United States Patent

Goodman et al.

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[54] **DISTRIBUTION TRANSFORMER HAVING STATIC SHIELD**

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[52] **U.S. Cl.**.....**336/84,** 336/192

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

[58] **Field of Search**.....336/69, 70, 84, 192

[56] **References Cited**

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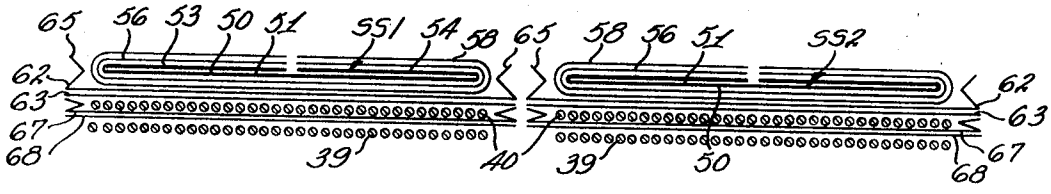
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Primary Examiner—Thomas J. Kozma
Attorney—Lee H. Kaiser et al.

[57] **ABSTRACT**

An electrical distribution transformer of the series-multiple type has a plurality of adjacent primary winding sections wound in radially superimposed helical layers of wire turns and also has a static shield for each winding section comprising a strip of aluminum-backed crepe paper disposed in overlaying relation to the outer wire turn layer and having both longitudinal edges folded over and flattened so that the aluminum is on the inside of the fold to provide minimum edge corona; a multi-layer insulation envelope wrapped around the aluminum-backed paper; a thin copper lead cold-welded to the aluminum and electrically connected to the finish wire turn of the outer layer; and a strip of insulation disposed between the static shield and the outer wire turn layer and having its longitudinal side edges folded over a short distance to position the static shield and provide a long creep path between shields of adjacent primary winding sections.

