United States Patent

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[54] **ELECTRICAL INDUCTIVE APPARATUS HAVING LIQUID AND SOLID DIELECTRIC MEANS**
11 Claims, 4 Drawing Figs.

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252/63, 252/64, 317/258, 336/94, 336/206
[51] Int. Cl. **H01f 27/10**
[50] Field of Search 336/58, 94,
206; 252/63, 64; 317/258

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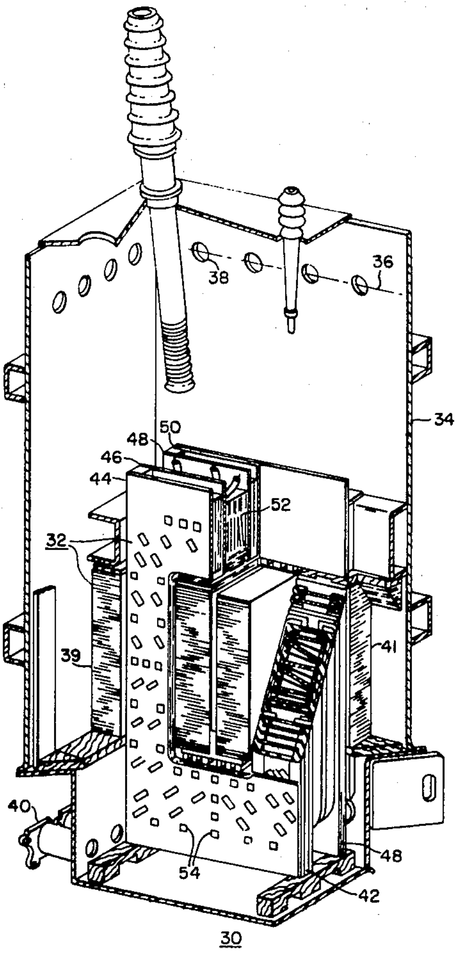
ABSTRACT: Electrical inductive apparatus of the type which includes an insulating structure comprising liquid dielectric means in series with solid insulating means. The solid insulating means is formed of a first organic resin and a filler which includes a second organic resin. The first organic resin is selected to provide the required chemical resistance and mechanical properties and the second organic resin is selected to have a dielectric constant which is lower than the first organic resin, to provide solid insulating means having a composite dielectric constant which more closely matches that of the liquid dielectric means than that of the first organic resin alone.



