improved shielding arrangement for the high voltage winding of a transformer.

A more specific object of this invention is to provide a new and improved high voltage instrument transformer, such as a potential transformer, which has substantially linear voltage distribution along the high voltage bushing.

A still further object of this invention is to provide a new and improved high voltage potential transformer that has reduced potential gradient adjacent the high voltage coil and static shield.

A further object of this invention is to provide a new and improved high voltage potential transformer that has an initial and final voltage distribution that are substantially the same.

Briefly, the present invention accomplishes the above cited objects by providing a properly designed and located intermediate shield that interposes and divides the pyramidal type primary coil of the inductive apparatus into two sections. More specifically, the intermediate shield is connected to a portion of the high voltage coil, fixing the potential of the intermediate shield at some point between the primary voltage applied to the transformer and ground or zero potential. The intermediate shield is interjacent the inner and outer shields and located relative to the inner and outer shields in such a manner that the intershield capacitances provide surge and final voltage distributions that are substantially the same. Further, the intermediate shield considerably reduces critical gradients in the inductive apparatus and provides favorable voltage distribution along the high voltage bushing and radially to the high voltage coil.

Further objects and advantages of this invention will become apparent as the following description proceeds and features of novelty which characterize the invention will be pointed out in particularity in the claims annexed to and forming a part of this specification.

For a better understanding of the invention, reference may be had to the accompanying drawings, in which:

FIGURE 1 is a front elevational view, partly in section, of a transformer constructed in accordance with the teachings of this invention;

FIG. 2 is a side elevational view, partly in section, of the transformer shown in FIG. 1;

FIG. 3 is a front elevational view partly in section of a static shield that may be used in the transformer shown in FIGS. 1 and 2;

FIG. 4 is a diagrammatic representation of the shielding arrangement utilized in the transformer shown in FIGS. 1 and 2; and

FIG. 5 is a diagrammatic representation of the effective capacitive relationships which exist in the shielding arrangement illustrated in FIG. 4.

Referring now to the drawings and FIGS. 1 and 2 in particular, there is illustrated a high voltage potential transformer 10 constructed in accordance with the teachings of this invention. The transformer 10 includes a coil and core assembly which comprises the primary or high voltage winding 12 and the secondary or low voltage winding 14, all disposed in an inductive relationship with the magnetic core 16, which may be of any conventional type. The high voltage winding is divided into sections 12A and 12B by intermediate shield 20, which will be described in greater detail hereinafter. Lead 22 from high voltage coil 12 extends radially outward and upward and is attached by soldering, or other suitable means, to terminal 21 on metallic cap 24. Primary terminal 26, which is also suitably attached to metallic cap 24, may be connected to a high voltage circuit whose potential is to be measured. The high and low voltage windings 12 and 14, along with magnetic core 16 are suit-

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ably disposed within a casing or tank 28. The lead 22 from the high voltage winding 12 is enclosed in a lead tube 30 and lead tube 30 is in turn enclosed in a suitable hollow cylindrical or tubular bushing or weather housing 32 whose central opening is tapered in cross-sectional area along its vertical axis. The casing 28 and bushing 32 are filled with a suitable fluid dielectric, such as an insulating oil. Metallic cap 24 is a conventional expansion cap suitably disposed at the top of bushing 32 to allow for expansion and contraction of the dielectric fluid provided inside casing 28 and bushing 32.

The bushing 32 is supported by and secured to the cover 34 of casing 28 in any suitable manner, such as by flange member 36 and flange member 38, which may be formed integrally with the top 34 of casing 28, as shown in FIGS. 1 and 2. The flange member 36 may be secured to the flange 38 and top 34 by any suitable means, such as bolts or a welded connection, similar to the construction disclosed in greater detail in U.S. Patent 2,508,184 which is assigned to the same assignee as the present application. Terminals 39 are low voltage terminals connected to the secondary winding 14.

More specifically, the high voltage winding 12 is pyramidal in shape or has continuously narrowing width of winding layers and is inductively disposed on a portion of magnetic core 16. The pyramidal type coil has very favorable voltage distribution characteristics and is less costly to construct, insulate, and shield than the multi-coil designs sometimes used. The low voltage winding 14 is disposed inside the high voltage winding 12 and is substantially concentric with it. In order to insulate the high voltage winding 12 from the low voltage winding 14 and from the grounded portions of the transformer 10, solid insulation 40 is disposed to substantially surround the high voltage winding 12 and to provide the necessary insulation between the high voltage winding 12 and the low voltage winding 14. The solid insulation 40 may be any suitable insulating material, such as crepe paper, in sheet or tape form, which is either taped, wrapped or folded around the high voltage winding 12 and between the high voltage winding 12 and the low voltage winding 14.