10 Claims, 5 Drawing Figures



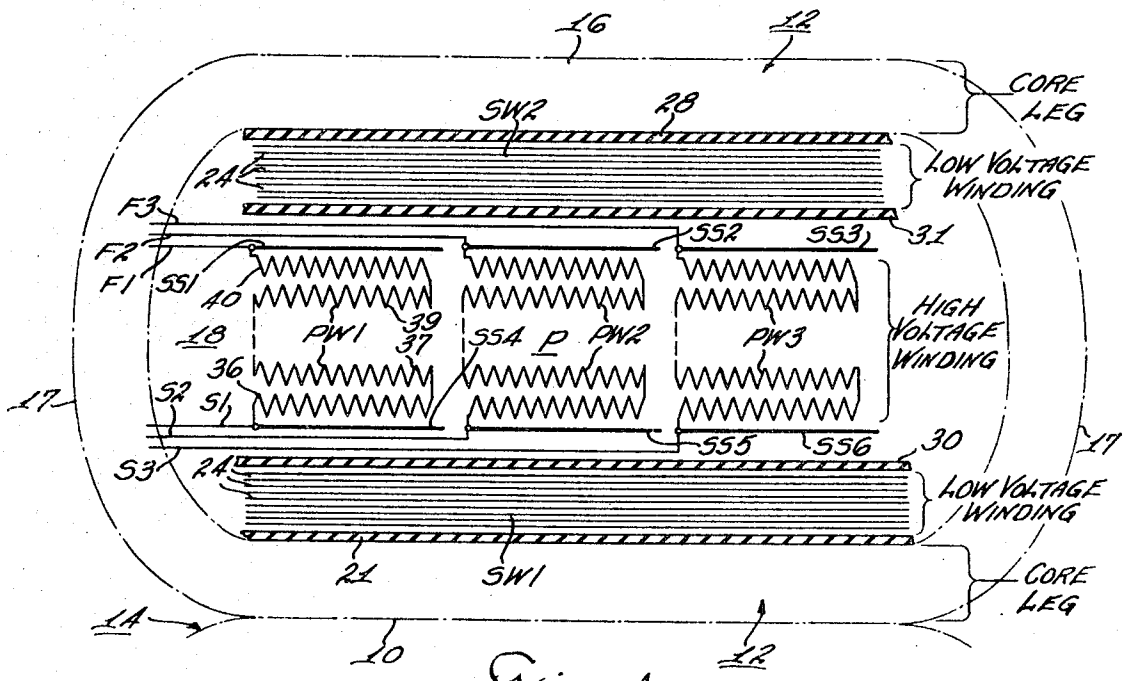


Fig. 1

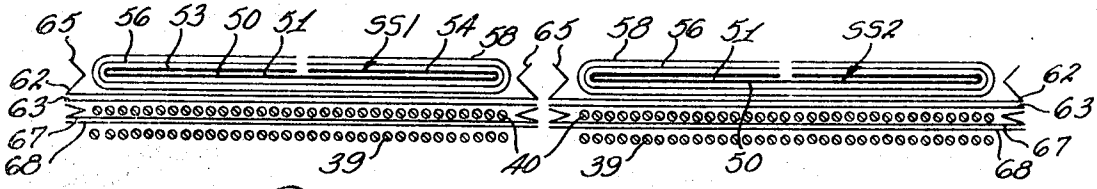


Fig. 2

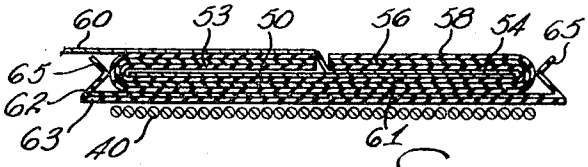


Fig. 5

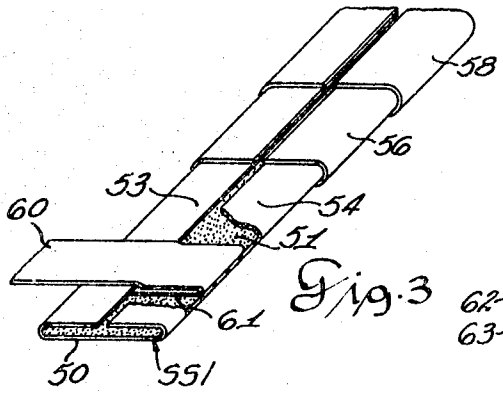


Fig. 3

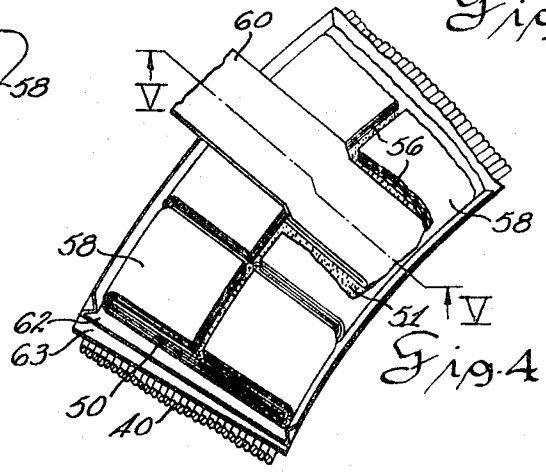


Fig. 4

DISTRIBUTION TRANSFORMER HAVING STATIC SHIELD

This invention relates to stationary induction apparatus and more particularly to a statically shielded, multi-layer high voltage winding for an electric power distribution transformer.

BACKGROUND OF THE INVENTION

When a transformer is subjected to a steep voltage impulse such as lightning, the initial distribution of the voltage throughout the transformer coil is determined by the relative capacitances between turns, between layers, between coils, and to ground, since only a negligible fraction of the initial surge current flows to ground through the turns of the winding because of its high inductance. Practically all of the initial surge current flows to ground through the capacitances between turns, between coils, and to ground. The coils close to the line end have, at least initially, higher voltages across them than the coils further from the line end, the relative values being determined by the ratio of the capacitances within and between coils to the capacitance to ground, and the number of coils in the winding. The maximum voltage stresses, and hence the dielectric requirements, near the line end are generally determined by the initial surge voltage distribution, but each part of the transformer must be provided with sufficient insulation to withstand the voltage surges to which it will be subjected.

It is known that an increase in the series capacitance of disk type high voltage windings of power transformers improves their impulse voltage handling characteristics, but the known methods of construction to increase the series capacitance are complicated and enlarge the size of the winding. The series capacitance of a multi-layer winding comprising a plurality of cylindrically arranged, helical winding layers is inherently larger than that of a disk type winding. This is due to the fact that the electrostatic coupling of each cylindrical winding layer to the adjacent winding layers has a larger series capacitance resulting from the large opposing areas and relatively short spacing of such opposing areas. While such relatively large series capacitance of a multiple layer winding provides more uniform potential distribution in this winding against a steep front impulse voltage than a disk type winding, still unbalanced initial potential distribution can occur in the most exterior (i.e., first or last,) layer of a multiple layer winding when it is subjected to a steep front impulse voltage.

