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CORONA SUPPRESSION IN HIGH VOLTAGE COILS

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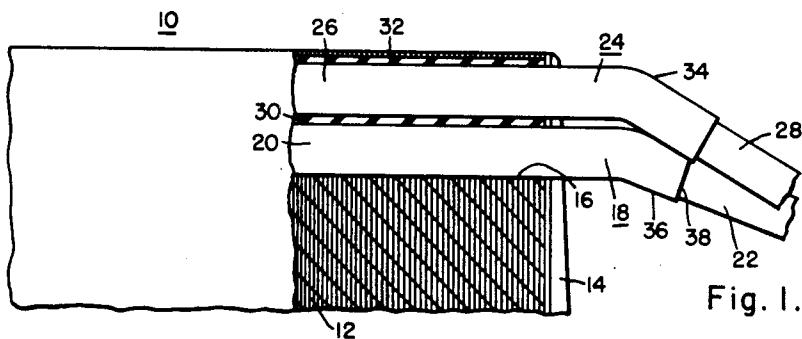


Fig. 1.

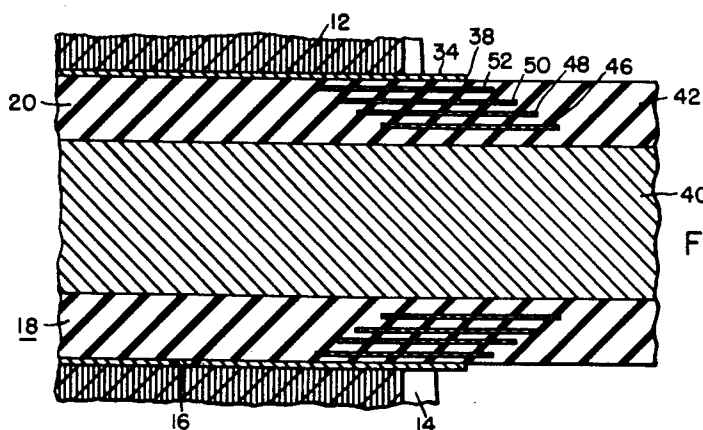


Fig. 2.

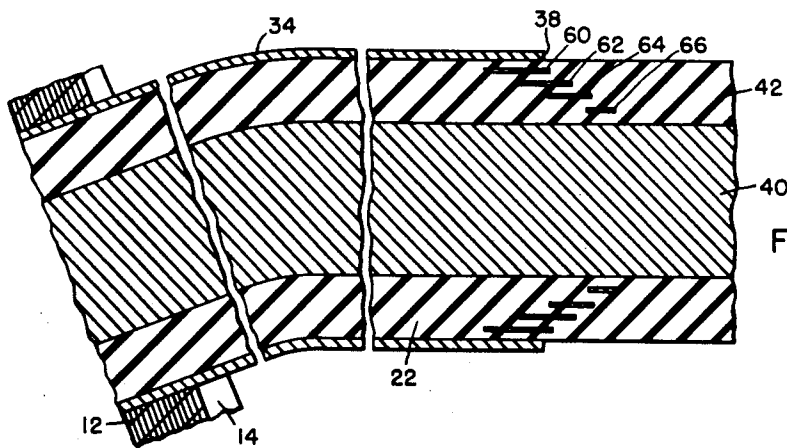


Fig. 3.

WITNESSES

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CORONA SUPPRESSION IN HIGH VOLTAGE COILS

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This invention relates to high voltage coils for dynamoelectric apparatus, constructed to greatly reduce or eliminate corona during use thereof.

The problem of suppressing or eliminating corona in high voltage conductors becomes increasingly more difficult with increase in voltage applied to the conductor. Thus while corona suppression has been attained to a reasonable degree in electrical coils employed at voltages of up to 13,000, corona is not controlled effectively by any conventional means when the voltages applied to the coils are of the order of 24,000 and higher. The presently applied corona suppressing means on high voltage coils are not always reliable and entirely effective even in conductors operating at voltages from 10,000 to 15,000.