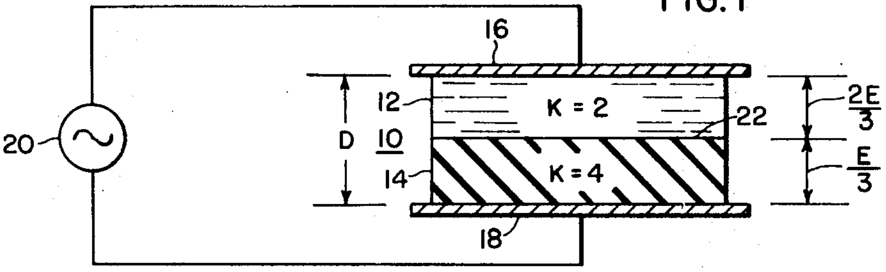


FIG. 1

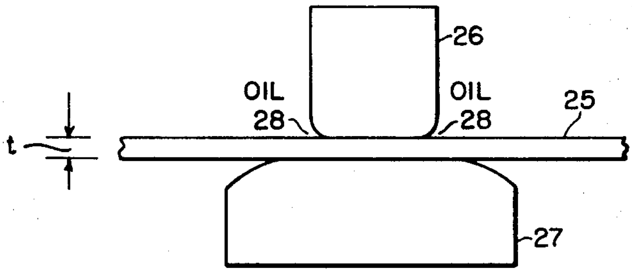


FIG. 3

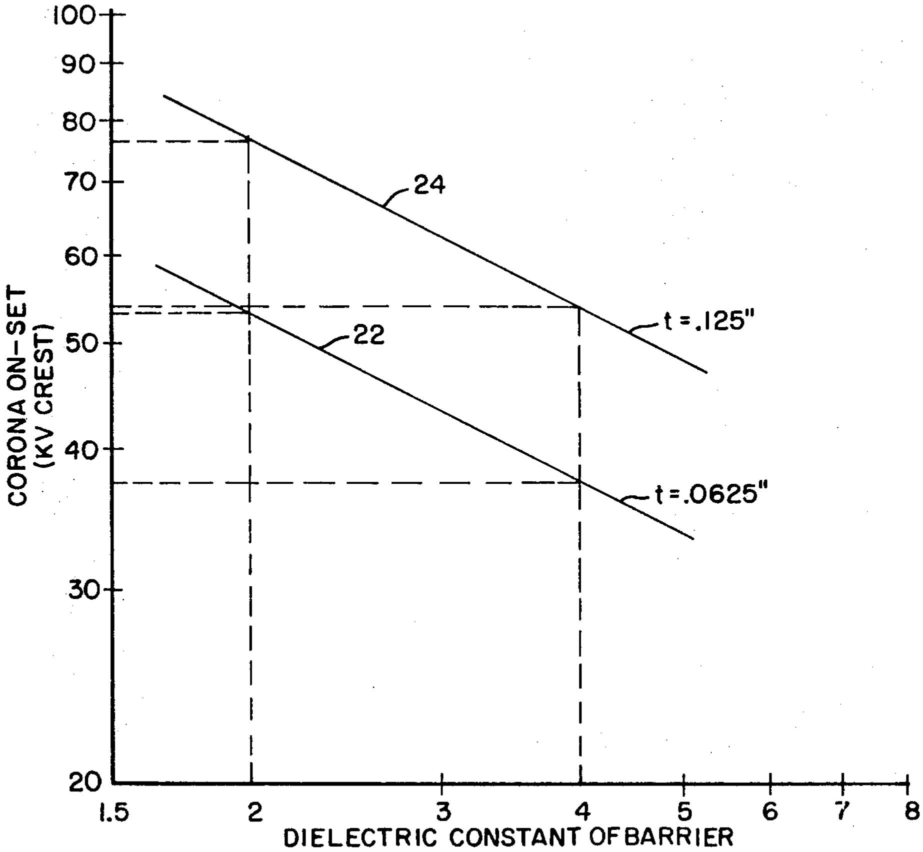


FIG. 2

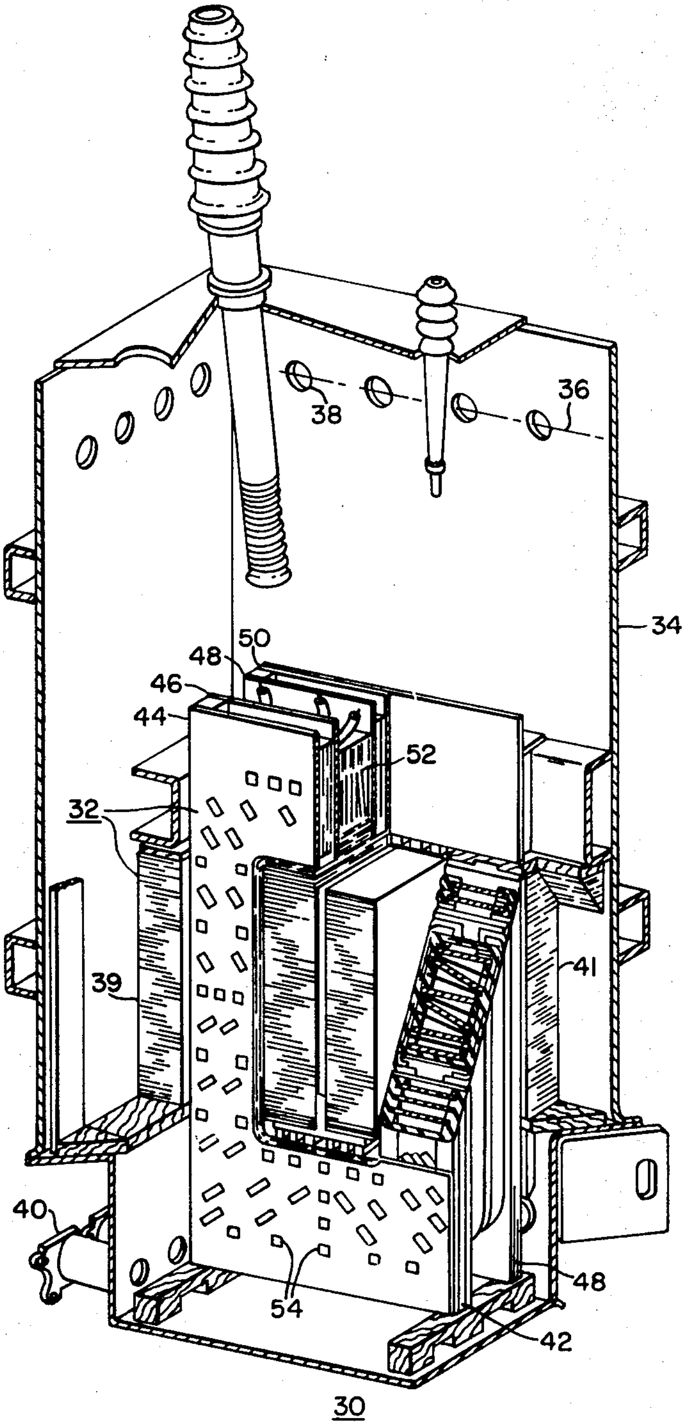


FIG. 4

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ELECTRICAL INDUCTIVE APPARATUS HAVING LIQUID AND SOLID DIELECTRIC MEANS

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates in general to electrical inductive apparatus, such as transformers and reactors, and more specifically to electrical inductive apparatus of the liquid insulated and cooled type.

2. Description of the Prior Art

Electrical inductive apparatus, such as transformers and reactors, conventionally utilize insulating structures which include combinations of oil filled ducts and pressboard barriers in series. In such a structure, the dielectric stress is distributed across the oil and solid insulation 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, and thus the electrical stress across the materials, is greatly affected by the dielectric constants of the two materials.

The liquid dielectric, conventionally mineral (petroleum) oil, is used to provide electrical insulation as well as to cool the inductive apparatus. In order to cool the apparatus, the oil must be free to circulate within the tank of the apparatus and through external heat exchangers, if used, and it must circulate as closely as possible to the source of the heat. Since the electrical strength of oil drops as the width dimension of the oil duct increases, oil spaces are conventionally broken into a plurality of small gaps or ducts, in order to optimize the electrical strength of the oil.

Transformer oil has a dielectric constant which is usually in the range of 2.0 to 2.2, while oil impregnated pressboard has a dielectric constant of about 3.75, or higher. Thus, electrical stress distributed across pressboard barriers and oil gaps in series, concentrates in the oil filed gaps or ducts. This unequal sharing of the stress is further complicated by the fact that the electrical breakdown strength of oil is lower than that of the oil impregnated pressboard. Thus, in conventional insulating structures, the "weaker" material electrically is stressed higher