

[54] **SOLID INSULATION FOR ELECTRICAL APPARATUS**

[75] Inventors: **Gordon C. Gainer**, Pittsburgh;
Russell M. Luck, Monroeville, both
of Pa.

[73] Assignee: **Westinghouse Electric Corporation**,
Pittsburgh, Pa.

[22] Filed: **Apr. 14, 1972**

[21] Appl. No.: **244,183**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 146,238, May 24,
1971.

[52] U.S. Cl. **336/58**, 174/25 R, 174/17 LF,
174/110 SR, 174/110 SY, 336/60, 336/94, 336/206

[51] Int. Cl. **H01f 27/12**

[58] Field of Search 336/58, 94, 60, 206;
317/258; 174/25 R, 25 C, 26 R, 17 LF, 110
R, 110 SR, 110 SY, 160 B

[56] **References Cited**

UNITED STATES PATENTS

3,611,225 10/1971 Dakin 336/58

3,548,354 12/1970 Schwab 336/60
3,078,139 2/1963 Brown et al. 264/288 X

OTHER PUBLICATIONS

"Modern Dielectric Materials," Birks, London
Heywood & Company Ltd., 1960, pages 140 and 241
relied upon.

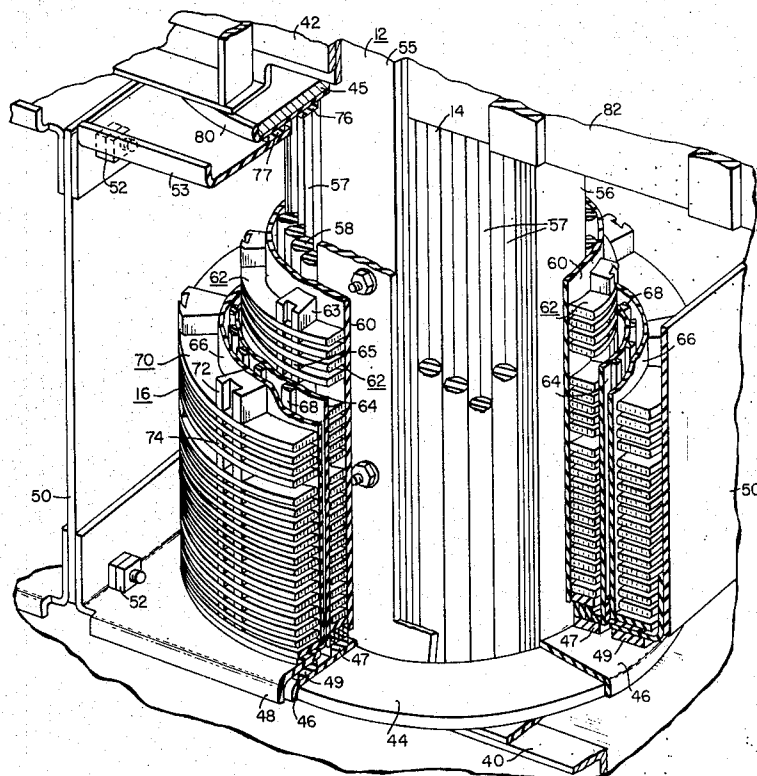
Primary Examiner—Thomas J. Kozma

Attorney—F. Shapoe

[57] **ABSTRACT**

An improved thermally stable polymeric insulation for use in electrical apparatus and particularly in transformers operated in the presence of transformer oil is a substitute for the conventional cellulosic pressboard, which improved insulation consists of an isotactic polymeric hydrocarbon resin in at least partially crystalline form and cross-linked, 1,2-butadienes and copolymers having a low dielectric constant substantially matching that of the liquid dielectric and having relatively low swelling characteristics when immersed in hot liquid petroleum oil dielectric over an extended period of time.

