April 16, 1963 M. L. MANNING 3,085,315

METHOD OF CONSTRUCTING INSULATING BARRIER FOR STATIONARY INDUCTION APPARATUS

Original Filed Aug. 6, 1952 2 Sheets-Sheet 1

Fig. 1.

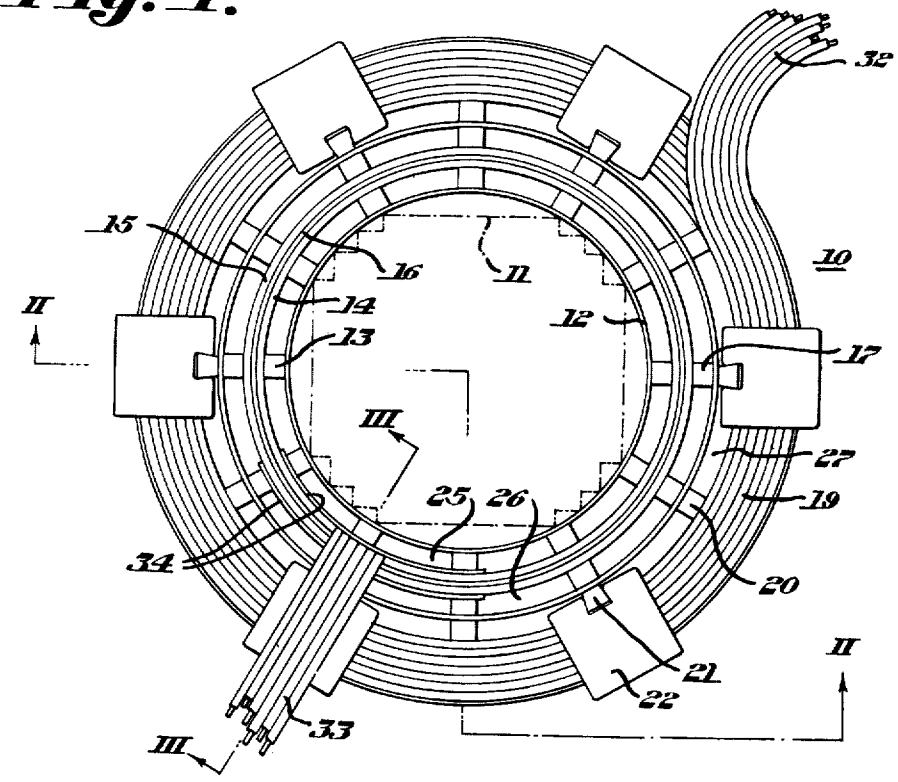
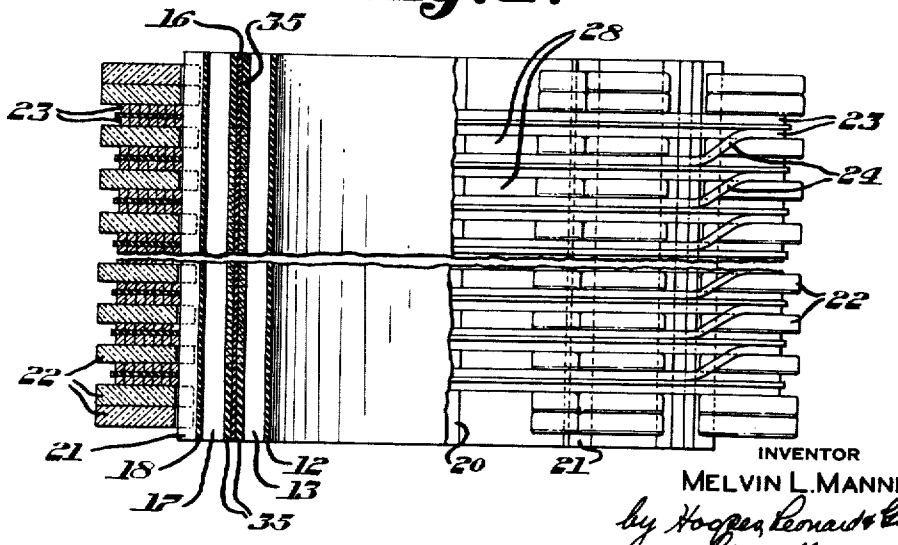


Fig. 2.