In order to provide a duct or channel through which fluid dielectric may flow vertically either in an upward or downward direction for reasons which will be explained hereinafter, the tubular or hollow cylindrical insulating member 30, formed of a phenolic laminate or other suitable insulating material, is disposed in this instance around lead 22 between the high voltage winding and the upper portion of said lead, inside bushing 32. The lower end of insulating member 30 is suitably attached to hollow static ring 42B, which will be described in detail hereinafter.

In order to additionally electrically insulate the high voltage lead 22 from the grounded portions of the transformer 10, solid insulation 140 is disposed to substantially surround the major vertical portion of said lead. The solid insulation 140 may be similar to the solid insulation 40 disposed around the high voltage winding 12, and may be crepe paper in flexible sheet form which is taped, wrapped, or folded around the lead 22. The thickness of the solid insulation 140 is generally tapered from a maximum value at the lower portion of the lead 22 to a minimum value near the upper portion of said lead.

The entire solid insulation structure may be oil impregnated, using high vacuum techniques. The absence of oil ducts in the solid insulation substantially eliminates or reduces the possibility of voids or pockets in the solid insulation surrounding the high voltage winding 12 and lead 22, which would otherwise be filled with a dielectric fluid having a lower specific inductive capacity than the associated solid insulation. The presence of such voids or pockets in areas of high dielectric stress is particularly undesirable at higher operating potentials, and may eventually lead to an insulation failure or

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breakdown in the solid insulation surrounding the high voltage winding and its leads. This is due to the fact that voltage is distributed between two media in a manner inversely proportional to the capacitance of the two materials. Since the capacitance of the materials is directly proportional to their dielectric constants, the voltage distribution is greatly affected by the dielectric constants of the two materials. Therefore, an oil pocket, with a dielectric constant of approximately 2 would be subjected to more than its normal share of voltage where the dielectric constant of the surrounding oil impregnated crepe paper insulation is 4. In addition, the breakdown strength of oil is lower than that of the solid insulation.

In order to reduce the concentration of dielectric stress in the solid insulation 40 surrounding the high voltage winding 12, particularly adjacent to the outer ends or corners of said high voltage winding, and in the solid insulation 140 surrounding the lead 22, the inner shielding member 42 having upper and lower portions 42A and 42B, respectively, is disposed to substantially surround the high voltage winding 12 and the major portion of lead 22. The inner shielding member 42 also substantially eliminates any potential stress which the fluid dielectric might be subjected to in the channel or duct formed by the tubular insulating member 30 surrounding the lead 22, as previously described. The lower portion 42B of the inner shielding member 42, sometimes called a static ring, has several basic functions. It serves as a shield with rounded edges, it has an opening to the tubular insulating member 30 and acts as an inner cooling duct, and it protects the high voltage coil 12 mechanically and forms a rigid base to which the insulating member 30 can be attached.

FIG. 3 shows the static ring portion of the inner shield 42 in greater detail. The static ring 42B is comprised of an outer tubular member 50, formed of pressboard, laminated plastic, or other suitable insulating material, having an opening 52 over which the insulating member 30 is suitably disposed. If pressboard is used, the meeting ends may be folded to form a base to which the insulating member 30 may be attached by means of flexible insulating material in the form of tape.

An inner tubular member 54 is disposed concentrically within the outer tubular member 50 and may be constructed of the same material as said outer member. The inner member 54, however, has no opening or folded ends.

The inner and outer members 54 and 50, respectively, are concentrically located and held in place by spacing members 56 and 58, which may be corrugated pressboard strips fastened to said inner and outer members by cementing, or other suitable means. Spacing members 60 and 62 are similar to spacing members 56 and 58, except members 60 and 62 are short pieces or strips so that dielectric fluid may flow freely along the length of the static shield 42B.

Rounding means 64 and 66, located on both ends of the tubular assembly, partially between the inner and outer tubular members 54 and 50, respectively, may be formed of materials such as rope or metal tubing. If metal tubing is used it may function as the sensing portion of a capillary thermometer mounted on top of bushing 32, thus allowing the high voltage coil temperature to be monitored visually.