15 Claims, 6 Drawing Figures



SHEET 1 OF 3

FIG. 1

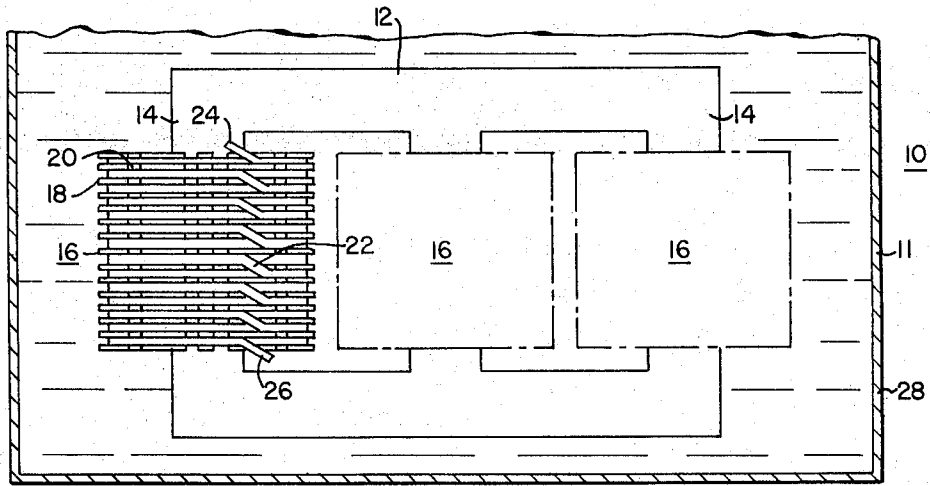
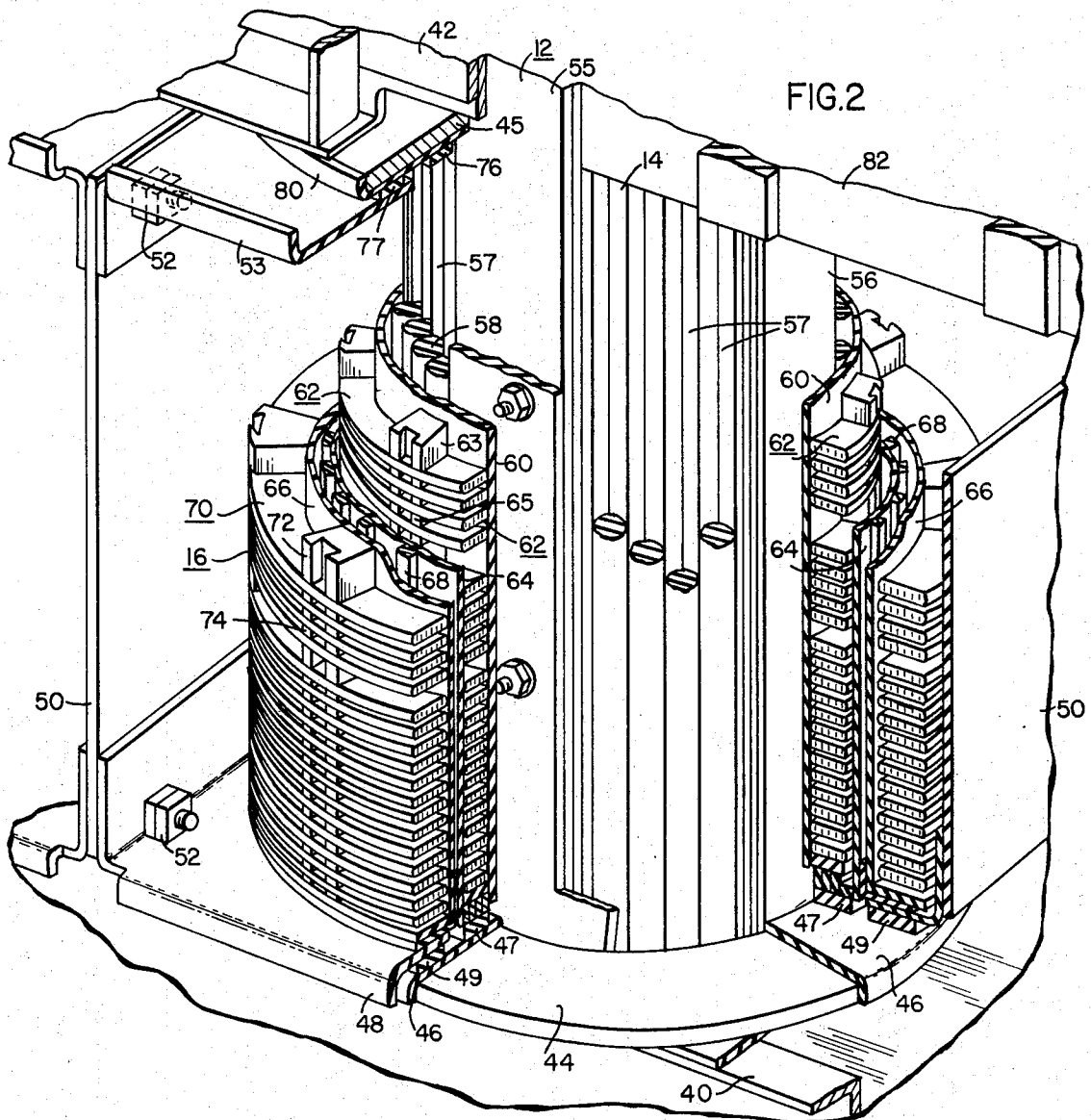