As is well known, corona is highly detrimental to organic electrical insulation applied to conductors. Thus corona appears to generate highly corrosive acids which will attack and rapidly deteriorate conventional organic insulation. In some cases the corona produces ionized particles which degrade and corrode away the electrical insulation in a relatively short period of time. Regardless of the mechanism by which the corona operates, the degradation of the insulation leads to an eventual electrical failure of the apparatus.

The junction between the slot portion of an insulated coil and the end turn or diamond portion of the coil has been found to be the point at which corona tends to occur in greatest amounts and in preference to any other portion of the coil. In the event that a conducting coating has been applied to the slot portion of the coil and such coating extends beyond the slot portion the point on the end turn at which the conducting coating end constitutes the junction at which corona tends to occur. In nearly all high voltage machines such conducting coating is employed. It has been extremely difficult to suppress corona at such critical junctions.

The object of this invention is to provide for high voltage coils constructed with corona suppressing conducting layers distributed through the insulation at critical junction points so as to reduce the potential gradients between coils as well as between grounded stator parts and the coils by extending the length of the voltage grading zones of each coil and thereby reduce the possibility of corona occurring.

A further object of the invention is to provide a coil for a dynamoelectric machine wherein corona suppressing foils are disposed in the portion of the coil at the junction between the slot portion, or a surface conductive coating thereon, and the end turn portion thereof.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

For a better understanding of the nature and objects of the invention, reference should be had to the following detailed description and drawing in which:

Figure 1 is a fragmentary view partly in section of a dynamoelectric machine;

Fig. 2 is a vertical cross section through an enlarged

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portion of a dynamoelectric machine showing one modification of the present invention; and

Fig. 3 is a reenlarged vertical cross section showing another modification of the present invention.

5 The present invention is particularly directed to high voltage coils for dynamoelectric machines, which coils are so constructed that corona is greatly reduced or substantially completely suppressed. In such dynamoelectric machines the slot portion of the coil is disposed 10 in a magnetic core while the end turns are disposed in an ambient atmosphere which may be air or a suitable gas. The slot portion of the coils is provided with a substantial thickness of insulation to withstand the full voltage developed in the coil inasmuch as the magnetic 15 core is essentially at ground potential. In order to protect the slot portion from corona the exterior of the insulation is always coated with a low resistance coating which comes in contact with the core and in effect the entire surface of the slot portion insulation is at ground 20 potential.

Referring to Fig. 1 of the drawing, there is illustrated a portion of a dynamoelectric machine 10, which in this case is a stator. The dynamoelectric machine comprises a magnetic core 12 comprising a plurality of stacked 25 laminations which are compressed by finger plates 14. The magnetic core is provided with a slot 16 within which is disposed a lower insulated coil 18 and an upper insulated coil 24. The insulated coil 18 comprises a slot portion 20 and an end or diamond portion 22. 30 The upper coil 24 comprises a slot portion 26 and an end or diamond portion 28. An insulation strip 30 may be disposed between the coils 18 and 24. A slot wedge 32 is driven in the upper part of slot 16 above the slot portion 26 to retain both coils 18 and 24 within the slot. 35 The surfaces of the slot portions 20 and 26 are provided with a conducting coating 34 and 36, respectively, of low resistance material. This coating usually extends to an end point 38 a moderate distance beyond the end of the magnetic core. Such relatively low resistance coating usually has a resistance of the order of 500 to 40 75,000 ohms per square inch of surface. A coating of colloidal graphite or acetylene black in a suitable binder such as a resin is ordinarily employed for this purpose. However, other coating materials may be employed. It is in the immediate area at the end 38 of the coatings 34 and 36 that corona will appear in preference to almost any other point on the insulated conductor.

It has been discovered that corona may be substantially completely suppressed at the area adjacent the end point 38 of the resistance coating applied to the end 50 portion of a coil, by disposing within the coil insulation a series of overlapping conductive foils or films which function capacitatively to provide a uniform low voltage gradient over a substantial distance. Such foils or 55 films disposed within the insulation are arranged in a staggered or stepwise arrangement such that the foil nearest the electrical conductor extends farthest from the end of the surface resistance coating while the foil or film nearest the surface of the insulation is disposed at least partly under the resistance coating applied to the slot portion of the electrical conductor.