The static shield 42B is completed by disposing a shielding member around the entire static ring assembly. More specifically, a conducting or semiconducting tape is so disposed as to cover the entire assembly, inside as well as out. In particular, the shielding member 70 covers the rounded ends of the static ring 42B formed by members 64 and 66. The shielding member portion 70 of static ring 42B is formed by tightly winding a flexible conducting material having a layer of electrically insulating material secured thereto, such as crepe paper backed metallic foil in the form of tape, around and through the

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static shield 42B. The circumferential ends of the lower portion 42B of the inner shield 42 are preferably overlapped, but with a gap which is filled with solid insulation 40 to prevent a short circuited turn around the magnetic core 16.

Referring again to FIGS. 1 and 2, the upper portion 42A of inner shield 42 may be formed by tightly winding a flexible conducting material having a layer of insulation secured thereto, such as crepe paper backed metallic foil, in the form of a sheet or tape, substantially around the tubular insulating member 30 prior to the assembly of the solid insulation 140. The upper and lower portions 42A and 42B, respectively, of the inner shielding member 42 are electrically connected to one another to form a continuous conducting path throughout the shielding member 42 which will limit the potential difference between the different portions thereof to a negligible value so that there is no interruption in the shielding effect between the upper and lower portions of the shielding member 42.

The upper end of the inner shielding member 42 is electrically connected to the terminal 21 by the flexible conducting lead 80 in order that the shielding member 42 provides a substantially equipotential surface around the high voltage winding 12 and high voltage lead 22, which is at substantially the same potential as the outermost layer of the high voltage winding 12, to thereby substantially eliminate any potential stress to which any fluid dielectric inside said shielding member is subjected. It should be noted that the fluid dielectric uses the upper and lower portions of the inner shield 42 as ducts or channels. Fluid flow is accomplished by the counterflow method, wherein heated fluid rises up through the insulating member 30 and cooler fluid flows down said insulating member.

It is to be understood that although a separate lead 22 is shown connected from the high voltage coil 12 to terminal 21, the high voltage coil 12 could just as effectively be connected to the metallic portion of the inner shield at the lower end of insulating member 30. Then, the only connection to terminal 21 would be a flexible lead 80 from the metallic shield at the upper end of insulating member 30 to terminal 21. The shield around insulating member 30 may effectively be utilized as the high voltage lead because of the small currents involved.

In order to reduce the concentration of dielectric stress in the solid insulation 140 which surrounds lead 22 adjacent to the grounded portions of the casing 28 through which said lead passes, and to substantially eliminate any potential stress to which the fluid dielectric is subjected inside the casing 28 and in the lower portion of the central opening of the bushings 32, the outer shielding member 90 is disposed to substantially surround the high voltage winding 12 and its associated solid insulation 40, as well as the lower portion of lead 22 and the solid insulation 140 which is disposed around said leads.

The outer shielding member 90 is formed by winding around and through the central opening of the high voltage winding 12 a flexible conducting material having a layer of insulation secured thereto for mechanical purposes, after the solid insulation 40 has been assembled around the high voltage winding 12 and by winding the same type of flexible sheet material snugly and tightly around the outer surface of a solid insulation 140 after the latter insulation has been assembled around the lead 22. The upper portion of outer shield 90 is embedded in the solid insulation 140 which surrounds the lead 22 and the upper end of shield 90 is folded back on itself, as indicated at 92, to form a stress collar and reduce the concentration of dielectric stress in the adjacent solid insulation 140 and fluid dielectric.

The outer shield 90 may be formed of materials such as aluminum foil backed crepe paper or carbon backed crepe paper. When carbon backed crepe paper is used, its higher resistivity makes it possible to allow the shield

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to form a complete circuit around the core leg that carries the high and low voltage coils 12 and 14. When metal backed crepe paper is used, it is necessary to include a gap in the shielding, in order to prevent a short circuited turn around the magnetic core 16. Carbon backed crepe paper has other advantages over metal backed crepe paper, in that wrinkles and sharp edges are not as detrimental when using carbon backed paper as opposed to metallic type shields. Also, the higher resistance of carbon has a potential grading effect because the displacement current due to stress concentration causes a voltage drop along the semiconducting layer. This phenomenon is well known and utilized in condenser bushings and windings of high voltage generators. It is also known that due to so called "surface activity," an insulation with a semiconducting electrode, such as carbon, in the highest stressed boundary has higher dielectric strength than a system with metallic electrodes only.