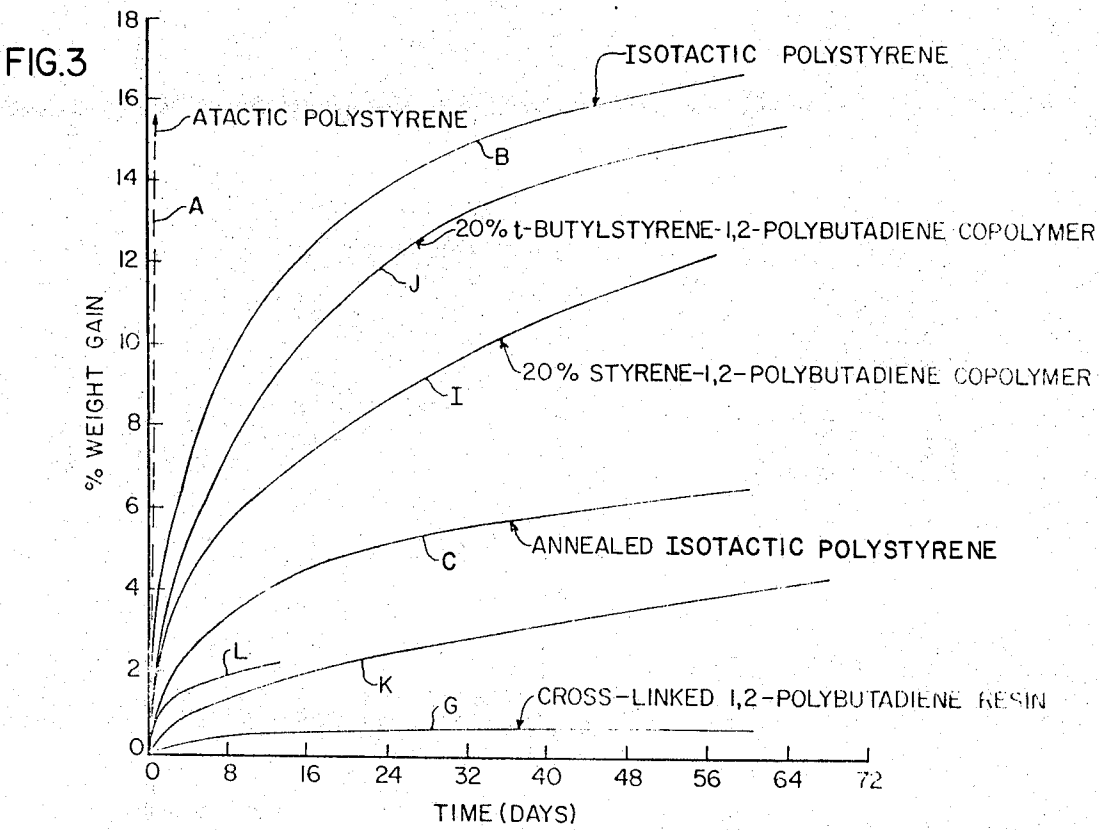
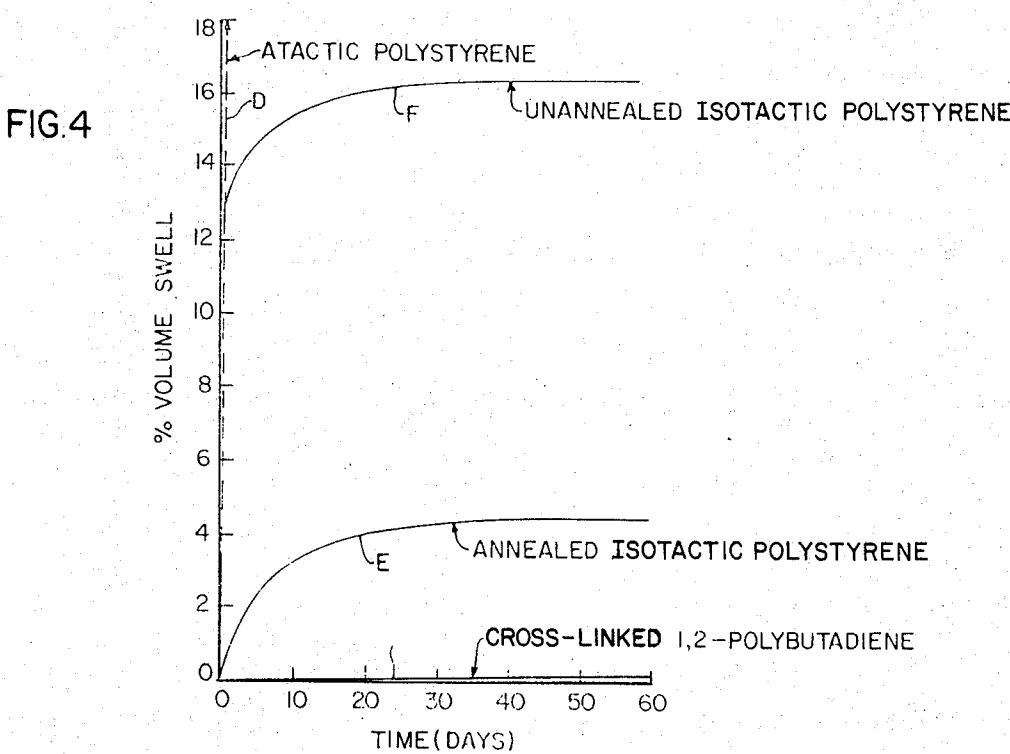
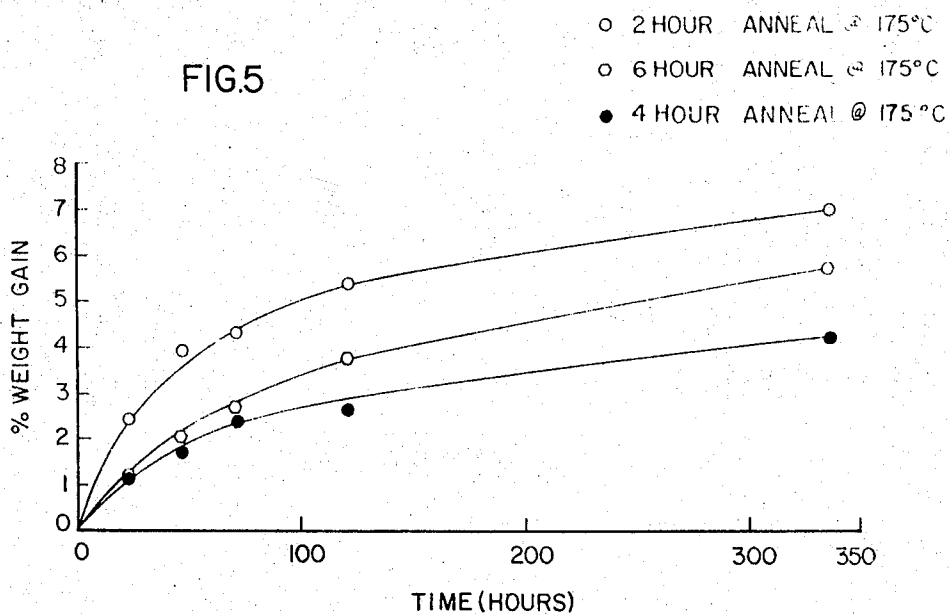
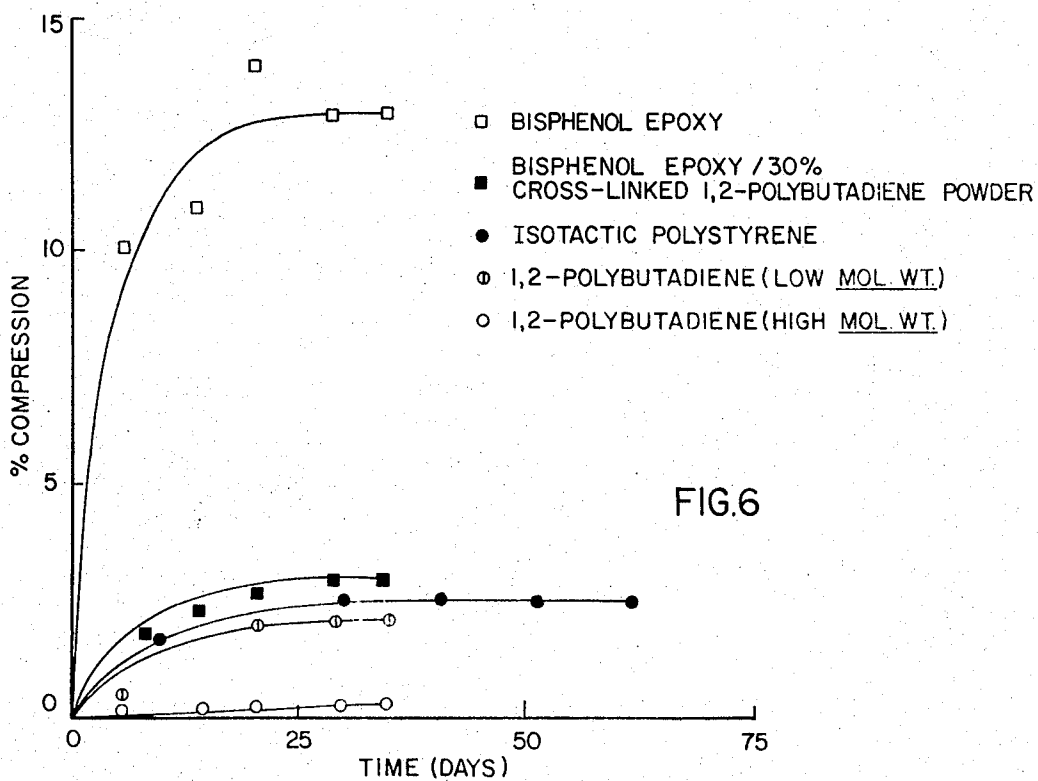