Referring to Fig. 2 of the drawing, there is illustrated one form of the present invention wherein the resistance coating on the surface of an insulated coil terminates 60 near the magnetic core. The coil 18 is shown disposed within the slot 16 of the magnetic core 12. The slot portion 20 is provided with the relatively low resistance coating 34 extending a short distance to point 38 beyond the end of the core slot and plate 14. In some cases from end 38 to plate 14 will not exceed 6 to 10 inches, 70 though this will vary considerably depending on the design of the coil, its size, and voltage of the machine.

The coil 18 comprises an electrical conductor 40 which will ordinarily comprise a plurality of copper straps. In some instances the copper straps are transposed. Upon the conductor 40 is applied a surface layer of insulation 42 of a suitable thickness to withstand the voltage between the conductor 40 and the magnetic core 12. As illustrated in Fig. 2, four foils 46, 48, 50 and 52 are disposed in stepwise, overlapping fashion throughout the insulation 42 at the point 38 where the resistance coating ends on the end portion of the coil. The foil 46 nearest the conductor 40 extends to a point farthest beyond the magnetic core, while the outermost foil 52 has a substantial part disposed underneath the relatively low resistance coating 34 on the conductor adjacent end 38.

The capacitive foils or films 46, 48, 50 and 52 comprise a wrapping of narrow metal films or conductive tapes or the like with each ply insulated from the others to reduce eddy currents. Therefore, each foil comprises a wrapped layer of overlapped plies in which each spiral ply is insulated from the one below. The metal foil tape can be of a width of the order of $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches. Ordinarily these foils are prepared from thin metal sheets, for example, aluminum or lead foil of a thickness of the order of 0.001 to 0.0001 inch. The metal films or foils are provided with an insulating backing. Good results have been obtained by employing a tape composed of aluminum foil of a thickness of $\frac{1}{2}$ mil attached to a sheet of paper of a thickness of 1 mil in order to strengthen the foil and enable it to be applied satisfactorily.

Since the insulation for practically all high voltage electrical conductors comprises a wrapping of mica tape insulation, the foils 46, 48, 50 and 52 are each applied after a predetermined number of plies of the mica tape have been wrapped on the conductor. Thus 3 to 5 plies of mica tape may be applied to the conductor 40 and then the first foil 46 will be wrapped thereon. A plurality of overlapping turns of the paper backed aluminum foil are wrapped until a sufficient length is applied. Additional plies of the mica tape may be then wrapped over the foil and the first layer of insulation, and then the second foil 48 is applied. This alternate wrapping of mica tape and foil is continued until the desired total thickness of insulation has been applied to the conductor. The conductor may be then impregnated with resins or subjected to heat and pressure to consolidate the resins that are present in the mica tape.

It will be understood that the insulation 42 may be prepared from other materials than mica tape. Thus, for example, glass fiber tape or resinous films or tapes may be wrapped on the conductor until the desired thickness necessary for service requirements has been so applied. Suitable impregnation with resins and curing of the applied resins by heating, with or without pressure, may be carried out to consolidate the insulation. The low resistance coating 34 is ordinarily applied to the coil after the insulation 42 has been consolidated or molded following impregnation and otherwise processed to substantially its final shape and size.

Each of the capacitor foils 46, 48, 50 and 52 are insulated from one another. The total length of each of the foils 46, 48, 50 and 52 will depend on the size of the conductor and the voltage present therein during service. For high voltage machines of the order of 11,000 to 30,000 volts the total length of each applied layer of foil may be from 30 to 80 inches, the longer lengths being employed for coils of greater copper perimeters and higher voltages. In a coil designed to operate 24 kilovolts, the copper conductor proper having a perimeter of 14 inches, the total length of the section embodying the foil layers was 34 inches. Each foil layer is produced by wrapping, for example, $\frac{3}{4}$ inch wide aluminum foil tape of a thickness of $\frac{1}{2}$ mil applied to a 1 mil paper backing. These layers are over-

lapped slightly, for example from $\frac{1}{4}$ to $\frac{1}{2}$ lap until the desired length of foil layer has been secured.