The outer shielding member 90 forms a continuous conducting surface or electrode having a cylindrical configuration around the high voltage winding 12 and a generally hollow cylindrical shape around the lower portion of lead 22. The outer shielding member 90 is maintained at ground or zero potential by electrically connecting said shielding member by a flexible conducting lead as indicated at 94 in FIG. 1 to the casing 28, or any other grounded portion of the transformer 10.

The outer shielding member 90 is disposed in substantially concentric relation with the inner shielding member 42, and similar to the latter shielding member, the outer shielding member 90 forms a continuous, substantially equipotential surface around the outer surface of the solid insulation 40 and the outer surface of the lower portion of the solid insulation 140. The flexible shielding material from which the outer shielding member 90 is formed permits said shielding member to closely follow the contour or outer surface of the solid insulation 40 and prevents the occurrence or voids or pockets which would otherwise be filled with the associated fluid dielectric and which would be subject to possible insulation failure or breakdown.

In order to reduce the radial stresses on the static shield 42B and the high voltage coil 12, and produce a favorable voltage distribution longitudinally along the bushing 32, an intermediate shielding member 20, having upper and lower portions 20A and 20B, respectively, is disposed to substantially surround the high voltage winding 12 and the lower portion of the lead 22. In addition to surrounding the high voltage coil 12, the intermediate shield 20 interposes the high voltage coil 12, dividing said high voltage coil into two portions or sections, 12A and 12B. It is to be noted that the outer surface of the lower portion 20B of intermediate shield 20 is embedded in the solid insulation 40. The inner surface of said lower portion of intermediate shielding member 20 interposes and separates the high voltage winding 12 into inner and outer portions designed as 12B and 12A, respectively. The upper portion 20A of intermediate shielding member 20 is embedded in the solid insulation 140 which surrounds lead 22. The upper and lower portions 20A and 20B of the intermediate shielding member 20 may be formed in a manner similar to the outer shielding member 90, as previously described, by winding a flexible conducting or semiconducting material having a layer of insulation secured thereto, such as crepe paper with metallic foil or carbon attached to it, in the form of a tape or sheet, around and interposing the high voltage winding 12, after approximately half the solid insulation 40 has been assembled around the high voltage winding and around the lower portion of the lead 22 after approximately half the solid insulation 140 has been assembled around said lead. The intermediate shielding member 20B includes a gap if a metallic shield is used in order to prevent a short circuited turn around the magnetic core 16. As previously explained, no gap is necessary if a semicon-

ducting shield, such as carbon, is used. The upper end of the upper portion 20A of the intermediate shielding member 20 is folded back on itself as indicated at 96 to form a stress collar and thereby increase the effective radius of curvature of the upper end of said shielding member and reduce the concentration of dielectric stress in the adjacent solid insulation 140 and fluid dielectric below the corona level.

The upper and lower portions 20A and 20B, respectively, of the intermediate shielding member 20 are electrically connected with one another or former from the same flexible conducting material to provide a continuous, substantially equipotential surface around the high voltage winding 12 and the lower portion of lead 22. Similar to the outer shielding member 90, the intermediate shielding member 20 forms a generally cylindrical electrode surface around the high voltage winding 12 and also a generally cylindrical electrode surface around the lower portion of lead 22 in substantially concentric or parallel relation with the inner shielding member 42 and the outer shielding member 90. Unlike the outer shielding member 90, however, the intermediate shielding member 20 does not completely encircle the high voltage coil through the central portion of the coil opening. The intermediate shielding member interposes the high voltage coil 12 at some intermediate point, dividing said high voltage coil into portions 12A and 12B. The potential of the intermediate shielding member 20 is fixed to a suitable value by connecting said intermediate shielding member to that point in the high voltage coil 12 having the desired inductively fixed alternating potential. The potential of the intermediate shield is fixed to a value between the potential applied to the transformer primary terminal 26 and ground or zero potential, with the value usually being between 30 and 70 percent of the applied potential. Locating the intermediate shield 20 in this manner, interposing and dividing the high voltage coil 12 into two portions 12A and 12B, reduces appreciably the maximum voltage gradients on the static shield 42B by moving the intermediate shielding member 20 radially away from the location where the corresponding equipotential surface would be located in the absence of said intermediate shield. By reducing the critical voltage gradients on the static shield 42B, the intermediate shielding member 20 makes possible a marked reduction in major insulation and improves the corona characteristics of the transformer 10. Also, the reduction in insulation makes heat transfer less of a problem and more efficient cooling is obtained, even when using a smaller volume of fluid dielectric. A further advantage of the intermediate shielding member 20, as will be explained in greater detail hereinafter, is the more favorable voltage distribution obtained longitudinally along the bushing 32. This more linear voltage distribution along the bushing 32 also contributes to a reduction in the amount of fluid dielectric and major insulation required.