FIG. 2







SOLID INSULATION FOR ELECTRICAL APPARATUS

RELATED APPLICATIONS

This application is a continuation-in-part of our U.S. Patent application Ser. No. 146,238, filed May 24, 1971.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to an improved solid polymeric insulation material for use in an oil immersed transformer and, more particularly, it pertains to insulation material especially suitable for use in either a core or shell-form power transformer.

2. Description of the Prior Art

Mineral oil impregnated cellulosic materials such as paper, cotton cloth, cotton tape, pressboard, and wood have long been employed in the electrical industry as insulation for various types of apparatus, because of their excellent overall dielectric properties, satisfactory initial dielectric strength and low cost. The electrical and physical properties of cellulosic material, however, deteriorate at an increasing rate when the operating temperatures of the electrical apparatus rise above about 100°C whether exposed to air or in contact with fluid dielectric compositions such as transformer oil. The deterioration in the physical properties is accompanied by a corresponding decrease in electrical insulation properties. For these reasons, there has been a need for more satisfactory solid spacing materials for use as insulators for the electrical windings in an oil immersed transformer particularly where the highest electrical stresses may be present and good impulse strength is required.

The primary requirements for such a solid insulator are a low dielectric constant and low swelling characteristics when immersed in transformer oil at elevated temperatures over an extended period of time. With regard to the dielectric constant, in oil immersed transformers a reduced intensity of electric stress may be obtained if properly selected solid dielectrics are utilized as substitutes for oil impregnated cellulose whose dielectric constant is 3.75. For best results, such solid insulator should have a dielectric constant of about 2.2 that more nearly matches the dielectric constant of the transformer oil. The dielectric constant of the refined petroleum oil used in transformers is about 2.2. Generally, a solid insulating material of low dielectric constant closely or exactly matching that of oil as a substitute for oil impregnated pressboard in areas of high electric stress (including particularly high electric stress in the case of impulse currents due to lightning strokes), enables a reduction in insulating thickness or spacing to as much as about 2/3 of that now used.

One of the principal problems associated with achievement of that reduction of insulation clearance is that available low dielectric constant resins, such as hydrocarbon polymers, are excessively swollen by contact with hot transformer oil so that after a brief period of time it renders the resins unserviceable. Many commercially available resins, such as atactic polystyrene, polyethylene, and isotactic polypropylene, soften excessively at 125°C and show considerable swelling and weight pickup.

SUMMARY OF THE INVENTION

In accordance with this invention, it has been found that the foregoing problems may be overcome by providing an improved solid polymeric insulation for use in transformers, reactors and other electrical apparatus in which petroleum oil is used as insulation, which polymeric insulation consists of a material selected from at least one of the group consisting of certain thermosetting 1,2-polybutadiene hydrocarbon resins and certain copolymers of these, and partially crystalline isotactic polystyrene, which materials have a dielectric constant of from about 2.0 to about 2.7 and which closely corresponds to that of the oil, and have long term swelling properties of less than about 15 weight per cent in petroleum oil at a temperature of about 125°C.

The advantages arising from the use in oil impregnated electric apparatus of such solid insulating materials instead of oil impregnated cellulosic pressboard, are cost savings, due to smaller size and total lower weight by virtue of reduced insulation clearance otherwise required, and longer life of transformers and other oil insulated apparatus.

Thus, a cellulosic pressboard cylinder of a thickness of 1 inch, is replaced by a cylinder of isotactic polystyrene of a thickness of about 0.65 inch with equally effective electrical insulation.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference is made to the attached drawings in which similar numerals refer to similar parts throughout the several views of the drawings, and in which:

FIG. 1 is a schematic elevational view of a magnetic core and winding assembly;

FIG. 2 is a fragmentary enlarged, perspective view, partly in section, in detail of a core type transformer;

FIG. 3 is a graph showing the weight per cent gain for various types of resins versus time;

FIG. 4 is a graph showing the volume per cent swell for various types of resins versus time;

FIG. 5 is a graph showing the weight pickup of transformer oil in isotactic polystyrene as a function of time of anneal; and

FIG. 6 is a graph showing the per cent compression under a pressure of 750 p.s.i. load in oil at 125°C for various resins versus time.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A core type transformer is specifically disclosed and described hereinbelow, but other forms of transformers such as the shell type, reactors and other oil immersed electrical apparatus are suitable for the practice of this invention.

In FIG. 1, there is shown schematically a three-phase core type of power transformer generally indicated at 10, comprising a casing 11 in which is disposed a magnetic core 12 having three spaced legs 14 with a winding assembly 16 which comprises primary and secondary coils, disposed around each leg. Each winding assembly 16 is comprised of separate coil sections 18, each of which includes one or more pancake coils or coil discs. Radial spacers 20 separate each coil section 18 to provide flow paths for oil dielectric coolant and to electrically insulate the adjacent discs. Interconnections 22 electrically connect the turns of the coil sec-

tions 18. The type and placement of the interconnections 22 between the discs depends upon the type and class of the winding assembly 16, for which reason the interconnections 22 as shown are illustrative only. Terminals 24 and 26 provide means to electrically connect the winding assembly 16 to the associated apparatus or circuitry, however, other terminals at other terminal positions may be utilized.

One practical construction of a core type transformer is more particularly illustrated in FIG. 2, wherein the leg 14 of the core 12 and the winding assembly 16 are shown partly in section with their associated solid insulation. The core 12 is provided on each side with lower channel members 40 fastened thereto for supporting the working components of the transformer in casing 11, and upper channel members 42 between which channel members the windings 16 are clamped. To accomplish this, a heavy steel ring 44 rests on the lower channel members 40, while an upper steel ring 45 abuts against the bottom of the upper channel members 42. A flanged ring 46 of solid insulation of molded fiber reinforced resinous material rests on the ring 44 and a series of spaced insulating members in ring arrangements 47 and 49 are disposed on the flanged ring 46. Inner phase insulation barriers of solid insulation are provided to isolate each of the transformer phases from each other. The barriers comprise a rectangular flanged bottom sheet 48 with its center cut out just beyond ring 49 on which it is disposed, insulating side walls 50 bolted to the bottom sheet 48 by bolts 52 of electrically insulating material such as fiber reinforced molded resin, and a flanged top sheet 53 which is a mirror image of bottom sheet 48, also bolted by bolts 52 to the side walls 50, the whole forming a rectangular compartment. The transformer casing walls usually close the open front and rear sides of the compartment.