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Original Filed Aug. 6, 1952 2 Sheets-Sheet 2

Fig. 3.

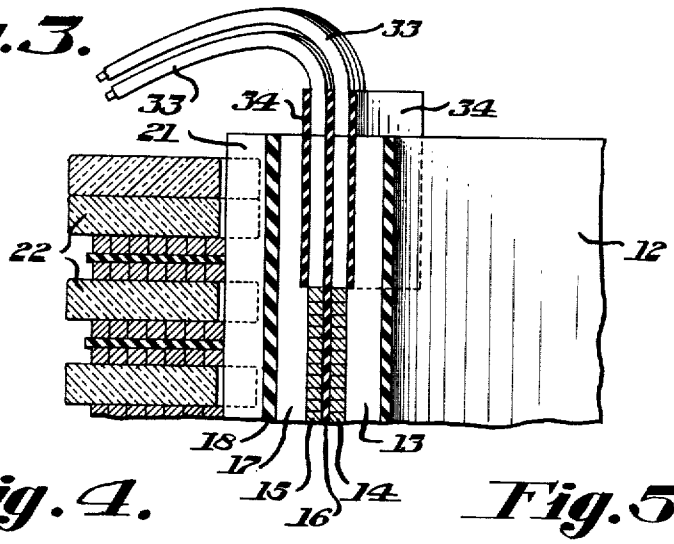


Fig. 4.

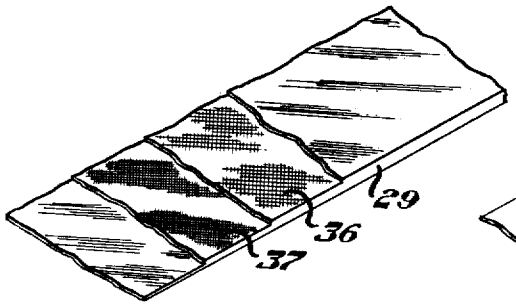


Fig. 5.

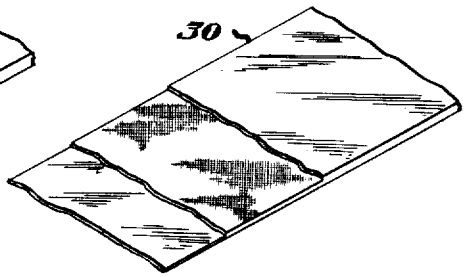


Fig. 6.

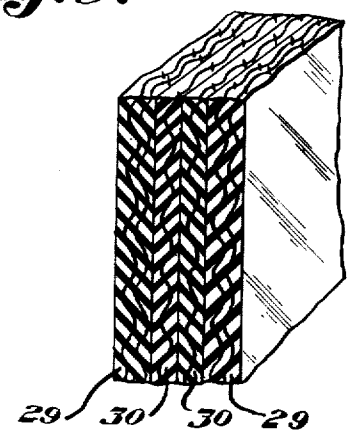
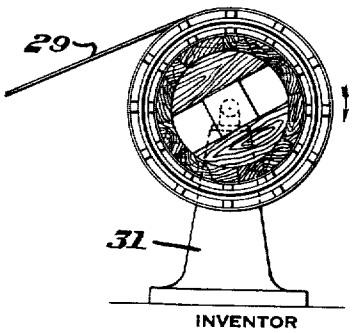


Fig. 7.