Such unbalanced, or nonlinear, initial potential distribution across the most exterior winding layer of a multi-layer primary distribution transformer winding is concentrated near the line end. In such a distribution transformer high voltage multi-layer winding, all the turn-to-turn dielectric strength is usually provided by the insulation of adjacent magnet wire turns. The thickness of film coating and its dielectric strength often decreases with round magnet wire diameter. Inasmuch as the surge voltage distributes non-uniformly across the coil, the thickness of wire insulation for the entire winding must be selected for the worst condition, i.e., the end turn-to-turn stresses. Also wire insulation is generally not perfect and fairly variable so that weak points, or even pinholes, may see the highest turn-to-turn surge voltage.

It is known to dispose a static shielding plate outside the most exterior cylindrical winding layer of a power type transformer and to apply the line-side potential to such shielding plate in order to improve the potential distribution of multi-layer winding. However, known static shielding structures have been relatively expensive and have resulted in considerable increase in the diameter of the transformer winding and thus in the width of the core window.

OBJECTS OF THE INVENTION

It is an object of the invention to provide a primary winding for an electrical distribution transformer having an improved static shielding means which distributes surge voltage linearly across the most exterior helical layer of wire turns and is simple and inexpensive to construct and does not appreciably increase the diameter of the transformer winding.

It is an further object of the invention to provide an improved static shield for an electrical distribution transformer which can be constructed using conventional insulation-folding machinery and conventional cold-welding apparatus for joining a lead to the shield, both of which result in low material and low labor cost.

Another object of the invention is to provide an improved static shield construction for a dual-rating distribution transformer provided with a plurality of primary winding sections which has the same basic impulse level (BIL) for either series or parallel connection of the primary winding sections.

Still another object of the invention is to provide an improved static shield construction for a series-multiple distribution transformer provided with a plurality of primary winding sections which, in the series connection, has a high section-to-section corona starting and extinction level and a low radio noise (RI) voltage level.

A still further object of the invention is to provide an improved static shield for an electrical distribution transformer which substantially reduces corona and results in low losses and heating from stray flux even under short circuit conditions and still permits uniform insulation and electrical clearances to be used throughout the portion of the winding radially inward from the shield.

SUMMARY OF THE INVENTION

In accordance with the invention a static shield for a distribution transformer primary winding of superimposed helical layers of wire turns comprises an insulating strip carrying a conductive coating positioned contiguous an exterior primary winding wire turn layer so that the conductive coating is on the surface disposed away from the wire turns and having both longitudinal side edges folded over and flattened so that the conductive coating is on the inside of the fold to minimize edge corona; a strip of conductive material electrically connected, preferably by cold welding, to the conductive coating and also connected to the line end wire turn of said exterior layer to distribute surge voltages linearly across said exterior layer; and an envelope of insulation wrapped around the static shield so that it is disposed between the conductive coating and said exterior layer of wire turns.

DESCRIPTION OF THE DRAWING

These and other objects and advantages of the invention will be more readily apparent from the following detailed description when considered in conjunction with the accompanying drawing wherein:

FIG. 1 is a partial sectional view through the winding of a dual-rating (series-multiple) electrical distribution transformer embodying the invention, the view being partly diagrammatic;

FIG. 2 is an enlarged schematic sectional view through the exterior winding layers and static shields of a plurality of side-by-side primary winding sections of the distribution transformer of FIG. 1;

FIG. 3 is a perspective view of the aluminum-backed crepe paper of a static shield shown in FIG. 2 to which the conductive strip lead is cold welded and also of the paper insulating layer envelope wrapped around the shield;

FIG. 4 is a perspective view of a static shield embodying the invention in overlying relation to the most exterior layer of wire turns of a distribution transformer primary winding section shown in FIG. 2; and

FIG. 5 is a view taken along line V—V of FIG. 4.

DETAILED DESCRIPTION

Referring to FIG. 1, an electrical distribution transformer of the dual-rating (series-multiple) type may include a center winding leg 10 of magnetic steel laminations (not shown) formed by back-to-back sides of a pair of closed, generally rectangular magnetic cores 12 and 14 shown by dot-dash lines. Closed core 12 may have an outer leg 16 of magnetic steel laminations (not shown) which, together with winding leg 10 and end yokes 17 define a core window which receives a transformer winding 18. Only one leg of magnetic core 14 is shown in FIG. 1.