In the larger transformers the legs 14 are not rectangular, but are composed of laminations that diminish stepwise in width from the widest extending from face 56 to a corresponding face on the left side in FIG. 2, to the narrowest width at face 55. The stepwise arrangement of the laminations results in corners 57 in which are placed filler rods or strips 58. The filler strips 58 may be round or quarter round or of other suitable shape and are of a solid insulating material. The purpose of the filler strips 58 is to support a cylindrical shell 60 of solid insulation which shell in turn supports and electrically insulates low voltage windings 62 of the electrical coil comprising a series of pancake coils 18. The pancake coils 18 are separated by two types of insulating radial spacers 20, which may comprise relatively thick spacers 63 and thinner spacers 65 to enable flow of insulating oil between the coils. The thick spacers 63 enable a greater flow of cooling oil as well as providing a space to apply electrical taps, and for other purposes.

After the entire low voltage winding is built up by stacking coils 18 on ring 47 with intervening insulating radial spacers 63 and 65 between them, a cylindrical insulating shell 64 closely conforming to the other periphery of winding 62 is slipped over it, then a larger outer tubular insulating shell 66 is placed about the shell 64 and vertical spacer strips 68 are introduced in a predetermined pattern in the space between shells 64 and 68. The vertical spacer strips fit tightly into the space so as to enable the shells 64 and 66 to strengthen each other, while enabling oil to flow freely upwardly

between the shells when the transformer is in operation.

The high voltage winding 70 is then applied by slipping individual pancake coils over the shell 66, at least some of the coils fit closely, the bottom coil resting on the insulating sheet 48 and concentric with ring arrangement 49. Thick radial spacers 72 and thin radial spacers 74 are disposed between each pancake coil of winding 70.

In practice, a thin insulating tube is applied to the outside of the winding 70 to direct the flow of oil. Schwab U.S. Pat. No. 3,548,354 shows various arrangements of such insulating tubes and baffles or barriers about coils to direct oil flow over the coils.

After both the high voltage windings 70 and low voltage windings 62, as well as the several insulating shells 60, 64 and 68, are placed around core leg 14, an upper spaced series of insulating members in a ring arrangement 76 is placed over the top pancake coil of the low voltage winding 62, the upper rectangular insulating sheet 53 is placed over the top pancake coil of the high voltage winding 70, and a second spaced series of insulating members in a ring arrangement 77 is disposed on sheet 53 in line with winding 70, a flanged solid insulating ring 80 and the steel ring 45 is then disposed on top of the windings. The rest of the magnetic core comprising the horizontal yoke 82 is then assembled on the vertical legs 14. The upper channel members 42 are put in place and suitable bolts are applied to bolt the channels to the magnetic core and to apply pressure to the plates 45-44 so as to compress the windings 62-70 therebetween. The electrical connections to the several coils at terminals 24 and 26 and any coil taps have also been made during the assembly process. The transformer tank 11 is filled with oil so as to cover the core 12 and windings 62 and 70.

When the transformer is put into operation, hot oil flows over the insulating tubes 60, 64, 66, the strips 58 and 68, and also the various insulating members 46, 47, 48, 53, 63, 65, 72, 74, 76, 77 and 80. All of these insulating tubes, strips and members are also subject to heavy pressures both static, as when the transformer coil assembly is bolted firmly together, and dynamic when surges and short circuits pass through the windings and affect the transformer. The sudden increase in current flow during surges and short circuits on the windings creates shock forces that severely stress the spacers and tubes. It is necessary that the hot oil not react with or adversely affect the resinous insulation comprising these tubes, strips and spacers.

Furthermore, the insulating members immersed in the insulating oil must be capable of withstanding the voltage and electric stresses applied to the windings. When the solid insulating materials have a dielectric constant nearly the same as that of the oil, namely from 2.0 to 2.7 and preferably about 2.2, the electrical voltage stress is graded more uniformly and neither the oil nor the solid electrical insulation is subjected to a disproportionate voltage gradient. Consequently, the solid insulating materials, namely, tubular members, strips, spacers and the like resinous insulating materials as shown in FIG. 2, may be much thinner than more conventional solid insulating materials with dielectric constants of 3.7 and more.

Petroleum base dielectric liquids such as those commonly known as transformer oil are highly refined petroleum oils of a very low acid number. Stabilizers and

antioxidants, such as para-t-butyl phenol, may be present therein.

In accordance with this invention, the several solid resinous electrically insulating parts subject to the high electrical voltages and stresses, particularly comprising members 46, 47, 48, 76, 77 and 80, the radial spacers 63, 65, 72 and 74, the vertical spacers or strips 58 and 68, and the insulating tubular cylinders 60, 64 and 66 are composed of certain hydrocarbon polymers having dielectric constants substantially matching that of the transformer oil and resistant to reaction with or adverse swelling action of the oil at temperatures of up to about 125°C for extended periods of time.

More specifically, the hydrocarbon polymers found to fulfill the requirements of low dielectric constant and minimal swelling characteristics in petroleum oil consist of a material selected from the group consisting of thermosetting cross-linked 1,2-polybutadiene hydrocarbon resins and copolymers thereof with vinyl monomers, and at least partially crystalline isotactic polystyrene.

The thermosetting cross-linked 1,2-polybutadiene hydrocarbon resins and certain vinyl copolymers thereof which are derived from butadiene exhibit low dielectric constants and low swelling characteristics in hot transformer oil.

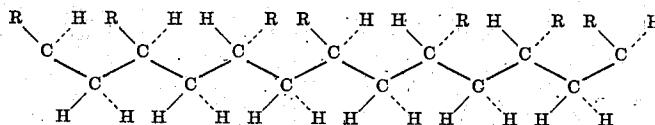
Isotactic polystyrene at least partially crystalline is particularly suited for use in the practice of this invention. The crystalline structure comprises at least 10 percent by weight of the total resin and is preferably greater, for instance, up to about 30 to 35 percent. So far as is known, up to the present time isotactic polystyrene has crystallized in amounts of up to about 35 percent of the whole.