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3,085,315

METHOD OF CONSTRUCTING INSULATING BARRIER FOR STATIONARY INDUCTION APPARATUS

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Original application Aug. 6, 1952, Ser. No. 302,887, now Patent No. 2,827,616, dated Mar. 8, 1958. Divided and this application July 15, 1957, Ser. No. 675,792

10 Claims. (Cl. 29—155.57)

This application is a division of application Serial No. 302,887, filed August 6, 1952, now patent No. 2,827,616.

This invention relates to a new high temperature transformer construction or the like. More particularly, it pertains to an improved method of constructing insulating barriers for stationary induction apparatus in which silicone and fiber insulating materials are combined.

High temperature transformers and other high temperature electrical induction constructions have been an objective of various manufacturers for some time. The work in that direction received added impetus upon the widespread introduction of silicone materials a few years ago. Despite the recognition of the electrical qualities of such materials, a number of drawbacks attended use of them. One manufacturer despite the availability of such silicone materials provided heat-resistant glass cylinders for insulating barriers.

I have discovered a new method of constructing insulating barriers for high temperature transformers which enables the remarkable properties of silicone materials to be fully employed for insulation and support purposes to provide a transformer or the like with a Class-H rating. At the same time, I am enabled to shield the leads and windings by means of my new method of construction in a manner which preserves the advantages thereof without risk of creepage or breakdown in that area. Other advantages of my new method of construction are that it provides protection against local dielectric and thermal weakness points and permits efficient construction practices to be employed.

Other objects and advantages of this invention will be apparent from the following description and from the drawings, which are illustrative only, in which

FIGURE 1 is a plan view, partly schematic, of low and high voltage windings, barriers and spacers of a high temperature dry transformer embodying my invention;

FIGURE 2 is a view in elevation of the structure shown in FIGURE 1 taken along line II—II of FIGURE 1;

FIGURE 3 is a somewhat detailed view of the portion of the structure shown in FIGURE 1 adjacent the low voltage winding leads and shielding, taken along the line III—III of FIGURE 1;

FIGURE 4 is an illustrative dissected view of a formable silicone resin laminate employed in my new construction;

FIGURE 5 is an illustrative dissected view of a flexible silicone rubber and fiber ply material employed in my new construction;

FIGURE 6 is a section through a core to low voltage winding barrier in my new construction showing the silicone materials of FIGURES 4 and 5 in an interleaved combination; and

FIGURE 7 is a diagrammatic showing of one end of a transformer embodying my invention in the course of being constructed.

Referring to the drawings, a power transformer **10** is shown in FIGURES 1 and 2 in sufficient detail to illustrate the new construction features in one embodiment of my invention. In that embodiment, a cruciform laminated core leg **11** of a conventional magnetic core may be illustrated as shown in FIGURE 1 by dot-and-dash lines. A core to low voltage winding (CL) barrier envelope **12** surrounds core leg **11** in close proximity thereto. Axial spacers **13** may be positioned around the outside of CL barrier **12** in spaced arrangement where they are held in the course of the winding of the concentric layers **14** and **15** of a helically wound low voltage winding. Spacers **13** may be held against barrier **12** by a suitable silicone adhesive or other means. The conductors employed in winding the low voltage winding layers **14** and **15** may be wire which is served with a glass silicone resin bonded tape insulation prior to winding. In other cases, such conductors may be served with other materials such as flexible asbestos or glass cloth silicone tape or "Teflon" tape. Insulation in the form of a cylindrical envelope **16** may be interposed between the layers **14** and **15** by using, for example, silicone rubber ply material similar to that employed in the construction of CL barrier **12**.

A further series of axial spacers **17** may be held against and spaced around the exterior of the low voltage winding coil comprising layers **14** and **15**. A further insulating (HL) barrier envelope **18** between the low voltage coil **14—15** and a high voltage coil **19** may be provided under my new construction entirely of silicone and fiber matrix materials. HL barrier **18** may comprise a combination of more of the interleaved plies than the number used for the CL barrier as shown in FIGURE 6. Barrier **18** insulates the low voltage windings from the high voltage windings and must withstand the relatively high voltage potentials and thermal increases to which it is subjected. A further series of axial spacers **20** of solid or molded U shapes may be fastened at uniform intervals around and to the exterior of HL barrier **18**. Alternate spacers **21** in the series of spacers **20** may be of keystone shape, if desired, to permit keying engagement with and movement during assembly for lateral spacers **22**.