While the easiest manner of fixing the voltage of the intermediate shield 20 to the desired value is to actually make a physical connection from the appropriate portion of the high voltage coil 12 to the intermediate shielding member 20, it will be appreciated that the desired potential at the intermediate shielding member 20 could also be obtained without any physical connections. The desired potential at the intermediate shielding member 20 could be obtained by proper arrangement of the shielding members 20, 42 and 90 with respect to each other and with respect to the grounded portions of transformer 10.

The intermediate shielding member 20 not only reduces critical high stress areas on the static shield 42B, but also allows the capacitance of the transformer to be adjusted to a value that substantially eliminates harmful transient oscillations that occur upon applying a high voltage to a transformer. Once current is flowing through a transformer, the voltage distribution is determined in-

ductively or by magnetic coupling and may be designed to be substantially uniform. The initial voltage distribution, upon application of the high voltage to the transformer, may be entirely different from the final distribution, however, because initial voltage distribution is determined entirely electrostatically, or by the capacitances of the coils and turns to each other and to the various shields. The greater the deviation of the initial voltage distribution from the final voltage distribution, the greater the harmful transient voltage oscillations produced as the voltage distribution changes from capacitive voltage distribution to inductive voltage distribution. Therefore, it is essential that the transformer be designed to provide substantially similar initial and final voltage distribution curves. The intermediate shield makes it possible to obtain an initial voltage distribution that is substantially similar to the final voltage distribution. For example, if the intermediate shield 20 is designed for fifty percent potential, then in addition to the proper connection to the corresponding point in the coil, the intermediate shielding member must be placed so that the total capacitance between the inner shielding member 42 and the intermediate shielding member 20 equals the capacitance between the intermediate shielding member 20 and the outer shielding member 90 and other grounded portions of the transformer 10. For potentials other than 50% at the intermediate shield, it is only necessary to design the shields so that the total capacitances between shields are inversely proportional to the potential differences under normal operating conditions.

More specifically, FIG. 4 illustrating diagrammatically the shielding members 20, 42 and 90 and the associated effective capacitances and inductances which exist between the different portions thereof as well as the effective capacitances which exist between the shielding members 20 and 42 and the grounded portions of the transformer 10. The effective capacitance between the lower portion 42B of shielding member 42 and the lower portion of the intermediate shielding member 20B is indicated at C_{1C} . The effective capacitance which exists between the lower portion 20B of intermediate shielding member 20 and the lower portion of outer shielding member 90 is indicated at C_{2C} . The effective capacitance between the upper portion 42A of the inner shielding member 42 and the upper portion 20A of intermediate shielding member 20 is indicated at C_{1T} . The effective capacitance between the upper portion 20A of intermediate shielding member 20 and the portion of outer shielding member 90 is indicated at C_{2T} . The effective capacitance between the upper portion 42A of inner shielding member 42 and other grounded portions of transformer 10 is indicated at C_{1G} . The effective capacitance which exists between the upper portion 20A of intermediate shielding member 20 and other grounded portions of the transformer 10 is indicated at C_{2G} . The latter capacitive relationships which exist between the shielding members 20, 42 and 90 and between certain of said shielding members and the grounded portions of transformer 10 are indicated by the equivalent schematic diagram shown in FIG. 5. It is well known that if a plurality of capacitors are connected in series and a potential applied to the series circuit, the potential will divide or distribute itself across the respective capacitors inversely in accordance with the capacitance value of said capacitors. By providing an intermediate shielding member 20 having its respective portions disposed at an intermediate radial point in the solid insulation 140 which surrounds the lead 22, and in the solid insulation 40 disposed around the high voltage winding 12 and interleaving the high voltage winding 12 and by varying the effective capacitances between various portions of the shielding members 20, 42 and 90, the potential at the radial point in the solid insulation 40 at which the intermediate shielding member 20B is disposed can be increased to a value above that which would otherwise exist in the absence of the intermediate

shielding member 20. Therefore, the maximum potential gradient which exists at the outer corners of the high voltage winding 12 adjacent to the inner shielding member or static shield 42B in the solid insulation can be reduced, permitting an important reduction in the amount of thickness of the solid insulation 40 required around the high voltage winding 12 and between the high voltage winding 12 and the low voltage winding 14.