A support tube 21 of suitable insulating material such as kraft paper surrounds winding leg 10. Transformer winding 18 may be of the low-high-low type with a radially inner secondary winding section SW1 of sheet conductor material 24 such as aluminum wound in surrounding relation to support tube 21 and electrically connected to a radially outer secondary winding section SW2 of sheet conductor material 24 of greater diameter than inner section SW1 and disposed adjacent outer core leg 16 and insulated therefrom by tubular insulating barrier 28 of suitable material such as kraft paper. A tubular barrier 30 of suitable insulating material such as kraft paper may surround radially inner secondary winding section SW1, and radially outer secondary winding section SW2 may surround a tubular barrier 31 of suitable insulating material such as kraft paper.

Transformer primary, or high voltage winding P, is disposed between tubular barriers 30 and 31 and comprises a plurality of cylindrically arranged, helical winding layers of wire turns surrounding barrier 30. In some embodiments of the invention each helical winding layer may extend the entire width (axial length) of the winding, but the embodiment depicted in FIG. 1 is shown with three substantially identical side-by-side primary winding sections PW1, PW2, and PW3 each comprising a plurality of concentric helical layers of wire turns (each helical layer of wire turns is represented by the symbol for resistance). Primary winding section PW1 begins at a start lead S1 and includes a radially inner helical layer 36 of wire turns; a second helical layer 37 of wire turns surrounding and insulated (by means not shown in FIG. 1) from inner layer 36; a plurality of additional helical layers of wire turns concentric with layers 36 and 37 (shown by dashed lines) terminating in a most exterior helical layer 40 of wire turns, and winding section PW1 ends at a finish lead F1.

Primary winding section PW2 is similar and adjacent to winding section PW1 and begins with a start lead S2 and ends with a finish lead F2. Primary winding section PW3 is similar to winding sections PW1 and PW2 and begins with a start lead S3 and ends with a finish lead F-3.

The distribution transformer shown in FIG. 1 is of the series-multiple, or dual voltage rating type, and the primary winding sections PW1, PW2 and PW3 may alternatively be connected in series to provide a higher primary voltage rating or in parallel (multiple) to provide a lower primary voltage rating. Such series or parallel connection of the primary winding sections PW1, PW2 and PW3 may be effected by a terminal board or a series-multiple switch arrangement of the type disclosed in U.S. Pat. No. 3,440,586 in the name of Ernest A. Goodman. For example, the primary winding sections PW1, PW2 and PW3 may be of 2,400 volt rating so that when they are connected in parallel the voltage rating of the transformer is 2,400 volts, and when they are connected in series the rating of the transformer is 7,200 volts.

The invention is also applicable to dual rating transformers wherein one primary winding section is larger than the others, e.g., a transformer of 2,400–7,620 volt rating.

A static shield SS1 surrounds primary winding section PW1 and is electrically connected to the end turn at lead F1 so that line-side potential is applied to the shield SS1 to achieve linear surge voltage distribution across the exterior layer 40 of wire turns by providing uniform capacitance between static shield SS1 and each wire turn of most exterior layer 40. Inasmuch as the capacitance between line shield SS1 and each wire turn of exterior layer 40 is the same, any surge voltage across the layer is capacitance-graded and uniform across all the turns. Also, the voltage stress across the layer insulation (not shown) between adjacent helical wire layers 39 and 40 is lower and more uniform. Similarly a static shield SS2 surrounds primary winding section PW2 and is electrically connected to end turn F2, and a static shield SS3 surrounds primary winding section PW3 and is connected to finish terminal F3. Similar static shields SS4, SS5 and SS6 may underlay the innermost wire layer 36 of the primary winding sections PW1, PW2 and PW3 respectively and be connected to the line ends S1, S2 and S3.

The static shields SS1–SS6 are similar and only shield SS1 will be described. Shield SS1 includes an elongated thin strip of insulation 50, such as paper, having a conductive coating 51 thereon and having its longitudinal side edges 53 and 54 folded over to provide a relatively rounded edge which reduces corona, and preferably shield SS1 comprises aluminum-backed crepe paper. The conducting coating is on the inside of the fold for

minimum edge corona. Shield SS1 of aluminized crepe paper tape with its side edges folded over is enclosed in an envelope of suitable insulating material shown in FIGS. 2 and 3 as comprising an inner layer 56 of 5-mil kraft paper having its side edges folded over so that it is wrapped around shield SS1 and which, in turn, is surrounded by an outer layer 58 of 5-mil kraft paper having its longitudinal side edges folded over so that it envelopes shield SS1 and inner paper layer 50 to form a thin, flat elongated shield structure which overlaps most exterior helical wire layer 40 of primary winding section PW1. The total thickness of insulation 56 and 58 is a function of dielectric requirements (i.e., BIL) and of insulating material. The aluminum-backed crepe paper shield 50–51, as well as the inner and outer insulating layers 56 and 58, may be folded by conventional insulation-folding, or crimping, machinery used in production to manufacture conventional folded-edge insulation for high creep and puncture strength between adjacent winding sections.