The high voltage coil **19** may comprise a plurality of double layer horizontal pancake windings **23** in vertically stacked arrangement as shown in FIGURE 2, respective ones of said such windings being interconnected electrically by crossover conductors **24**. The radial spacers **22** may be made of a mechanically and electrically strong material like porcelain. Axial spacers **13**, **17** and **20** may be made of Class-H insulating material in the form of solid or channel-shaped spacers. As an example, I have discovered that glass cloth or asbestos cloth bonded with silicone resin materials may be molded or otherwise shaped and cured to provide axial spacers of markedly superior mechanical and dielectric strengths. The annular pressure plates and tie rods which respectively bear endwise on the respective windings and lateral spacers **22** have not been illustrated as such features will be well understood by those skilled in the art. The vertical ducts **25** between the axial spacers **13**, the vertical ducts **26** between the axial spacers **17**, the vertical ducts **27** between the axial spacers **21** and the lateral ducts **28** between the lateral spacers **22** afford access to the turns of the respective windings for whatever cooling or ambient fluid may be employed. In the case of a sealed dry-type transformer embodiment, a gas like nitrogen may be used to fill the gas space within a transformer tank in which my new construction is placed.

In construction the embodiment shown in FIGURES 1 and 2, one mode of making the new barrier envelope is illustrated in connection with making a barrier **18** and other barrier **12** may be similarly made. In the transformer or the like being constructed, any entire or other partial barriers, whether cylindrical or arcuate, may be constructed in accordance with my invention. In that invention, one or more sheets **29** of a formable silicone resin and fiber laminate is combined in interleaved man-

ner with one or more plies **30** of flexible silicone rubber and fiber material. Generally, in preparing a cylindrical envelope barrier in accordance with this invention, each kind of material is formed into the desired cylindrical shape beginning with the innermost layer. Thus, a cylinder of the laminate may be provided and the ends overlapped and fastened by a silicone adhesive, for example, or by Class-H tapes of sufficient strength, enough turns being made in the laminate layer to provide a due share of the total insulation of the new combination. Then one or more layers of the silicone rubber and fiber material may be formed in cylindrical shape around the laminate and the outermost end of said material fastened again by silicone adhesive or other means. In some cases, the laminate material may have a silicone rubber layer affixed to one or both surfaces of the laminate before the laminate is formed. Around the silicone rubber and fiber material, another one or more layers of laminate material may be wound against the exterior of the silicone rubber and fiber material layer or layers to complete the interleaving. As shown in FIGURE 6, barrier **12**, for example, may be made in the form of a right cylinder, the innermost layer of which as shown is a layer of formable laminate surrounded by two layers of silicone rubber and fiber in turn surrounded by a single layer of laminate again, the entire construction comprising a single barrier envelope with markedly superior features, both dielectrically and mechanically, to any insulation heretofore provided.

The construction of a new barrier envelope may be performed in a winding lathe such as those used in the transformer industry. For example, as illustrated in FIGURE 7, a barrier such as HL barrier **18** is shown being formed in place. The CL barrier has already been formed and is molded in a lathe **31** which rotates in the direction of the arrow. If desired, a steel cylinder may be used as the innermost mold to initiate the construction of barrier **12** thereagainst in which event a mold release compound, for example, may be used between the exterior of the mold cylinder and the interior cylindrical surface of the CL barrier **12**. In the partially completed construction shown in FIGURE 7, the axial series of spacers **13** has been positioned, the low voltage winding **14—15** has been wound on the lathe around the spacers **13**, the spacers **17** have been positioned and the lathe is in the midst of winding the HL barrier **18** as aforesaid with a strip **29** of laminate. Enough layers of silicone laminate and silicone rubber material will be utilized in the new interleaved relation to provide the necessary mechanical and dielectric strength required for the high-low voltage barrier envelope service in the particular transformer or the like under construction. When such winding of barrier **18** is completed, that barrier, as is the case of barrier **12**, will have sheets **29** and **30** interleaved throughout. Preferably, the sheets **29** and **30** are of a width equal to the entire height of the transformer windings plus the additional height equal to the keep-back insulation length desired at the respective axial ends of the transformer or the like.