than the "stronger" material. This results in ineffective utilization of the electrical characteristics of the solid insulation, requiring greater spacing between the windings of the apparatus, and between the windings and ground, than would be required if a more favorable ratio of the dielectric constants of the solid and liquid materials could be achieved. Thus, a more effective utilization of the electrical characteristics of the solid insulation would enable insulating clearances to be reduced, which would reduce the length of the mean winding turn and the length of the magnetic circuit, resulting in a reduction in the size, weight and manufacturing cost of the electrical apparatus.

SUMMARY OF THE INVENTION

Briefly, the present invention is new and improved electrical inductive apparatus of the liquid insulated and cooled type, which incorporates an insulating structure including solid insulation and oil in series. However, instead of using pressboard for all the solid insulating members of the structure, at least certain of the solid insulating members are cast or molded to the desired shape from synthetic organic resins. The solid insulating members must be stable in oil at the elevated operating temperature of the oil, and they must retain their mechanical strength, as these insulating members are often used to support part or all of the weight of the windings; and, in order to eliminate the disadvantages of oil impregnated pressboard, the solid insulating members must have a lower dielectric constant than oil impregnated pressboard. Organic resins which have dielectric constants which closely match the dielectric constant of oil, are, in general unsuitable as they have marginal retention of mechanical strength at the elevated operating temperature of the oil. The oil attacks the resins, causing them to swell and weaken mechanically.

On the other hand, high strength, oil resistant casting or molding resins which are suitable mechanically have dielectric constants in the range of 3.0 to 5.0, depending upon the concentration of polar groups in the resin structure. Thus, they would have the same disadvantages as oil impregnated pressboard, as their dielectric constants are in a similar range.