Isotactic polystyrene may be produced by polymerization of styrene with stereo-specific catalysts of the Ziegler-Natta type as set forth more particularly by (1)

rate is relatively slow compared with other crystallizable polymers, such as polyethylene or polypropylene. Amorphous isotactic polystyrene has properties somewhat similar to those of conventional atactic polystyrene.

However, crystalline isotactic polystyrene has a high melting temperature showing a first order transition temperature of about 240°C. It is insoluble in most common solvents for polystyrene, and, as a result of the spherulitic structure of the crystalline phase, is opaque. From X-ray data the density of the 100 percent crystalline polymer is calculated to be 1.12. Polystyrene with a high degree of isotacticity is readily prepared. On annealing, partially crystalline isotactic polystyrene has been obtained, generally with less than 35 percent relative crystallinity.

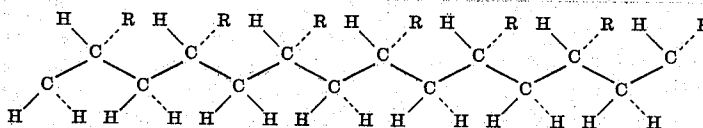
As indicated by Sorenson and Campbell in "Preparative Methods of Polymer Chemistry," the various polymeric configurations of polystyrene may be visualized by imagining the carbon-carbon polymer chain laid out on a plane in the extended zigzag conformation. If the substituents (in this case, the phenyl group) from the monosubstituted vinyl monomer are arranged at random above and below the plane of the carbon chain, the polymer lacks stereochemical regularity and is called atactic. The chain configuration is as follows:



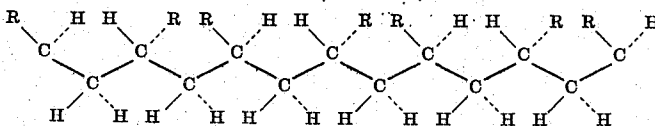
wherein R represents the phenyl group.

Generally, the titanium-based catalysts give, by a mechanism which is still unclear, a stereoregular chain in which each succeeding asymmetric carbon has the same configuration as the preceding one.

If the substituents all fall on one side of the plane, the polymer is said to be isotactic; and has the following chain structure:



Finally, if the substituents fall alternately above and below the plane of the chain, the polymer is designated syndiotactic; whose chain configuration is as follows:



G. Natta and F. Danusso, "Stereo-regular Polymers and Stereo-specific Polymerization" Pergamon Press, Inc., N.Y. 1967, (2) N. E. Gaylord and H.F. Mark, "Linear and Stereo-specific Addition Polymers," Interscience Publishers, Inc., N.Y. 1959, and (3) Wayne Sorenson and Tod W. Campbell "Preparative Methods of Polymer Chemistry," 1961, pages 201 and 202, Interscience Publishers, Inc. As a result of the regular isotactic structure it can be crystallized and has a three-fold helix-chain conformation. Isotactic polymer can exist in the amorphous or crystalline state. Samples quenched from the melt are amorphous but become crystalline if annealed for some time at a temperature below the crystalline melting point. The crystallization

The stereoregularity permits the chains to crystallize, hence the properties of the isotactic and syndiotactic polymers differ markedly from the random counterpart. Thus, atactic polystyrene is clear, noncrystalline, and of a low melting temperature, while stereoregular polystyrene is hazy like nylon, crystalline, orientable and of a high melting temperature. The nature of the R group also affects the melting point markedly; in general, the bulkier it is the higher melting the polymer.

Theoretically, the syndiotactic polymer should crystallize in a sufficient amount that it is of potential interest in this invention.

Unlike ordinary atactic polystyrene, the crystalline isotactic polystyrene is relatively insoluble in such sol-

vents as benzene, chloroform, acetone, and more particularly it exhibits low weight increase when contacted with hot mineral oil over a period of time. Isotactic polystyrene has a low dielectric constant, high melting point, and a low power factor. It is a solid insulating material that in highly crystalline form exhibits low swelling in hot transformer oil. Moreover, the material has a relatively low cost because it is readily made from styrene by polymerization with a special catalyst. Because of such low cost the isotactic polystyrene can be used in transformers as a highly improved substitute for paper, pressboard, wood and similar cellulosic insulation.

The partially cross-linked 1,2-polybutadiene hydrocarbon resins and copolymers thereof with vinyl monomers and the partially crystalline isotactic polystyrene can be employed alone or with various fibrous fillers to produce strong molded members. It is important that the fibrous fillers be of a dielectric constant close to that of the resin. A particularly suitable fibrous material is crystalline isotactic polystyrene made into fibers, as set forth in U.S. Pat. No. 3,078,139. The fibers can be woven into cloth, matted, chopped or employed as strands and impregnated with partially crystalline isotactic polystyrene, or the 1,2-polybutadiene hydrocarbon resin or the latter resin partly dissolved in vinyl monomers such as monostyrene. The fibrous-resin composite can be laminated or molded under heat and pressure into plates, tubes, sheets, rods, washers and other shapes for use in transformers or other electrical apparatus. Polypropylene fibers have excellent strength and a satisfactory dielectric constant, but swell excessively in hot oil. Short chopped polypropylene fibers completely enclosed or embedded in the resin, such as partially crystalline isotactic polystyrene can be employed as long as no fiber ends extend to or protrude from the surface of any member.

The partially crystalline isotactic polystyrene may be admixed with small amounts, up to several percent by weight, of other polymers prior to crystallizing the isotactic polystyrene. The added polymer may be also crystallizable. After crystallization, the mixed polymer product may be shaped to the desired insulator member and used in the practice of the invention. In some cases, there may be added to the monostyrene small amounts of other copolymerizable monomers, as for example, methyl styrene, and then the mixture is polymerized into a copolymer comprising primarily isotactic polystyrene groups and then crystallized. Further, after the isotactic polystyrene is produced, but prior to crystallization, coreactive monomers may be added and reacted in situ to function as end-blocking groups, or the added monomer may be primarily polymerized into polymeric groups relatively homogeneously admixed in the main body of polystyrene, and then the copolymer, or mixture, is crystallized into a body suitable for practicing the invention. The added polymers preferably should be relatively insoluble in oil and have a low dielectric constant comparable to that of the isotactic polystyrene.

