An Antitracking Varnish for Rated Electrical Application

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Received 15 February 2008; accepted 5 August 2008
DOI 10.1002/app.29329

ABSTRACT: We report on a synthesis, characterization, and thermal evaluation of a pigmented and silicone-modified medium oil alkyd insulating varnish for antitracking application in rated electrical machines such as traction motors, transformers, and large generators. The varnish is generally applied on the top surface of the main insulation of coils by spray or brush and then baked to remove solvent. The semiconducting pigments entrapped in solid polymer matrix reduces surface corona, flash-over, and tracking of the main insulation by distributing uneven charges from polar or charged particles deposited on the surface after long time use of the machines. The varnish was thoroughly evaluated by means of electrical and mechanical properties over a temperature range. The temperature class of the antitracking varnish was 191.22°C determined by IEC 60216 methods on helical coil bond strength of the cured films. The dielectric strength, tracking, and arc resistance of the pigmented varnish were exceptionally high and it will save core insulation from the tracking, corona and short-time flash-over. © 2008 Wiley Periodicals, Inc. J Appl Polym Sci 111: 3065–3073, 2009

Key words: antitracking varnish; tracking and arc resistance; thermal class; silicone modified alkyd resin; hot spot temperature

INTRODUCTION

Most dc machines operate at 600 to as high as 1000 V, but ac machines start at 2300 V and can run as high as 26,000 V with large turbine generators, and the insulation must withstand this voltage stress for the life of the machine, say 10–20 years. This voltage endurance is the ability to withstand corona. With high voltage, the air within the field of conductors is ionized and corona is produced.[1] It can be internal within the insulation wall as voids or external between the insulation wall and ground. The internal corona is reduced to a great degree by the use of modern resin rich tape (semicured glass fiber impregnated with resin that flows on heating to fill voids) and the use of vacuum pressure impregnation (VPI) technique. Experience suggests that most failures of low voltage equipment are due to heating, cracking, or surface tracking. In the kilovolt range and up, internal and external corona become the major cause of long-time failure. The external corona, flash-over and tracking are surface phenomena. In recent years, with the development of modern electrical machines that use conductor for maximum current carrying capacity in a limited space, the sudden discharge of static electricity can damage the equipment. The antitracking varnish can be used for the protection against discharge, formation of surface corona and tracking of the main insulation in coil Industry.

We have developed a silicone modified alkyd resin having semiconducting pigments for antitracking application.[2–4] Evaluating the voltage gradient of the composite insulation of transformer, traction motor and industrial turbine generator, we have made a mixture of cadmium sulfide, titanium oxide, iron oxide, and alkyd resin that gave an optimum dielectric constant of 4.8–5 over a wide-temperature range required for this type of equipment.[5,6] The antitracking varnish was solvent-based and applied by brush or spray on the preheated coils at 150–160°C. It gave very red glazy finishing to the coils after baking. Physical, electrical, and mechanical properties of the resin were determined following ASTM methods.[7–9] As the varnish contained semiconducting (having high dielectric constant) particles, the cured films of the resin had shown excellent tracking and arc resistance. Like other insulating varnishes, the temperature class of the antitracking varnish was 191.22°C[10–12] determined by IEC 60216 procedure on helical coil bond strength.

GE 702 and HEW 290 are unsaturated polyester and epoxy-based polymers respectively, widely used in traction motors, generators as VPI core insulation resin. GE 702 has a temperature class of 180°C and HEW 290 of 200°C. The former is mainly used in TAO series of motors and the later in Hitachi series of motors. Both the resins have advantages and disadvantages in long-term use in rated electrical machines. The cured films of GE 702 are more

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Journal of Applied Polymer Science, Vol. 111, 3065–3073 (2009)