The present invention utilizes solid insulating members cast or molded of a resin system which includes a main or base organic resin, and a filler which is also an organic resin. The base resin is a thermosettable resin, such as an epoxy or thermosettable polyester, preferably having a dielectric constant on the low side of the hereinbefore mentioned 3.0 to 5.0 range. The organic filler resin may be thermosettable or thermoplastic, and is selected to reduce the overall dielectric constant of the resulting thermoset solid, below that of the first or base organic resin. The organic filler is used only as a filler, and thus may be one of the less costly resins having a relatively low dielectric constant, such as one of the hydrocarbons. The polyolefins are specially suitable, even though they are thermoplastic materials having little mechanical strength at the elevated operating temperature of the transformer oil, as they are inexpensive and have a dielectric constant in a range of 2.2 to 2.6. The concentration of the organic filler may be in the range of 20 to 60 percent by volume of the resulting thermoset solid, and is preferably about 50 percent of the volume. Since the sole purpose of the organic filler is to lower the composite dielectric constant of the resulting resinous system, the maximum amount of filler is a practical one, being that amount which will not reduce the mechanical strength and oil resistance of the resulting resinous system below that necessary for the solid insulation system to perform its required functions in the oil filled electrical apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

Further advantages and uses of the invention will become more apparent when considered in view of the following detailed description of exemplary embodiments thereof, taken with the accompanying drawings, in which:

FIG. 1 is a diagrammatic view of an insulating structure subjected to an electrical stress which simulates many of the insulating structures used in liquid cooled electrical inductive apparatus;

FIG. 2 is a graph which illustrates how the electrical strength of an insulating structure comprising a solid barrier in mineral oil varies with the dielectric constant of the barrier;

FIG. 3 is diagrammatic view of the test arrangement used to obtain the curves shown in the graph of FIG. 2; and

FIG. 4 is a perspective view, partially cut away, of a liquid filled transformer which may utilize the teachings of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and FIG. 1 in particular, there is shown a diagrammatic representation of a typical insulating structure in oil cooled electrical inductive apparatus, such as transformers and reactors of both the shell and core-form type. The conventional pressboard-oil type of insulating structure is represented by block **10**, which includes blocks **12** and **14** disposed in series between electrodes **16** and **18**. Electrodes **16** and **18** are connected to a source **20** of alternating potential, thus creating an electrical stress across the insulating structure **10**. Block **10** represents transformer (mineral) oil having a dielectric constant of about 2, and block **14** represents oil impregnated pressboard, a cellulosic insulation having a dielectric constant of about 4. For the most effective utilization of the insulating structure **10**, which would allow the dimension D to be reduced to a minimum, each of the elements in series between the electrodes should be stressed to a predetermined point dependent upon its electrical strength. Since oil impregnated pressboard has a higher dielectric strength than mineral oil, for efficient use of the insulating structure it should be stressed higher than the oil **12**. However, since the voltage distribution across two dissimilar dielectric materials in series is inversely proportional to the capacitance of the two material, the voltage distribution is affected by the dielectric constants of the materials. As shown in FIG. 1, if the boundary **22** between the oil and pressboard insulations **12** and **14** is midway between the electrodes **16** and **18**, two-thirds of the voltage will appear across the oil **12** and only one-third across the solid insulation **14**, due to their different dielectric constants. Thus, instead of transferring the stress to the solid electrical insulation **14**, which has the higher electrical strength, stress is transferred to the oil **12**, which has the lower electrical strength of the two materials, and which is subject to contamination which will lower its electrical strength still further. Moving the boundary line **22** closer to electrode **16**, to achieve the same voltage drop across each of the materials is not a practical solution, as regardless of where the boundary **22** is located, the voltage gradient at the boundary will be twice as high in the oil **12** as in the solid insulation **14**, due to the relationship of their dielectric constants.

Since the use of mineral oil and pressboard in insulation structures has been the most economical and practical approach to insulating power transformers the disadvantages of their combination, hereinbefore set forth, have been overcome by adjusting or designing the insulating clearances in the apparatus to compensate for their different dielectric constants. It would be desirable to more effectively utilize the insulating structures in liquid filled inductive apparatus, which would enable the insulating clearances between the high and low voltage windings, between the coils of a winding, between electrical phases, and between the windings and ground, to be reduced, thus reducing the mean length of the coil turns, and the length of the magnetic circuit, which reduces the required amount of copper or aluminum, and magnetic core steel. Reducing the physical size of the magnetic core-winding assembly reduces the size of enclosing tank, and the amount of oil required to fill the tank. Thus, the size, weight and cost of the inductive apparatus may be reduced by lowering the dielectric constant of the solid insulation.