The new construction of this invention also effects a marked improvement in taking care of lead outlets particularly in the case of the more interior windings such as the low voltage coil **14—15** shown in the illustrated embodiment. Leads **32** from the high voltage coil **19** do not generally present any particular problem in the case of an embodiment such as that shown because of their presence in the vicinity of the exterior of the transformer where they can, for example, be readily conducted upwardly through an insulating tube, which, again, may be made of tubular silicone material now available on the market.

On the other hand, conductor leads **33** are generally connected not only to the ends of the low voltage coil **14—15** but also to intermediate points therein and all of the leads or taps have to have an outlet from the interior

of the embodiment of the new transformer which is shown. In my invention, cylindrical insulation plates **34** which are arcuate and may be preformed of interleaved layers of laminate like laminate **29** alternating with interleaved layers of silicone rubber material like ply **30** are provided and inserted in place as shown in FIGURES 1 and 3 generally in the course of the construction winding as on lathe **31**. The surface of the insulation exposed to the lead or leads is preferably faced with a silicone rubber coated glass cloth or asbestos cloth.

In such construction, as an example, the innermost plate **34** may be pinched between and held between the top turns of layer **14** and the adjacent axial spacers **13** on the other side of that plate **34**. On the other hand, if keep-back insulation of a Class-H category is interposed between the plates **34** above the topmost turn of the layers **14** and **15**, and, on each side of leads **33** in a circumferential direction, as shown in FIGURE 3, then the plates **34** may respectively be held between such keepback insulation **35** and the axial spacers **13** and **29** respectively. The height of the plates **34** above the barriers **12** and **18** guards against creepage and any possibility of short-circuiting at the outlet shown of the taps **33** relative to parts of the transformer at different voltage potentials.

Laminate sheets such as sheets **29** may now be obtained as a commercial article having a fiber cloth matrix of an inorganic material like heat-cleaned glass or asbestos. Such fibrous matrix in the case of glass, for example, may be in part a staple cloth **36** woven of short lengths of glass filaments in the manner of a staple vegetable fiber cloth. Laminate **29** also preferably employs a fiber matrix cloth **37** woven of continuous glass filaments placed in juxtaposition to the cloth **36**. These cloths **36** and **37** are impregnated with a silicone resin which enters the interstices of the cloth and wholly covers them to form, when solidified, the laminate sheets **29**. In place of such fiber matrix, it may also be possible to use such inorganic fibers in the form of a felted cloth or matte highly resistant to electrical, mechanical and thermal deterioration. The silicone resins may be of a kind such as those sold by Dow Corning Corporation under the trade identification "DC 2104." A silicone material laminate of suitable character for employment in my invention is one such as that made by Mica Insulator Company of Schenectady, New York, having the trade designation "E–724 Lamacoid." In preparing laminate **29**, usually from 40 to 60 percent of the weight thereof will be the partially or wholly cured and solidified silicone resin. In applying the laminate **29**, it is preferable to place the staple cloth **36** on the inside of the bend and the continuous fiber cloth **37** on the outside, generally with the warp of both cloths parallel to the longitudinal axis of the insulation envelope or cylinder being constructed.