The foils 46, 48, 50 and 52, if of substantial length, may overheat particularly at high voltage conditions if the foil were to comprise a single sheet of aluminum, for example. By employing relatively narrow tape comprising aluminum foil cemented to an insulating backing of paper, resin or the like and wrapping such relatively narrow tape in a slightly overlapped fashion to produce the full foil length, excessive eddy current losses are greatly minimized. Particularly, for higher voltage service it is desirable that the aluminum foil tape not exceed a width of $1\frac{1}{2}$ inches. Good results have been obtained with tape of a width of $\frac{3}{4}$ inch and $\frac{1}{2}$ inch.

The successive foils 46 to 52 distribute the voltage across the ground wall insulation 42 and also distribute the voltage across the surface of the end portions of the coil to ensure uniform low gradients.

Exceptionally good results have been obtained by a variable length construction in accordance with the present invention in which each succeeding foil in progressing from the one nearest the conductor to the outside of the insulation is longer than the one below it. Such construction is illustrated in Fig. 3 of the drawing wherein the insulated coil 18 comprising the electrical conductor 40 and the insulation 42 is provided with foils 60, 62, 64 and 66 of progressively shorter length. It will be observed that the conductive or resistance coating 34 extends a substantial distance to end 38 from core 12 upon end turn 22. A portion of each foil is disposed in overlapping fashion above the foil below it with a substantial portion of the topmost foil 60 being located beneath the conductive coating 34 which is at ground potential. The construction shown in Fig. 3 will have an average voltage gradient of approximately 40 volts per mil thickness of insulation for a conductor to be employed at 18 kilovolts. The total lengths of the grading section, namely from the extreme left edge of foil 60 to the extreme right edge of foil 66, is 29 inches for an 18 kilovolt coil of copper perimeter of 5 inches. The total length of the foil section for the variable length system of Fig. 3 can be as low as 7 inches for a conductor operating at 11,000 to 14,000 volts and increases with voltage up to as much as 30 to 70 inches for a conductor operating at 45 to 50 kilovolts.

It will be appreciated that the topmost foil 52, or foil 60, and the next foil therebelow may be disposed within the slot portion of the core without resulting in undesirable hot spots. However, the foils nearest the conductor 40 are located substantially beyond the slot portion.

The separate foil layers as illustrated in Figs. 2 and 3, have the outermost edges of the foil layers staggered a substantially uniform distance. The edges of the succeeding foil layers can be displaced as little as $\frac{1}{2}$ inch, though displacements of from 2 to 4 inches are preferred. However, the edge displacement can be varied depending on the voltage between the foil layers.

The number of foil layers is dependent on the total voltage in the coil, one foil layer being used for each 1500 to 3000 volts, and preferably one foil layer for each 2000 to 2500 volts.

The space between the successive foils 60, 62, 64 and 66 is filled with the insulation, which space is shown as being substantially constant. However, the spacing between foils may be varied, for example, increasing slightly between foils as they progress from the conductor 40. Likewise, the number of foils that may be employed need not be restricted to four foils as shown, but may comprise five or seven foils or even more. Thus, in one particular application the foil nearest the conductor comprised a total length of four inches of half-lapped $\frac{3}{4}$ inch wide aluminum foil $\frac{1}{2}$ mil thick on a paper backing, and was applied after five layers of half wrapped mica tape had been wrapped on the copper conductor 40.

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Then three half wrapped layers of mica tape was applied over the initial foil layer. A second foil layer extending for a length of six inches was applied at a point two inches nearer the slot portion than the first foil. Thereafter, five additional foil layers were applied, each separated from the other by three half wrapped layers of mica tape, each foil layer being two inches nearer the slot portion than the preceding foil layer. The third foil layer was nine inches in length, the fourth was twelve inches in length, the fifth was 15 inches in length, the sixth was 18 inches in length and the seventh was 22 inches in length. Upon the seventh foil layer were applied three layers of half lapped mica tape and a half lapped layer of glass tape, and the entire insulation layers impregnated with resin, and cured under heat and pressure to size and shape. The surface of the slot portion of the cured conductor insulation was coated with a conducting varnish film comprising acetylene black in an organic varnish which terminated approximately two inches from the end of the seventh or outermost foil layer furthest from the slot portion. The surface resistance of the coating was approximately 1,000 ohms per square inch. This construction was particularly adapted for application to a 24 kilovolt stator half coil.