FIG. **2** is a graph containing curves **22** and **24** which illustrate how the electrical breakdown strength of insulating structures containing solid insulation and mineral oil may be substantially increased by lowering the dielectric constant of the solid insulation. The dielectric constant of a solid insulating barrier or member is listed on the abscissa while the on-set of conrona in kilovolts (kv.), measured from the crest of the voltage wave, is listed on the ordinate. Curve **22** is for an insulating barrier having a thickness dimension of 0.0625 inch, while curve **24** is for an insulating barrier having a thickness dimension of 0.125 inch. The test data for curves **22** and **24** was obtained from a test arrangement as shown in FIG. **3**, which diagrammatically illustrates a barrier **25** having a thickness dimension *t* disposed in mineral oil, with electrodes **26** and **27** disposed to contact opposite sides of barrier **25**. Electrical breakdown occurs in the areas **28**, which, due to the fringing effect of the electrical field, places the oil in these areas in series with the barrier **25**. It will be noted from curve **22** in FIG. **2**, that with a barrier having a thickness dimension of 0.0625 inch, that the corona on-set level is increased from about 38 kv. to 55 kv. by reducing the dielectric constant of the barrier from 4 to 2. Curve **24** illustrates that increasing the thickness of the barrier to 0.125 inch raises the electrical strength of the oil barrier combination. With the thicker barrier, the corona on-set level is increased from about 55 kv. to about 76 kv. by reducing the dielectric constant of the barrier from 4 to 2.

Ideally, the solid insulation and the oil should be stressed according to their electrical strengths. This would require the solid insulation to have a lower dielectric constant than the oil. In substituting a solid insulating material for the pressboard, however, the dielectric constant of the new material is only one of the factors which must be considered. For example, the cost of the solid insulating material must not be so much greater than the pressboard that the savings achieved by reducing insulating clearances are offset by the additional cost of the solid insulation. Cost is also one of many reasons why the problem has not been attacked by using a liquid dielectric having a higher dielectric constant. The synthetic liquid dielectrics have a higher dielectric constant than mineral oil, but their cost is also substantially higher. The high cost of the synthetic liquids compared with the cost of mineral oil, has limited the use of these synthetic materials to applications where the fire hazard of mineral oil is a determining factor in the application.

The solid insulating material substituted for pressboard, or used in combination therewith, must be compatible with mineral oil, it must have sufficient mechanical strength to provide support for the windings, and this strength must not be adversely affected at the maximum operating temperature of the liquid dielectric. Finally, the solid insulating material substituted for pressboard, or used in combination therewith, must have a high electrical strength.

The present invention provides a solid insulating system having a dielectric constant sufficiently lower than that of oil impregnated pressboard, that a reduction in total spacing as much as 30 percent may be obtained, which substantially reduces the manufacturing cost of the apparatus.

More specifically, the present invention is electrical inductive apparatus of the liquid cooled type, which utilizes insulating structures which include solid insulation and oil filled ducts in series between electrically stressed parts of the apparatus, with at least certain of the solid insulating members being molded or cast of a synthetic resin system. The synthetic resin system includes first and second organic resins. The first organic resin is selected for its mechanical strength, electrical strength, and resistance to attack from hot transformer oil. Since synthetic resins of this nature, in general, have a dielectric constant which is about the same, or higher than that of oil impregnated pressboard, their use as a direct substitute for pressboard is not economical, as the insulating clearances would remain the same. The second organic resin is selected primarily for its dielectric constant, i.e., for its relatively low dielectric constant, and is used as a filler for the first resin to provide a composite dielectric constant for the resulting resinous system which is substantially midway between that of the first and second resins. The second organic material is used primarily as a filler, and not to cross-link the first resin, with the maximum amount of the second resin used being that amount which will still enable the first resin to meet its requirements of mechanical and electrical strength as well as resistance to hot transformer oil. Thus, the concentration of the filler isn't critical, with at least 20 percent by volume being about the minimum, and 50–60 percent being a practical maximum. The practical maximum is determined by the ability to obtain a uniform dispersion of the filler throughout the resin system, as well as the ability to mold or cast structures having the requisite mechanical characteristics. It is very important that a uniform dispersion of the filler be obtained, and that the filler particles are set by and completely surrounded by the thermosettable base resin. Otherwise, the oil may come into contact with the filler particles, causing them to swell.