TABLE I
Name and Source of Ingredients and Approximate Quantities

S. No.	Name	Quantity (g)	Source
Silicone modified alkyd			
1	Linoleic acid	185.71	Alfa Chem, Kings Point, NY
2	Glycerine	71.42	Fine chemicals, Ontario, Canada
3	Penta erythritol	30.89	Fine chemicals, Ontario, Canada
4	Isophthalic acid	99.80	Fluka, Mumbai, India
5	Terephthalic acid	17.60	Fluka, Mumbai, India
6	Tetra butyl titanate	0.05	Aldrich, St. Louis, MO
7	Silicone intermediate Z-6018	152.41	Dow corning, Midland, MI
8	Cobalt naphthenate	0.6	Fine chemicals, Ontario, Canada
9	Xylene	500	Nocil, Mumbai, India
Phenolic resin			
1	Para tertiary amyl phenol	301.50	Fluka, Mumbai, India
2	Bisphenol-A	46.70	Fluka, Mumbai, India
3	Formalin (36%)	330.40	Fine chemicals, Ontario, Canada
4	Sulphuric acid	1.20	Fine chemicals, Ontario, Canada
5	Caustic soda	2.00	Fine chemicals, Ontario, Canada
6	Xylene	162.90	Nocil, Mumbai, India
7	Butyl cellosolve	150	Nocil, Mumbai, India

flexible and have excellent electrical properties initially but they are deterioted drastically on ageing. On the other hand, HEW 290 cured films are comparatively hard and develop miniature cracks on heating and cooling cycles of electrical coils although they have excellent weather stability. Both of the resins require an extra top layer of antitracking varnish to reduce the damage on ageing. We have applied the antitracking coating on epoxy and unsaturated polyester-based insulation films and then measured the dissipation factor over a wide-voltage and temperature range to see if any dielectric properties of the main insulation were affected for this layer having high dielectric constant. It was observed that dielectric properties had changed little but the insulation system had gained extra protection from tracking, corona, and flash-over.

EXPERIMENTAL

Synthesis of silicone modified alkyd resin

A three-neck round-bottom flask (3 L) with a digital controlled heating mantle, a thermometer, a stirrer, an inlet tube for introducing nitrogen gas and a distillation apparatus was set up for the esterification reaction. The reactants and their sources are given in Table I. Calculated amounts of linoleic acid, glycerine, penta erythritol, iso phthalic and terephthalic acids, tetrabutyl titanate, and xylene (see Table I) were charged in the flask and temperature was gradually raised to 200–220°C in the presence of inert nitrogen gas.[2] Water, a by product, of the reaction was removed continuously with xylene reflux until acid value (mg of KOH required to neutralize 1 g of xylene-free reacted mass) of the hot mass was reduced to 5–8. The reaction time was 8 h and the extent of reaction was 99% as calculated from the weight of water collected.[2]

The silicone intermediate, Z 6018, was then added to the alkyd resin at 100°C and temperature was again raised to 180°C slowly.[4] Reflux was started at 160°C and water was removed from the reaction mass by azeotropic distillation method. A clear viscous mass was produced at the end of the reaction and then the batch was cooled down to 90°C. The reaction time was 5 h and extent of reaction was 99.6% as calculated from the weight of the water collected.[4] Xylene and cobalt naphthenate were added to adjust viscosity and solid content of the alkyd resin. Tetrabutyl titanate, xylene, and cobalt naphthenate were used as esterification catalyst, azeotropic distillation solvent and drying agent respectively, for the alkyd resin.

Synthesis of phenolic resin

Phenols and formalin (Table I) were added all at once to a three-neck round bottom flask (3 L) fitted with vacuum reflux, heating mantle and an agitator.[3] The PH of the mixed mass was kept at 8 with stepwise addition of caustic soda. The reaction was run at 80–90°C for 2 h with continual removal of water by vacuum reflux. The end point of the reaction was found by manual determination of specific hot plate gel time. The batch was neutralized with sulfuric acid and cooled down to room temperature with the addition of xylene and butyl cellosolve.

Preparation of antitracking varnish

Pigments, silicone modified alkyd and phenolic resin were charged in a grinding mill. The grain size of

TABLE II
Composition of Antitracking Varnishes and Their Dielectric Properties Measured at 25°C in Air

S. No.	Name	Quantity (g)					Source
1	Silicone-modified alkyd resin	1000	1000	1000	1000	1000	
2	Phenolic resin	200	200	200	200	200	
3	Cadmium sulphide	40	40	40	40	40	Suderson chemical, Pune, India
4	Red iron oxide	50	50	50	50	50	Bayer, Mumbai, India
5	Titanium dioxide (rutile)	10	20	30	40	50	Degussa, Mumbai, India
Dielectric properties of the dry films							
1	Dielectric constant	3.0	3.5	4.8	5.7	6.2	
2	Dissipation factor	0.01	0.03	0.05	0.15	0.28	

the pigments was maintained at 8 in a Hegman gauze scale by running the mill for [1/2] hours. Finally, antitracking varnish was collected for testing.