While metallic foils have been particularly emphasized, it will be appreciated that fiber glass tape coated with a conductive material such, for example, as silver metallic flake containing paint, or graphite, or other conductive carbonaceous material may be employed for the foil portions. The foils should have a resistance of the order of 10 to 500 ohms per square inch, or less.

It will be understood that the above description and drawing are illustrative of the invention and not limiting. I claim as my invention:

1. In a high voltage dynamoelectric machine having a magnetic core and an insulated coil disposed partly in the magnetic core and having an end portion extending into a gaseous medium surrounding the magnetic core, the insulated coil being subjected in service to a high voltage normally tending to produce corona, the coil comprising a metallic conductor and insulation applied to the exterior thereof, in combination, a coating of relatively low resistance applied to the surface of the insulation of that part of the coil disposed in the magnetic core and ending at a point on the end portion there being no other conductive coating applied to the rest of the surfaces on the end portion beyond said point, a plurality of separate, spaced, concentrically disposed layers of low resistance material not in excess of about 500 ohms per square inch disposed in the insulation on the end portion at the point at the end of the coating of low resistance, the layers being arranged in stepwise fashion so that the layer nearest the metallic conductor extends farthest beyond the said end point and each succeeding layer terminates at a point nearer the said point on the end portion, at least the outermost layer being disposed so that a substantial part is immediately below the low resistance coating, no layer of low resistance material being disposed within the magnetic core, the coating and layers, cooperating to reduce corona.

2. In a high voltage dynamoelectric machine having a magnetic core and an insulated coil disposed partly in the magnetic core and having an end portion extending into a gaseous medium surrounding the magnetic core, the insulated coil being subjected in service to a high voltage normally tending to produce corona, the coil comprising a metallic conductor and insulation applied to the exterior thereof, in combination, a coating of relatively low resistance applied to the surface of the insulation of that part of the coil disposed in the magnetic core and ending at a point on the end portion, there being no other conductive coating applied to the rest of the surfaces on the end portion beyond said point,

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a plurality of separate, spaced, concentrically disposed metallic layers of low resistance metal disposed in the insulation at the end of the low resistance coating, the layers being arranged in stepwise fashion so that the layer nearest the metallic conductor extends farthest beyond the said end and each succeeding layer terminates at a point nearer the said end, no layer of low resistance metal being disposed within the magnetic core, the layers progressively increasing in area in proportion to their distance from the metal conductor, at least the outermost layer being disposed so that a major part is immediately below the low resistance coating, the coating and layers cooperating to reduce corona.

3. In a high voltage dynamoelectric machine having a magnetic core and an insulated coil disposed partly in the magnetic core and having an end portion extending into a gaseous medium surrounding the magnetic core, the insulated coil being subjected in service to a high voltage normally tending to produce corona, the coil comprising a metallic conductor and insulation applied to the exterior thereof, in combination, a coating of relatively low resistance of the order of from 500 to 75,000 ohms per square inch applied to the surface of the insulation of that part of the conductor disposed in the magnetic core and ending at a point on the end portion, at least four separate, spaced, concentrically disposed wrapped layers of metal foil tape of a thickness of the order of 0.0001 to 0.001 inch and a width of the order of $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches disposed in the insulation at the end point of the low resistance coating, each of the plies of the metal foil tape wrapping being applied in overlapping fashion and insulated from one another, the layers being arranged in stepwise fashion so that the layer nearest the metallic conductor extends farthest beyond the said end and each succeeding layer terminates at a point nearer the said end point, the layers progressively increasing in length in proportion to their distance from the metal conductor, at least the outermost layer being disposed so that a substantial part is immediately below the low resistance coating, the coating and layers cooperating to reduce corona.