The intermediate shielding member 20 also produces substantial reduction in the insulation 140 surrounding lead 22 and the length and size of bushing 32 by enabling the proper capacitances to be established between shielding members and between shielding members and the grounded portions of transformer 10, and thus obtaining a favorable longitudinal voltage distribution along bushing 32.

Referring to FIG. 5 and assuming $C_1 = C_{1T} + C_{1G}$ and $C_2 = C_{2T} + C_{2G}$, the voltage distribution is determined by the relationship $E_1/E_2 = C_2/C_1$. If the design is based on equal voltages on both sides of the intermediate shielding member 20, C_1 would equal C_2 . Otherwise, different capacitive relationships would exist. To obtain the desired capacitive relationships, it may be necessary to increase the total capacitance between the inner shielding member 42 and the intermediate shielding member 20. The total capacitance between the inner shielding member 42 and the intermediate shielding member 20 may be increased by moving the upper portion 20A of the intermediate shielding member 20 radially inward towards the upper portion 42A of inner shield 42, or by axially extending the length of the intermediate shielding member 20 in an upward direction. In addition to designing the capacitive relationships between shielding members and between shielding members and ground to provide substantially linear voltage distribution along the bushing 32, said capacitive relationships are designed so that under impulse conditions the favorable voltage distribution is not disturbed. Flux mapping techniques may be used to determine the effective capacitance of the windings upon initial application of the high voltage to the transformer.

In summary, the effect of the intermediate shielding member in a winding and insulation structure as disclosed is threefold. First, the intermediate shielding member 20 reduces the maximum potential gradient which would otherwise exist at the surface of the inner shielding member 42B at the outer corners of the high voltage winding 12 and increases the potential gradient in the portions of the solid insulation 40 which are radially removed from the outer corners of the high voltage winding 12. It is important to note that it is possible to reduce the maximum potential gradient in the manner disclosed by moving the upper portion 20A of the intermediate shielding member 20 radially inward toward the upper portion 42A of the inner shielding member 42, since the effective radius of curvature of the inner shielding member 42, which is at substantially the same potential as the high voltage winding 12, is much greater than the effective radius of curvature at the outer corners of the high voltage winding 12 at the surface of the lower portion 42B of the inner shielding member 42, although it is possible to alternatively extend the axial dimension of the upper portion 20A of the intermediate shielding member 20 in an upward direction to obtain the desired increase in total capacitance between the inner shielding member 20 and the outer shielding member 90 in a particular application and to obtain the desired potential relationship between the respective shielding members. The intermediate shielding member 20 thus permits a substantial reduction in the amount of thickness of solid insulation required around the high voltage winding 12 and substantially improves the space factor of the transformer 10, since the required size of the magnetic core is correspondingly reduced as well as the physical weight and size of the overall transformer 10. Second, further reduction in insulation and high voltage bushing weight

and size is attributed to the intermediate shielding member 20 in that proper placement of said intermediate shielding member more uniformly distributes the voltage longitudinally along said bushing. This eliminates the requirement for condenser type bushings or step-concentric shields as hereinbefore described. Third, the requirement for excessive insulation to prevent insulation failure from surges and voltage oscillations due to initial application of the voltage to the transformer is eliminated. The intermediate shielding member 20 makes it possible to obtain capacitive relationships that produce an initial voltage distribution substantially similar to the final voltage distribution. Thus, there are substantially no harmful voltage oscillations as the voltage changes from capacitive or initial to inductive or final distribution.

It is to be understood that in certain applications, additional intermediate shielding members may be employed to improve the potential gradient in certain portions of the solid insulation and provide a more linear voltage distribution along the high voltage bushing in a transformer of the type disclosed. Also, the shielding members as disclosed may be formed from semiconducting or conducting materials of other types, such as semiconducting rubber, flexible insulating material with a metallic coating sprayed therein, or Coronox tape. Further, it is to be understood that the outer shielding member 90 may be omitted in certain applications, with the metallic casing 28, which is normally at ground potential, functioning as an effective outer shield.