In a similar manner the thermosettable 1,2-polybutadiene hydrocarbon resins and vinyl copolymers thereof may be admixed with small amounts of one or more other relatively oil insoluble resins. A homogeneously, admixed resinous body may be prepared which is suitable for the practice of the present invention.

It should be understood that the resinous insulating members, such as tubes or cylinders, separators, rods and spacers, will comprise essentially the crystalline isotactic polystyrene or the thermoset 1,2-polybutadiene hydrocarbon resins and vinyl copolymers thereof, and any added or admixed resin and/or fillers therein will not appreciably impair the oil insolubility and non-swelling properties thereof, nor raise the dielectric constant of the entire insulating member above about 2.7, so that when incorporated in oil filled apparatus, the dielectric stress is not disproportionately distributed as between the oil and this solid insulation.

The following example is exemplary of the invention:

EXAMPLE

Sample discs of isotactic polystyrene, atactic polystyrene, and a polymer of 1,2-butadiene with 20 percent by weight of monostyrene were molded at temperatures of from 225° to 250°C in a compression mold. The isotactic polystyrene discs were then annealed at 175°C for about 1 hour so that crystallization occurred, and the samples changed from transparent to opaque.

The discs were then immersed in hot transformer oil and held at 125°C for 60 days and weight gain and volume swell for the isotactic polystyrene as well as the other polymers was found as shown in FIGS. 3 and 4, respectively. In FIG. 3, the weight gain comparisons indicate that atactic polystyrene (curve A) increases rapidly. The isotactic polystyrene (unannealed curve B) has a decrease in weight gain with the passage of time; however, when annealed at 175°C for 1 hour to effect a high degree of crystallinity (curve C) it has a greatly reduced weight gain.

In FIG. 4, somewhat similar results were obtained for the property of per cent volume swell. The atactic polystyrene (curve D) has a very rapid increase in swelling as compared with isotactic polystyrenes. Further, swelling for highly crystalline isotactic polystyrene (annealed curve E), is considerably less than the noncrystalline isotactic polystyrene in the unannealed state (curve F). More particularly, the as-molded isotactic polystyrene (unannealed curve F) in the relatively noncrystalline state, swells (FIG. 4) up to over 16 percent in volume in 58 days. The swelling, however, was greatly reduced by annealing the isotactic polystyrene to the crystalline state to just over 4 percent in 8 days (curve E).

The effect of annealing time on the isotactic polystyrene on the weight pickup is shown in FIG. 5. Samples of isotactic polystyrene were annealed at 175°C for periods of 2, 4 and 6 hours and then immersed in transformer oil at 125°C for a period of time. The results, shown in FIG. 5, indicate that annealing for the isotactic polystyrene some time between 2 and 6 hours, since an optimum value is achieved in 4 hours, for a minimum weight pickup in transformer oil.

As is also shown in FIGS. 3 and 4, the cross-linked 1,2-polybutadiene-styrene copolymer resin has a satisfactory property of low swelling and per cent weight gain as compared with the other resins included in this Example. The test samples which provided the data for the curves plotted in FIGS. 3 and 4, were cross-linked by incorporating from 1 percent to 2 percent of dicumyl peroxide as catalyst in the viscous resin and curing in an oven for 1 hour at 110°C followed by an overnight cure at 130°C. Other cure schedules may be employed depending upon the ratio of 1,2-polybutadiene to

monostyrene and the resin catalysts used. The samples were then tested for weight increase in hot transformer oil at 125°C and displayed an extremely low volume swell and low weight gain. The cross-linked 1,2-polybutadiene resins exhibited only 0.7 to 0.8 percent weight increase in 60 days with no visible evidence of change in appearance of the aged samples. (Curve G, FIG. 3, and Curve H, FIG. 4). This type of cross-linked 1,2-polybutadiene resin is a satisfactory material for insulators in oil filled transformers.

Electrical measurements were also made on the samples of the cross-linked 1,2-polybutadiene resins and the data obtained thereby is listed in the following Table:

TABLE

Temp.	Frequency Hz	100 tan	Dielectric Constant	Resistivity (ohm-cm)
25°C	60	0.15%	2.3	
	10 ³	0.14	2.3	
	10 ⁴	0.20	2.3	
	10 ⁵	0.32	2.3	
	DC resistivity test:			1.8×10 ⁷
100°C	60	3.2%	2.3	
	10 ³	2.6	2.1	
	10 ⁴	0.47	2.1	
	10 ⁵	0.13	2.1	
	DC resistivity test:			1.1×10 ⁷

The dielectric constant of 2.3 for cross-linked 1,2-polybutadiene resin is substantially identical to that of between 2.1 to 2.2 for transformer oil. The power losses at 25°C are excellent but the losses (3.2 percent) at 60 cycles at 100°C were higher than expected or desired and were attributed to the presence of residual catalysts remaining in the polymer. To prove this a sample of non-cross-linked 1,2-polybutadiene resin in liquid form was extracted in deionized water for several days while the conductivity of the water solution was monitored. Washing was continued until the conductivity of freshly added deionized water remained low. It was then cross-linked in the manner mentioned earlier and the electrical losses were substantially reduced.

Other samples were prepared which consisted of copolymers of 1,2-polybutadiene with varying amounts of t-butylstyrene and monostyrene. The swelling effect of hot transformer oil on such samples is shown in FIG. 3, where the 1,2-polybutadiene content is 80 percent, the balance being styrene (curve I) and t-butylstyrene (curve J, FIG. 3). Use of styrene or t-butylstyrene as a co-monomer with the 1,2-polybutadiene has an advantage in reducing the viscosity of the latter so that the mixture is easier to mold and form.