We have made five different antitracking varnishes with all the ingredients remained same but titanium dioxide varied in weight (dielectric constant of titanium dioxide is 110).[6] The dielectric constants of five different antitracking varnishes were determined (on dry films) to be 6.2, 5.7, 4.8, 3.5, and 3. The ingredients of the antitracking varnishes having different dielectric constants are given in Table II.

Physical properties

Physical properties of the antitracking varnish having dielectric constant of 4.8 were measured by ASTM methods[9] as done with other insulating varnishes. Viscosity of the varnish was measured by Brookfield viscosity meter (Model KU-2) following ASTM D6267-08 method at 25°C.[10] The drying time of the antitracking varnish was determined by a mechanical recorder following ASTM D5895-03 method at 160°C.[11] The solid content of the varnish was determined by evaporating 2 g of liquid resin on a glass Petridis at 155°C for 2 h in a hot air circulating oven following ASTM D4209-07 method.[12] The flash point of the varnish was determined by Elcometer (Model 6910/1) following ASTM D1310-01 (2007) method.[13] Specific gravity (following ASTM D891-95)[14] and storage stability of the varnish were measured at 25°C. The flexibility of the cured films of the varnish was determined by bending the films on copper panels in a 1/6 in. mandrel following ASTM F137-03 (2007) at 25°C.[15] After bending the panels in the mandrel at room temperature, the sets were thoroughly investigated for any crack and void in the cured films under high power microscope. The results are given in Table III.

Electrical properties

Electrical properties of the antitracking varnish having dielectric constant of 4.8 were measured on dry films deposited on ms sheet (panel) having dimension of $6 \times 4 \times 0.09$ cm^3. Several testing panels were made by pouring ~ 20 g of red resin on one side of very clean and dry ms sheets. Once uniform layer on the sheet was formed, excess varnish was allowed to fall freely. The panels were then placed in an oven at 60° inclination and temperature was gradually raised to 160°C. All the panels were double coated for 80–90-μm film thickness and dried for 10 h. Similarly, two layers of the varnish were applied on few ms panels that were already coated with unsaturated polyester (GE 702 of General electric) and epoxy (HEW 290 of Hitachi) resins separately to study the effect of the antitracking varnish on main insulation system. Few copper panels were made by two layers of the varnish for flexibility measurement.

Dielectric strength of the varnish was measured on the dry films on the panels by an instrument (Model: HVO-35 35KV Ac 75mA, Sivanand Electronics, India) following ASTM D149-97a procedure.[16] Volume resistivity, dielectric constant and dissipation factor were measured on these ms panels by an instrument (Model EW188 of Sivanand Electronics) following ASTM D257-07 and ASTM D150 methods respectively,[17,18] Some of the panels were immersed in water, boiling water and transformer oils for few days (see Table IV) and dried at room temperature and then tested for the electrical properties. All testing were fivefolds and average values were

TABLE III
Physical Properties of the Antitracking Varnish Having Dielectric Constant 4.8

S. No.	Properties	Unit(s)	Value(s)
1	Appearance		Red liquid
2	Specific gravity at 25°C		1.07
3	Viscosity at 25°C	cps	500
4	Flash point	°C	42
5	Drying time at 160°C	H	5
6	Flexibility at 25°C	1/6 in.	Pass
7	Storage time at 25°C	Months	12
8	Solid content	wt %	60