It will therefore be apparent that there has been disclosed a new and improved winding, insulation, and shielding structure for electrical inductive apparatus that reduces the potential gradient next to the high voltage coil and on the static shield adjacent the high voltage coil, provides a more favorable voltage distribution along the high voltage bushing, and provides an inductive device wherein the initial and final voltage distribution curves substantially coincide. The new and improved winding, insulation and shielding structure results in in several advantages. For example, the amount and radial thickness of the solid insulation required in a transformer of the type described is considerably reduced, thus reducing the physical size and weight of the transformer. Also, the high voltage bushing may be considerably smaller and lighter, further adding to the weight and size reduction of the overall transformer. In addition, the reduction in maximum potential gradient results in reduced possibility of insulation failures due to breakdown of the fluid dielectric. Finally, the reduction in solid insulation reduces the effect of said solid insulation as a thermal barrier and reduces the requirement for special cooling arrangements and reduces the amount of fluid dielectric required.

Since numerous changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit and scope thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative, and not in a limiting sense.

I claim as my invention:

1. A potential transformer comprising a pyramidal type high voltage winding, a lead electrically connected to and extending outwardly from said high voltage winding, a first shielding member formed from conducting material and connected to said lead disposed to substantially surround said high voltage winding and said lead, solid insulation substantially surrounding said high voltage winding, lead, and first shielding member, a second shielding member formed from conducting material and connected to ground potential disposed to substantially surround in a close fitting manner at least the major portion of said solid insulation, and an intermediate shielding member having lower and upper portions formed from conducting material disposed to surround said high voltage winding

and at least a portion of said lead, respectively, said lower portion of said intermediate shielding member being embedded in said solid insulation substantially halfway between said first and second shielding members and interposing and dividing said high voltage winding into two sections, said intermediate shielding member being electrically connected to said high voltage winding at a point intermediate the start and finish of said high voltage winding, with the point on said high voltage winding being selected to obtain a potential which provides the maximum reduction in potential gradient at said first shielding member, said upper portion of said intermediate shielding member being positioned closer to said first shielding member than to said second shielding member to produce a capacitance relationship between said shielding members that would force said intermediate shielding member to assume the same potential that said intermediate shielding member has assumed due to its being connected to the selected point of the high voltage winding.

2. A potential transformer comprising a pyramidal type high voltage winding, a lead electrically connected to and extending outwardly from said high voltage winding, a first shielding member formed of first and second electrically connected sections and connected to said lead, said first section of said first shielding member substantially surrounding said lead and said second section of said first shielding member substantially surrounding said high voltage winding, solid insulation substantially surrounding said high voltage winding, lead, and first shielding member, a second shielding member formed from conducting material and connected to ground potential and disposed to substantially surround in a close fitting manner at least the major portion of said solid insulation, and an intermediate shielding member having lower and upper portions formed from conducting material disposed to surround said high voltage winding and at least a portion of said lead, respectively, said lower portion of said intermediate shielding member being embedded in said solid insulation substantially halfway between said first and second shielding members and interposing and dividing said high voltage winding into sections, said intermediate shielding member being electrically connected to the high voltage winding at a point intermediate its start and finish, the potential at said point being of a magnitude to increase the potential of the intermediate shielding member to a magnitude higher than would exist at the same location in said solid insulation in the absence of said intermediate shielding member, to substantially reduce the potential gradient at said inner shielding member, said upper portion of said intermediate shielding member being positioned closer to said first shielding member than to said second shielding member to produce a capacitance relationship between said shielding members that causes the initial and final voltage distribution across said transformer to be substantially the same.

3. A potential transformer comprising a high voltage winding, a lead electrically connected to and extending outwardly from said high voltage winding, a first shielding member formed from semiconducting material and connected to said lead disposed to substantially surround said high voltage winding and said lead, solid insulation substantially surrounding said high voltage winding, lead, and first shielding member, a second shielding member formed from semiconducting material and connected to ground potential disposed to substantially surround in a close fitting manner at least the major portion of said solid insulation, and an intermediate shielding member having lower and upper portions formed from a semiconducting material disposed to surround said high voltage winding and at least a portion of said lead, respectively, said lower portion of said intermediate shielding member being embedded in said solid insulation substantially halfway between said first and second shielding members and interposing and dividing said high voltage winding into two

sections, said intermediate shielding member electrically connected to said high voltage winding at a point intermediate the start and finish of said high voltage winding, with the potential of said point being selected to provide the maximum reduction in potential gradient adjacent said first shielding member, said upper portion of said intermediate shielding member being positioned closer to said first shielding member than to said second shielding member to provide a capacitance relationship that provides the same potential at the intermediate shielding member that said intermediate shielding member has assumed due to its being connected to said high voltage coil, to substantially reduce transient voltages as the voltage distribution across said transformer changes from a capacitance distribution to an inductive distribution.