Static shield SS1 is preferably electrically connected to the line end finish lead F1 by a thin conductive strip lead 60 of suitable material such as copper which is cold welded by suitable pressure applying means (similar to that disclosed in U.S. Pat. No. 2,807,231) to the conductive coating 51 on shield SS1, i.e., to the aluminum of the aluminum-backed crepe paper. The conductive strip lead 60 is preferably cold welded at 61 to the aluminum 51 before the longitudinal edges 53 and 54 of the aluminum-backed crepe paper are folded over, and the cold-welded end of lead 60 is preferably covered by the folded-over edges of the aluminum-backed crepe paper and extends out of the envelope of folded insulation 56–58 in a direction lateral of the longitudinal axis of shield SS1 as depicted in FIGS. 3 and 4. In alternative embodiments lead 60 is soldered or stapled to the crepe paper-backed foil shield SS1, but the cold-welded joint of the preferred embodiment minimizes labor and material cost.

In the embodiment illustrated in the drawing static shield SS1 extends across the width and around the circumference of outermost winding layer 40 and preferably is insulated from outer helical wire layer 40 to provide the same BIL (basic impulse level) for either series or parallel connection of the primary winding sections PW1, PW2 and PW3. Similar static shields may be used under the innermost layer 36 if it is the line lead, or under the innermost and over the outermost if both winding ends are line ends. In the FIG. 1 embodiment wherein each static shield SS1, SS2 and SS3 is electrically connected to the associated finish lead F1, F2 and F3, the shield-to-winding stresses are relatively small in comparison to other embodiments, e.g., to a winding wherein a single static shield extends across all three winding sections PW1, PW2 and PW3. For typical distribution transformers of the 95 kv BIL class, it may be reasonably assumed that approximately one-half of the 95 kv BIL impulse voltage appears across the outermost layer of insulation and that two-thirds of this potential will appear across the exterior helical layer 40 of wire turns. If the transformer is designed for 95 kv BIL, the shield-to-winding dielectric strength against impulse voltage should be approximately ½ times ⅔ × 95 = 32 kv, and 0.020 inch thickness of kraft paper in multiple layers would withstand this impulse voltage without failure. Thus, four layers of 5-mil kraft paper would adequately insulate shield SS1 from exterior layer 40 for 125 kv BIL, and assuming that insulating layers 56 and 58 of the insulation envelope wrapped around shield SS1 are each kraft paper of 5-mil thickness, sufficient shield-to-winding dielectric strength for this BIL is provided if two superimposed strips 62 and 63 of 5-mil kraft paper layer insulation are disposed between exterior wire turn layer 40 and outer layer 58 of the insulation envelope 56–58 surrounding static shield SS1. Further, it is desirable that at least one of the two kraft paper strips 62 or 63 have folded edges 65 to position static shield SS1 relative to winding section PW1 and to provide increased creep distance and dielectric strength between adjacent winding sections PW1 and PW2.

The shield-to-shield insulation must withstand the essentially full BIL impulse voltage if the primary winding sections PW1, PW2 and PW3 are connected in series. Assuming that the transformer is to be designed for a 95 kv BIL, adequate insulation will be provided if the folded edges 65 of layers 62 in winding sections PW1 and PW2 are each of 3/16-inch width to provide ⅜inch creep distance over kraft paper between shields SS1 and SS2 and if two 5-mil kraft paper layers 56 and 58 envelope each static shield SS1 and SS2. Other insulating materials may require different constants.

Inasmuch as each finish lead F1, F2 and F3 is connected electrically to the associated static shield SS1, SS2 and SS3 respectively, it will be appreciated that each static shield SS1, SS2 and SS3 is insulated to the same BIL for either series or parallel connection of the primary winding sections. Further, this disclosed construction permits uniform insulation and electrical clearances to be used throughout most, if not all, of the remainder of the primary winding P1, e.g., the same interlayer insulation comprising two sheets of kraft paper 67 and 68 (See FIG. 2) may be used between most, if not all, of the helical wire layers.