Although the cross-linked 1,2-polybutadiene resin possesses excellent properties for per cent of volume swell and per cent of weight gain it was relatively brittle. By incorporating in the resin a low dielectric constant reinforcing fiber such as isotactic polypropylene fiber and mat structures, prior to curing in the oven, a better thermoset polymer product was obtained. To enhance the product, the polypropylene fibers were chemically treated to condition and oxidize the surface of the fibers by immersion in sensitizing baths followed by subsequent oxidation in chromic acid-sulfuric acid bath solutions, whereby polar and more readily wetted surfaces were obtained. Polypropylene fibers were particularly suitable reinforcing fibers because of their low dielectric constant so that the overall dielectric constant of the impregnated resin system was not significantly increased. Thus, 50 grams of polypropylene fiber were incorporated in 100g. of 1,2-polybutadiene

resin containing 2g. of dicumyl peroxide catalyst and cured in a press as outlined earlier. Such compositions were useful for oil-filled transformer applications because of their low dielectric constant, low electric loss, and otherwise improved physical properties. Data on oil swell are shown in FIG. 3, (Curve K).

A polyester fiber reinforced sample of cross-linked 1,2-polybutadiene resin system was prepared by impregnating 10 grams chopped polyester fibers (derived from polyethylene terephthalate) in a liquid resin comprising 80 grams of 1,2-polybutadiene resin, 30 grams of divinylbenzene, with 3 grams of dicumyl peroxide, and molding to cure in the manner described earlier. Swell data obtained in hot transformer oil are also shown in FIG. 3, (Curve L).

In addition to the foregoing tests, samples of selected, cross-linked 1,2-polybutadiene resins some having high molecular weight and others lower molecular weight were subjected to compression tests under 750 psi loads in oil at 125°C and the results compared with tests on other materials including isotactic polystyrene, bis-phenol epoxy resin hardened with hexahydrophthalic anhydride and the same epoxy resin filled with 30 percent of cross-linked 1,2-polybutadiene powder. The results as shown in FIG. 6 indicate that under the compression load tests, the high molecular weight cross-linked 1,2-polybutadiene resin had the least physical deformation (compression under load). Next in value was the low molecular weight version. The isotactic polystyrene is found to display nearly identical values of compression to filled bisphenol-epoxy resin. The primary disadvantage of cross-linked 1,2-polybutadiene resins in the non-reinforced condition is that the material is fragile and requires care during handling and installation in a transformer.

Other isotactic hydrocarbon substituted polystyrene polymers that may be employed are the isotactic polymers derived from vinyl toluene (i.e., the isomeric methyl styrenes) and from t-butyl styrene in at least partially crystalline form for example, between 10 to 35 percent crystalline structure.

In summary, certain selected polymeric hydrocarbon resins are shown to have low dielectric constants which closely match that of transformer oil. These selected polymers likewise have relatively low swelling properties when immersed in hot transformer oil over extended periods of time. These properties of low dielectric constant and low swelling are in contrast with certain other hydrocarbon polymers, e.g., polyethylene, isotactic polypropylene, atactic polystyrene, and the like, which have very high swelling, substantially greater than 15 percent by weight, in a few days in the same hot oil medium. As a result, the isotactic polystyrene and selected cross-linked 1,2-polybutadiene resins are outstanding materials for use as solid electrical insulation in oil-filled transformers for replacement of cellulosic press-board and thereby result in cost reduction through a reduction in insulation clearances. The dielectric constant of the solid resinous insulating materials is optimally between 2.0 and 2.2, and preferably between about 2.0 and 2.5, however the solid insulating material may be as high as 2.7.

What is claimed is:

1. Electrical apparatus comprising an electrical conductor, solid electrical insulation applied to the conductor and an insulating petroleum oil applied to at least a part of the electrical insulation, the electrical in-

11

insulation having a dielectric constant of from about 2.0 to 2.7 and being relatively insoluble in the oil and of low swelling in hot oil, the solid electrical insulation comprising essentially a solid insulating material selected from at least one of the group consisting of thermosetting cross-linked 1,2-polybutadiene hydrocarbon resins and copolymers thereof, and at least partially crystalline isotactic polystyrene.

2. The electrical apparatus of claim 1 wherein the solid insulating material comprises essentially a thermosetting cross-linked 1,2-polybutadiene hydrocarbon resin.

3. The electrical apparatus of claim 1 wherein the solid insulating material comprises essentially at least partially crystalline isotactic polystyrene.

4. The electrical apparatus of claim 1 wherein the solid insulating material comprises essentially a thermoset copolymer of 1,2-polybutadiene hydrocarbon resin and a vinyl monomer.

5. The apparatus of claim 3 wherein the polystyrene has a crystalline structure of at least about 10 percent of the total resin.

6. The electrical apparatus of claim 1 wherein the solid material has a dielectric constant of from about 2.0 to 2.5.

7. The electrical apparatus of claim 5 wherein the solid material has a dielectric constant of about 2.2.

8. The electrical apparatus of claim 1 wherein the solid material exhibits a swelling of less than 15 percent by weight over a prolonged period of time when immersed in petroleum oil at a temperature of about 125°C.

9. The insulation of claim 1 wherein the solid material has a dielectric constant that is substantially that of the petroleum transformer oil.

10. The insulation of claim 1, wherein the solid insulating material includes fibrous material having a di-

12

electric constant close to that of the resin and the oil.

11. The insulation of claim 1, wherein fibers of isotactic polystyrene are imbedded in the cross-linked 1,2-polybutadiene resin.

12. The insulation of claim 1, wherein fibers of polyester resin are imbedded in the cross-linked 1,2-polybutadiene resin.

13. In a transformer comprising a magnetic core and electrical windings disposed on the legs of the core, and an insulating oil having a dielectric constant of about 2.2 applied to the electrical windings, solid electrical insulation disposed between the electrical windings and the magnetic core, and between portions of the electrical windings, the solid electrical insulation being selected from at least one polymeric material from the group consisting of thermoset 1,2-polybutadiene hydrocarbon resin and copolymers thereof with vinyl monomers, and at least partially crystalline isotactic polystyrene, the polymeric material having a dielectric constant of from about 2.0 to 2.5, and being resistant to swelling when immersed in the insulating oil at temperatures of up to 125°C, whereby improved dielectric strength is exhibited by the combined insulating oil and solid polymeric electrical insulation, and the solid polymeric insulation exhibits good mechanical strength.

14. The transformer of claim 13, wherein the solid electrical insulation comprises essentially the polymeric material and a fibrous material combined therewith, to provide a strong insulating material capable of withstanding the loads present during service.

15. The transformer of claim 13, wherein the solid electrical insulation is employed for tubular insulating members interposed between the electrical windings and between the magnetic core and the electrical windings.

* * * * *

40

45

50

55

60

65