4. A transformer comprising a pyramidal type high voltage winding, a primary voltage terminal, a first shielding member formed of first and second electrically connected sections, said high voltage winding electrically connected to said first section of said first shielding member and said first section electrically connected to said primary voltage terminal, said second section of said first shielding member substantially surrounding said high voltage winding, solid insulation substantially surrounding said high voltage winding and first shielding member, a second shielding member electrically connected to ground potential disposed to substantially surround in a close fitting manner at least the major portion of said solid insulation, and an intermediate shielding member having lower and upper portions disposed to surround said high voltage winding and first shielding member, the lower portion of said intermediate shielding member being embedded in said solid insulation substantially halfway between said first and second shielding members and interposing and dividing said high voltage winding into sections, said intermediate shielding member being electrically connected to said high voltage winding at a point between the start and finish of said high voltage winding, with the potential at said point being of a magnitude to increase the potential of the intermediate shielding member to a magnitude higher than would exist at the same location in said solid insulation in the absence of said intermediate shielding member, to substantially reduce the potential gradient at said high voltage winding and at said first shielding member, said upper portion of said intermediate shielding member being positioned closer to said first shielding member than to said second shielding member to produce a capacitance relationship between said shielding members that forces the initial and final voltage distribution across the transformer to be substantially the same.

5. A transformer comprising a metallic casing, a high voltage winding disposed in said casing, at least one lead electrically connected to said winding and extending outwardly therefrom, solid insulation substantially surrounding said winding and at least a portion of said lead, a first shielding member formed of conducting material and disposed between said solid insulation and said winding and between said solid insulation and lead to substantially surround said winding and leads, said first shielding member being electrically connected to said lead, and a second shielding member having lower and upper electrically connected portions formed from conducting material and substantially surrounding said winding and said lead, respectively, said lower portion of said second shielding member interposing and dividing the high voltage winding into two sections and positioned substantially halfway between said first shielding member and the outer surface of said solid insulation, said second shielding member being electrically connected to said high voltage winding at a predetermined point, with the potential at the point increasing the potential of the second shielding member to a magnitude higher than would exist at the same location in said solid insulation in the absence of said second shielding member, to substantially reduce the potential gradient at the first shielding member, said upper portion of said sec-

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ond shielding member being positioned closer to said first shielding member than to the outer surface of said solid insulation to produce a capacitance relationship between said first and second shielding members and between said second shielding member and said casing that provides an initial voltage distribution across said transformer that is substantially the same as the final voltage distribution.

6. An instrument transformer comprising a metallic casing, a high voltage winding disposed within said casing, a lead electrically connected to said winding and extending outwardly therefrom, solid insulation substantially surrounding said winding and at least a portion of said lead, a first shielding member electrically connected to said lead comprising lower and upper sections disposed between said solid insulation and said winding and between said solid insulation and said lead respectively, the lower section of said first shielding member being hollow and cylindrical in shape and having conducting material on its surface, the upper section of said first shielding member being a tubular insulating member having a conducting material on its external surfaces, the upper and lower sections of said first shielding member being mechanically and electrically connected, and a second shielding member having lower and upper portions formed from conducting material and substantially surrounding said winding and said lead, respectively, said lower portion of said second shielding member being disposed substantially halfway between said first shielding member and the outer surface of said solid insulation and interposing

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and dividing said high voltage winding into two portions, said second shielding member being electrically connected to said high voltage winding at a predetermined point, the point being selected to provide a potential that increase the potential of said intermediate shielding member to a magnitude greater than said intermediate shielding member would assume by its position alone to reduce the maximum potential gradient adjacent to the surface of said first shielding member and to provide a more linear voltage distribution along said high voltage lead, said second shielding member being positioned relatively closer to said first shielding member than to the outer surface of said solid insulation to produce a capacitance relationship that provides initial and final voltage distributions across said transformer that are substantially the same.

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