The folded-over aluminized crepe paper static shields SS1–SS6 provide rounded side edges and eliminate sharp points which would exist if a strip of slit aluminum material were wrapped in an insulation envelope, and the disclosed shield structure provides low section-to-section corona level and low RI (radio noise) voltage. Further, the aluminized crepe paper static shield exhibits low losses and heating from stray flux even under short circuit conditions.

While only a single embodiment of the invention has been illustrated and described, it should be understood that we do not intend to be limited to the single embodiment for many modifications and variations thereof will be obvious to those skilled in the art.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In an electrical distribution transformer having primary and secondary windings wherein said primary winding includes a plurality of superimposed helical layers of electrical wire turns, a static shield comprising an elongated strip of thin insulating material positioned contiguous an exterior layer of said wire turns and having a conductive coating on the surface thereof disposed away from said exterior layer and having both longitudinal side edges folded over and flattened so

that said insulating material is exposed on the outer surface of said shield, a thin strip of conductive material electrically connected to said conductive coating and also electrically connected adjacent the line end wire turn of said exterior layer, and an envelope of insulation wrapped around said elongated static shield so that it is disposed between said conductive coating and said exterior layer of wire turns.

2. In the combination of claim 1 wherein said strip of conductive material is cold welded to said conductive coating.

3. In the combination of claim 1 wherein said static shield comprises aluminum backed crepe paper.

4. In the combination of claim 1 wherein said static shield comprises aluminum-backed paper and said strip of conductive material is cold welded to said aluminum and said envelope of insulating material comprises a plurality of superimposed elongated strips of insulation having their longitudinal side edges folded over said aluminum backed paper shield and flattened so that they surround said shield and insulate it from said exterior layer of wire turns.

5. In the combination of claim 1 wherein said exterior layer is the radially outermost layer of wire turns, said static shield overlays said outermost layer, and said thin strip of conductive material is electrically connected adjacent the finish wire turn of said outermost layer.

6. In the combination of claim 1 wherein said exterior layer is the radially innermost layer of wire turns, said static shield underlays said innermost layer, and said thin strip of conductive material is electrically connected adjacent the start wire turn of said innermost layer.

7. In an electrical distribution transformer having primary and secondary windings wherein said primary winding includes a plurality of adjacent primary winding sections each of which includes a plurality of radially superimposed helical layers of electrical wire turns, a static shield for each primary winding section comprising an elongated first strip of thin insulating material wound in overlaying relation to the outer layer of wire turns of said primary winding section and having a conductive coating on the surface thereof away from said outer layer and having both longitudinal edges folded over and flattened so that said insulating material is exposed on the outer surface of said shield, an insulation envelope wrapped around said first insulating strip carrying said conductive coating, a thin conductive lead strip electrically connected to said conductive coating and also electrically connected adjacent finish wire turn of said outer layer of said section, and a second elongated strip of insulating material disposed between each said static shield and the corresponding outer layer of wire turns and having its longitudinal side edges folded over a short distance in the lateral direction to provide a long creep path between static shields of adjacent primary winding sections.

8. In the combination of claim 7 wherein said static shield comprises aluminum-backed crepe paper and said insulation envelope and said second insulating strip are of kraft paper.

9. In the combination of claim 8 wherein said thin conductive lead strip is cold welded to said aluminum coating of said static shield.

10. In an electrical distribution transformer having primary and secondary windings wherein said primary winding includes a plurality of adjacent primary winding sections each of which has a plurality of radially superimposed helical layers of electrical wire turns,

first and second static shields for each said primary winding section wound in overlaying and underlaying relation respectively to the outermost and innermost layers of wire turns of said primary winding section,

each said static shield comprising an elongated first strip of thin insulating material having a conductive coating on the surface thereof away from the adjacent layer of wire turns and having both longitudinal edges folded over and flattened so that said insulating material is exposed on the outer surface of said shield, an insulation envelope wrapped around said first insulating strip, a second elongated strip of insulating material disposed between said static shield and the adjacent layer of wire turns and having the longitudinal side edges folded over a short distance in the lateral direction to provide a long creep path between static shields of adjacent primary winding sections, and a thin conductive lead strip connected to said conductive coating,

said lead strips of said first and second shields being electrically connected to the finish and start wire turns of the associated primary winding section respectively.

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