The first organic resin system is preferably thermosettable, since it must retain its mechanical strength and stability in transformer oil at elevated temperatures, such as 110° to 130° C., or higher. Suitable resins are the unsaturated linear polyester resins, which are capable of cross-linking with a monomer to form a thermoset solid polymer, and resins of the epoxy type. Resins of these types are commercially available which oil resistant, have excellent mechanical and electrical strengths at ambient and at the elevated operating temperatures of the electrical apparatus, at a cost which will not offset potential savings. Both of these types of resins may be cast or molded to shape. The dielectric constants of suitable epoxy and polyester resins are in the range of 3 to 5, with resins having dielectric constants on the lower side of this range being preferred.

The second organic resin should be relatively inexpensive, such as one of the hydrocarbons, it should have a melting point greater than about 150° C., and it should have as low a dielectric constant as possible. Since the first organic resin satisfies the oil resistance and mechanical strength requirements of the insulation, the second resin need not have appreciable mechanical strength at the elevated operating temperature of the electrical apparatus. The polyolefins, such as polypropylene and high density (isotactic) polyethylene, have been found to be excellent, due to their low dielectric constants [about 2.2], their relatively low cost, and their high melting points. By using polypropylene or high density polyethylene in an epoxy or polyester resin system, with the epoxy or polyester resin system selected to have a dielectric constant which is on the low side of the available range, a composite dielectric constant in the range of 2.5 to 3 is achievable. For example, epoxy resin with 43 percent by weight polypropylene powder filler provides a dielectric constant of 2.7. Isotactic polystyrene and polymethyl pentene may also be used as the filler resin.

The filler resin is preferably in the form of a fine powder. The particle size of the powder, however, is not critical, with uniform dispersion being the important factor. In general, powders of 100 mesh, or finer, are preferred, as it is easier to uniformly mix them with liquid epoxy or polyester resin, but coarser powders may be used if desired.

The filler particles must be separated, and each encapsulated in the base resin, to prevent ingress of oil and resulting swelling of the filler. Wetting agents, such as those of the type which have a polar group on one end of the molecule, and a hydrocarbon chain on the other, may be used to insure wetting of the filler **64** by the base resin.

FIG. **4** is a perspective view, partially cut away, of a transformer **30** which may utilize the teachings of the invention. Transformer **30** is of the shell-form type, having a magnetic core-winding assembly **32** disposed in a tank **34**. Tank **34** is filled to a level **36** with mineral oil, such as Humble's Univolt **33**, with the magnetic core-winding assembly **32** being completely immersed in the oil. The oil aids in insulating the electrical windings from ground, and from one another, and it also serves to cool the transformer. Heat exchangers or coolers [not shown] are connected to the tank, in communication with the openings **38** near the top of the tank **54**, and the pipes **40** near the bottom thereof, with the oil circulating through the tank and through the ducts in the magnetic core-winding assembly **32**, either by thermal syphon or by forced circulation, to remove heat from the oil picked up from the magnetic core-winding assembly **32**.

Transformer **30**, which may be single or polyphase, has a plurality of high and low voltage coils which encircle the leg portions of magnetic core sections **39** and **41**. The coils are disposed in side-by-side relation, separated by solid insulating barriers. A group **42** of low voltage coils is disposed between barriers **44** and **46**, and a group **48** of low voltage coils is disposed between barriers **48** and **50**, while a group **52** of high voltage coils is disposed between barriers **46** and **48**. The barriers **44, 46, 48** and **50** have a plurality of spacer blocks **54** attached thereto for providing cooling ducts for the oil.

The electrical coils within each of the groups are also separated by insulating structures which include solid insulating members and spacers which provide oil ducts therein.

The solid barriers between groups of coils, such as barriers **44, 46, 48** and **50**, may all be constructed according to the teachings of the invention, or combination of pressboard and synthetic cast or molded members may be used. Additional savings may be realized by integrally casting or molding the spacer blocks **54** with the barriers, if desired. The costly conventional practice of manually gluing insulating spacer blocks to sheets of pressboard may thus be eliminated. The solid spacer members within the groups of coils may also be constructed by casting or molding, using the low dielectric constant resin system disclosed herein, as well as insulating channels and other insulating members which are in series with the oil across highly stressed locations in the transformer.