4. An insulated electrical coil comprising an electrical conductor, the electrical conductor having a slot portion adapted to fit a slot in a magnetic core and an end portion projecting beyond the slot portion and extending into a gaseous medium when the coil is disposed in the magnetic core, electrical insulation applied to the electrical conductor, the insulation comprising a plurality of plies of a tape comprising mica and a resinous binder, a low resistance coating applied to the exterior of the insulation at the slot portion and ending at a point on the end portion, there being no other conductive coating applied to the rest of the surfaces on the end portion beyond said point, a plurality of separate, spaced low resistance metal foils disposed concentrically within the insulation, each foil separated from the other foils by at least one layer of the mica tape, the low resistance foils being disposed at the end point of the low resistance coating, at least a substantial part of the outermost foil being located below the low resistance coating, the foils being disposed in stepwise fashion so that the foil nearest the electrical conductor is farthest away from the said end point, the foil nearest the conductor being not longer than the foil furthest away, the foils and the low resistance coating cooperating to enable the coil to withstand high insulation with greatly reduced corona.

5. In a high voltage dynamoelectric machine having a magnetic core and an insulated coil disposed partly in the magnetic core and having an end portion extending into a gaseous medium surrounding the magnetic core, the insulated coil being subjected in service to a high voltage normally tending to produce corona,

the coil comprising a metallic conductor and insulation applied to the exterior thereof, in combination, a coating of relatively low resistance of the order of from 500 to 75,000 ohms per square inch applied to the surface of the insulation of that part of the conductor disposed in the magnetic core and ending at a point on the end portion, at least four separate, spaced, concentrically disposed wrapped layers of metal foil tape of a thickness of the order of 0.0001 to 0.001 inch and a width of the order of $\frac{1}{4}$ inch to $1\frac{1}{2}$ inches disposed in the insulation at the end point of the low resistance coating, the plies of the metal foil tape wrapping being applied in overlapping fashion and insulated from one another, the number of foil layers comprising one for each 1500 to 3000 volts in the coil, the layers being arranged in stepwise fashion so that the layer nearest the metallic conductor extends farthest beyond the said end point and each succeeding layer terminates at a point nearer the said end point, the layers progressively increasing in length in proportion to their distance from the metal conductor, at least the outermost layer being disposed so that a substantial part is immediately below the low resistance coating, the total length of the entire foil section comprising at least 7 inches and being up to 70 inches, the shortest length being employed at voltages of the order of 11 kilovolts and the longest lengths at voltages of the order of 50 kilovolts, the coating and layers cooperating to reduce corona.

6. An insulated electrical coil comprising an electrical conductor, the electrical conductor having a slot portion adapted to fit a slot in a magnetic core and an end portion projecting beyond the slot portion and extending into a gaseous medium when the coil is disposed in the magnetic core, electrical insulation applied to

the electrical conductor, the insulation comprising a plurality of plies of a tape comprising mica and a resinous binder, a low resistance coating applied to the exterior of the insulation at the slot portion and ending at a point on the end portion, the resistance coating having a resistance of the order of 500 to 75,000 ohms per square inch, there being no other conductive coating applied to the rest of the surfaces on the end portion beyond said point, at least four separate, spaced foil layers disposed concentrically within the insulation, there being present a foil layer for each 1500 to 3000 volts applied to the coil, each foil layer being separated from the adjacent foil layers by at least one layer of mica tape, the foil layers comprising a wrapping of overlapped plies of metal foil tape of a thickness of the order of 0.0001 inch to 0.001 inch with insulation between the plies, the foil layers being disposed in the insulation at the end point of the low resistance coating, the foil layers being arranged in stepwise fashion so that the edge of each foil layer furthest from the slot portion is disposed from $\frac{1}{2}$ inch to 4 inches nearer the slot portion than the foil layer immediately below, and a major part of the outermost foil is immediately below the low resistance coating with at least one layer of mica tape therebetween, the low resistance coating and foil layers cooperating to reduce corona by grading the potential throughout the insulation.

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