Suitable silicone rubber plies such as the sheet **30** are also now commercially available on the market for employment in my invention. Such a silicone rubber material may comprise a cloth of inorganic fiber like glass or asbestos, thoroughly heat-cleaned to remove organic binders, which cloth forms a matrix for a silicone rubber coating. One suitable silicone elastomer for such coating purpose is "Silastic," a trade name of Dow Corning Corporation, which corporation also makes a suitable silicone rubber and fiber matrix material suitable for the sheets **30**. The fiber glass which may be utilized in the construction of the new insulation components of this invention should have characteristics suitable for satisfactory electrical, mechanical and thermal service in a Class-H transformer. Certain of the glass products termed "Fiberglas" by Owens Corning Fiberglas Corporation are suitable in making up the matrices for silicone sheet materials like sheets **29** and **30**.

In my employment of such new insulation in a transformer or the like, I have also found it useful to have the dielectric constants of the interleaved sheet materials

like sheets **29** and **30** of about the same dielectric constant, which may be in the neighborhood of 3.5. Thereby, the gradient through the materials in series because of their interleaved relation appears to be relatively uniform and the voltage strength throughout the new insulation structure will also be generally uniform and foci of weakness for breakdown in the course of use are avoided. The use of various filler materials such as titanium dioxide or zinc oxide may be employed in the manufacture of the silicone rubber material, as will be well understood by those in the art to whom this invention is disclosed, to achieve relative equality of the dielectric constants of the component laminate and silicone rubber materials in the composite insulation. Other ways may be employed to harmonize the respective constants of the two sheet materials.

In constructing the new transformer the laminate may be formed cold for bent diameters exceeding about 10 inches whereas formerly it was believed that such kind of material had to be heat formed. I find, however, that not only may such material be cold formed but that such cold forming for laminates not in excess of about 1/32 of an inch in thickness does not produce any tendency to craze it, particularly when used in cooperation with a silicone rubber material like the sheets **30** having a thickness between about 1/64 of an inch and 1/32 of an inch. In some cases the laminate, particularly for smaller diameter uses or thicker sheets, may be heated to about 165° C. for a relatively few minutes generally not in excess of four.

It appears that the new composite insulation forms a unitary mass which functions ideally as the supporting framework for the windings of the new transformer and provides dielectric characteristics and strength between the various parts of the transformer at different potentials to enable a new transformer to function in the Class-H category without the disabilities of prior transformers in such category. The sheet materials **29** and **30** so employed may in the case of the laminate be partly or fully cured whereas in the case of the silicone rubber and fiber matrix material it will generally be in a partly cured state. Curing of the insulation after completion of the winding assemblies may be performed at at temperature at about 250° C. Prior to such curing, the winding assembly may be dipped into a silicone type of varnish, as one example, to complete the mechanical binding of the new transformer windings and assembly. One advantage of such a varnish is that its high gloss reduces any opportunity for the settlement of dust or other contaminant which might constitute a leakage path and another is its high craze resistance. Thereafter, if not earlier, any mold cylinder which has been employed will be removed before the completion and performance testing of the entire transformer or the like.

A study of the advantages of my new composite insulation and cooperation in a transformer or the like leads to the belief that the interleaved substances complement one another in the course of use to a marked and unusual extent. For example, the silicone rubber and fiber matrix material appears to at least hinder the aging of the silicone resin and fiber matrix laminate and also to cooperate in dissipating any tendency to craze or crack which the laminate might otherwise have. Further, the heat conductive properties of the silicone rubber material appear to be superior to those of a silicone laminate such as that described with the consequence that the thermal lag of the one material like sheet **29** is materially aided if not overcome by the thermal conductivity of sheet material like sheets **30**. Thereby the new transformers or the like can be consistently worked and operated at higher levels and/or for longer times as in the case of varying load cycles or load demands on transformers, without detriment.