While transformer **30** is of the shell-form type it is to be understood the invention may be applied to single and polyphase transformers of the core-form type, as well as any electrical apparatus of the type wherein solid insulation and oil are disposed in series between two electrodes of different potential. For example, in core-form transformers, solid insulation, cast or molded of a low dielectric constant resin system, may be used as insulating barriers between phases, between the windings and phases to ground, between the ends of the windings and phases to ground, between the ends of the windings and the pressure rings, and in the high-low space between the high and low voltage coils of an electrical phase.

While the cast or molded low dielectric constant resin system disclosed herein would be used to replace pressboard or other cellulosic insulation, or used in combination therewith, it does not necessarily have to be formed in the same shapes. Pressboard for example, is available only in relatively thin sheets, which are shaped and stacked to form the desired insulating structure at a considerable additional assembly cost. Since the solid insulation of the present invention is cast or molded to shape, thicker sections and a greater variety of shapes may be easily formed.

The invention has been described primarily for use in mineral oil insulated electrical inductive apparatus, but it will be obvious that it may be used with any insulative liquid when a more favorable distribution of electrical stress may be obtained by reducing the dielectric constant of solid insulating members.

In summary, there has been disclosed electrical apparatus of the type which utilizes new and improved solid insulating members and oil in series between two electrodes of different electrical potential. The disclosed teachings enable the size and cost of such apparatus, such as transformers and reactors, to be substantially reduced, as it permits smaller spacings between the coils and windings, between electrical phases, and between the windings and ground, by significantly reducing electrical stress in oil filled ducts. For example, an insulating structure having equal amounts of pressboard and oil, with the pressboard having a dielectric constant of 3.75, in series with the coil, which has a dielectric constant of 2.2, in a uniform electrical field, results in the stress in the oil being 1.7 times the average stress. In a cast or molded resin system having a composite dielectric constant of 2.7 is used in the same proportions with the oil, the stress on the oil will only be 1.2 times the average stress. This reduction in stress permits a reduction in total spacing of up to 30 percent, without increasing the stress in the oil. Some voltage stress has been transferred to the solid insulation, which has a higher electrical strength than the oil, resulting in a more efficient use of the insulating materials, and a substantial reduction in the size, weight and cost of the apparatus.

I claim as my invention:

1. Electrical apparatus comprising:

an enclosure;

liquid dielectric means having a predetermined dielectric constant, said liquid dielectric means being disposed in said enclosure;

an electrical winding disposed in said enclosure and immersed in said liquid dielectric means;

an insulating structure comprising solid insulating means and said liquid dielectric means in series, said insulating structure providing at least a portion of the insulating system for said electrical winding;

said solid insulating means including a first organic resin having a dielectric constant greater than that of the liquid dielectric means, and filler means comprising a second organic resin having a dielectric constant lower than that of the first organic resin, to provide a composite dielectric constant for said solid insulating means which more clearly matches the dielectric constant of said liquid dielectric means than that of the first organic resin alone.

2. The electrical apparatus of claim **1** wherein the filler means is completely encapsulated by the first organic resin.

3. The electrical apparatus of claim **1** wherein the first organic resin is an epoxide and the second organic resin is a polyolefin.

4. The electrical apparatus of claim **3** wherein the polyolefin is isotactic polyethylene.

5. The electrical apparatus of claim **3** wherein the polyolefin is polypropylene.

6. The electrical apparatus of claim **1** wherein the first organic resin is a thermoset polyester and a second organic resin is a polyolefin.

7. The electrical apparatus of claim **6** wherein the polyolefin is isotactic polyethylene.

8. The electrical apparatus of claim **6** wherein the polyolefin is polypropylene.

9. The electrical apparatus of claim **1** wherein the second organic resin occupies 20 to 60 percent of the volume of the solid insulating means.

10. The electrical apparatus of claim **1** wherein the liquid dielectric means has a dielectric constant in the range of about 2 to 2.2, the first organic resin has a dielectric constant in the range of about 3 to 5, a second organic resin has a dielectric constant in the range of about 2 to 2.3, and the composite dielectric constant of the solid insulating means is in the range of about 2.5 to 3.

11. The electrical apparatus of claim **11** wherein the liquid dielectric means is a mineral oil.