The hot spot temperature standard of 180° C. set some years ago for Class-H insulation can be materially exceeded by means of the present invention without any observable deterioration. In constructing the new transformer or the like, it will be understood that other insulating materials that may be used for other parts of the transformer than those described herein will be of suitable electrical and mechanical characteristics for the intended purpose. The invention is applicable not only to dry but also to wet transformers or the like and to ventilated and sealed transformers and the like.

Various changes may be made in the practice of the present invention without departing from the spirit thereof or the scope of the appended claims.

I claim:

1. In the method of constructing a coil assembly of high heat resistance for a high temperature electrical transformer, the steps of winding a cylindrical first electrical coil, forming at least partially cured silicone resin impregnated sheets having an inorganic filler and silicone rubber sheets having an inorganic filler into an insulating barrier of concentric, radially staggered silicone resin impregnated and silicone rubber tubes supported on and surrounding said first coil, winding a second electrical coil supported on and concentric with said barrier, impregnating said coils and said barrier with a silicone varnish, and heating said coils and said barrier, whereby said coils and said tubes are mechanically bound together and the mechanical and dielectric strength of said barrier is materially increased.

2. In the method of constructing a coil assembly of high heat resistance for a high temperature electrical transformer, the steps of winding a first electrical coil upon a rotatable cylindrical mandrel, bending while rotating said mandrel stiff but formable, flat, at least partially cured silicone resin impregnated sheets having an inorganic filler and silicone rubber sheets having an inorganic filler into an insulation barrier of radially staggered, concentric silicone resin impregnated and silicone rubber tubes supported on and surrounding said coil, winding a second electrical first coil concentric with and supported from said barrier to complete an assembly of concentric coils having a tubular insulating barrier therebetween, removing said coil assembly from said mandrel, impregnating said coil assembly with silicone varnish, and heat curing said coil assembly.

3. In the method of constructing a heat resistive tubular insulation barrier for a high temperature electrical transformer, the steps of winding an electrical coil upon a rotatable mandrel securing an edge of a silicone resin impregnated rigid but bendable laminate sheet having an inorganic fiber cloth filler relative to said coil and said mandrel so that said edge is parallel to the axis of said mandrel and the warp of said cloth is also parallel to said axis, rotating said mandrel while retaining said sheet in tangential relation relative to a projected cylinder concentric with said mandrel to roll said sheet into a tube surrounding said coil, and repeating the last two steps to roll additional silicone resin impregnated sheets into tubes surrounding said coil and build up a tubular insulating barrier surrounding said coil having sufficient flexural strength to withstand the forces resulting from electrical short circuit on said coil.

4. In the method of constructing a heat resistive tubular insulation barrier surrounding the winding of a high temperature electrical transformer, the steps of winding a cylindrical electrical coil upon a rotatable mandrel, securing an edge of rigid but bendable, flat silicone resin impregnated laminate sheet having an inorganic filler relative to said coil and said mandrel so that said edge is parallel to the axis of said mandrel and said coil, rotating said mandrel while retaining said sheet in tangential relation relative to a projected cylinder concentric with said mandrel to roll said sheet into a tube surrounding said coil, holding said silicone resin laminate sheet in tubular from, repeating the securing and rotating and holding steps to roll additional silicone resin impregnated lami-

nate sheets into tubes surrounding said coil and build up a tubular insulation barrier surrounding said coil, and heating said coil and said tubular insulating barrier to effect curing thereof.

5. In the method of constructing a coil assembly having high heat resistance for a high temperature electrical transformer, the steps of winding a first electrical coil upon a rotatable cylindrical mandrel, securing an edge of stiff but formable silicone resin impregnated laminate flat sheet having an inorganic filler relative to said coil and said mandrel so that said edge is parallel to the axis of said mandrel, rotating said mandrel while retaining said insulation sheet in tangential relation relative to a projected cylinder coaxial with said mandrel to roll said sheet into a tube surrounding said first coil, repeating the last two steps to roll additional silicone resin laminate sheets into tubes surrounding said first coil and build up a tubular insulating barrier having sufficiently high flexural strength to withstand the forces resulting from electrical short circuit on said first coil, winding a second electrical coil coaxial with and supported from said barrier to complete an assembly of electrical coils having a tubular insulating barrier therebetween, and removing said assembly of electrical coils from said mandrel.

6. In the method of constructing a tubular insulation barrier of high heat resistance and high thermal endurance for an electrical transformer, the steps of winding a cylindrical first electrical coil, disposing elongated insulating spacers extending parallel to the axis of said coil at circumferentially spaced apart positions about the circumference of said coil, bending stiff but formable, flat, silicone resin impregnated laminate sheet having an inorganic filler into tubular form circumjacent said axially extending spacers, holding said silicone resin impregnated laminate sheet in tubular form, forming silicone rubber sheet having an inorganic filler into a tube surrounding said silicone resin laminate sheet in tubular form, repeating the bending, holding, and forming steps to build up a tubular insulating barrier of interleaved silicone resin laminate and silicone rubber tubes, and winding a second cylindrical electrical coil coaxial with and supported from said tubular barrier to complete an assembly of electrical coils having a tubular insulating barrier therebetween.

7. In the method of constructing a coil assembly having high heat resistance and high thermal endurance for a high temperature electrical power transformer, the steps of forming a silicone resin impregnated laminate sheet having an inorganic filler into a first tube, forming a silicone rubber sheet having an inorganic filler into a second tube surrounding said first tube, repeating the last two steps to build up a tubular insulating member of interleaved silicone resin impregnated laminate and silicone rubber tubes, and supporting a cylindrical portion of said coil assembly upon said tubular insulating member in coaxial relation thereto.

8. In the method of constructing a heat stable coil assembly for a high temperature electrical power transformer, the steps of winding a radially inner cylindrical portion of said coil assembly, forming an at least partially cured silicone resin impregnated laminate sheet having an inorganic filler into a first tube surrounding said radially inner portion, forming a silicone rubber sheet having an inorganic filler into a second tube surrounding said first tube, repeating the last two steps to build up a tubular insulating member of interleaved silicone resin and silicone rubber tubes, supporting a radially outer cylindrical portion of said coil assembly upon said tubular insulating member, and heating said assembled tubular insulating member and said radially inner and outer cylindrical portions of said coil assembly to effect final curing thereof.

9. In the method of constructing a high temperature transformer winding of high heat resistance and high thermal endurance upon a rotatable mandrel, the steps of securing an edge of a flat, rigid but formable, silicone resin impregnated sheet having an inorganic filler relative to said mandrel and parallel to the axis thereof, rotating said mandrel while retaining said sheet in tangential relation relative to a projected cylinder coaxial with said mandrel to roll said sheet into a tube surrounding said mandrel, forming a silicone rubber sheet having an inorganic filler into a second tube surrounding said first tube, repeating the above steps to build up a tubular insulating member of radially staggered silicone resin impregnated and silicone rubber tubes in said winding having sufficient mechanical strength to withstand the forces resulting from electrical short circuit on said winding, and supporting a cylindrical portion of said transformer winding upon said tubular insulating member in coaxial relation thereto.

10. In the method of constructing an electrical winding of high heat resistance and high thermal endurance for a high temperature electrical transformer upon a rotatable mandrel, the steps of securing an edge of a stiff but formable, flat, silicone resin impregnated laminate sheet having an inorganic filler and high flexural strength relative to said mandrel so that said edge is parallel to the axis of said mandrel, rotating said mandrel while retaining said sheet in tangential relation relative to a projected cylinder concentric with said mandrel to roll said sheet into a tube surrounding said mandrel and repeating said steps to roll additional silicone resin laminate sheets into tubes surrounding said mandrel and build up a tubular insulating member in said winding of sufficiently high mechanical strength to prevent collapse under the forces resulting from electrical short circuit on said winding, and supporting a cylindrical portion of said electrical winding upon said tubular insulating member in coaxial relation thereto.

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