TABLE IV
Electrical Properties of the Antitracking Varnishes

S. No.	Electrical properties	Antitracking varnish value(s)	Glyptal 1201 red value(s)
1	Volume resistivity (Ohm-cm)		
	In air at 25°C	2.5×10^{16}	
	After immersion in water for 7 days	4.5×10^{15}	Insulation resistance 7.5×10^{7} ohm
	After immersion in boiling water for 1 day	2.8×10^{14}	
	After immersion in transformer oil for 7 days	2.4×10^{16}	
2	Dielectric strength (kv/mm)		
	In air at 25°C	110	59
	After immersion in water for 7 days	98	34 (24 h immersion in water)
	After immersion in boiling water for 1 day	85	
	After immersion in transformer oil for 7 days	105	
3	Dielectric constant		
	In air at 25°C	4.8	
	After immersion in water for 7 days	5.2	
	After immersion in boiling water for 1 day	5.5	
	After immersion in transformer oil for 7 days	4.8	
4	Dissipation factor		
	In air at 25°C	0.05	
	After immersion in water for 7 days	0.08	
	After immersion in boiling water for 1 day	0.10	
	After immersion in transformer oil for 7 days	0.03	

presented in Table IV. Dissipation factor experiments were performed over a wide-range of voltage and temperature on both pure antitracking films and composite films with other resins (Figs. 1–3). Few panels with composite films of GE 702 and antitracking varnishes were kept in an oven at 180°C and dissipation factor was measured (in room temperature) in 15 days intervals over a period of 6 months. The electrical and antitracking properties of a standard product—Glyptal 1201 Red (from General Electric) are also given in Tables IV and V, and it has a temperature class of 135°C.

Antitracking properties

The antitracking property of the varnish was measured by means of tracking and arc resistance using ASTM D3638-07 and ASTM D 495 methods respectively,[19,20] An electrically conductive solution of ammonium chloride (0.1*N* NH_4Cl) was dripped (1 drop per second) between two platinum electrodes placed on cured films (3-mm thick) of the varnishes. The electrodes were positioned at a distance of 4 ± 0.1 mm and at an angle of 60° to the horizontal. The maximum ac voltage (60 Hz) at 50 drops of dripping of the solution when over-current of relay tripping first occurs is called comparative tracking index. For arc resistance two carbon electrodes were placed on sample surface at a distance of 1 mm and at an angle of 60° to the horizontal. The arc intensity was increased in every 30 s to double than its predecessor with an applied voltage of 220 V. The time in seconds the insulating surface survived to the arc is

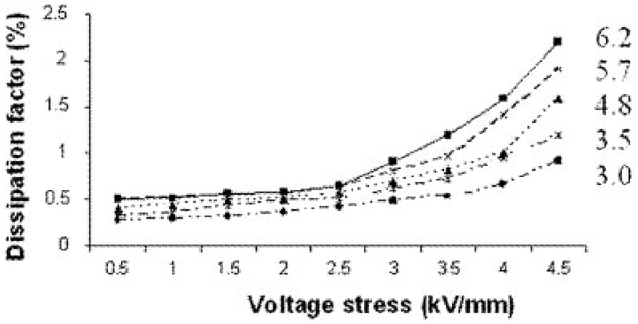


Figure 1 Change of dissipation factor with voltage stress for antitracking varnishes having different dielectric constants (6.2, 5.7, 4.8, 3.5, and 3) applied on GE 702 polyester films at room temperature.

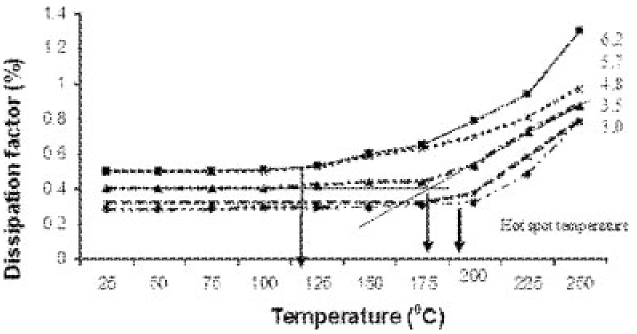


Figure 2 Change of dissipation factor with temperature for antitracking varnishes having different dielectric constants (6.2, 5.7, 4.8, 3.5, and 3) applied on GE 702 polyester films. Hot spot temperature was observed at 175°C for the coating having dielectric constant of 4.8.

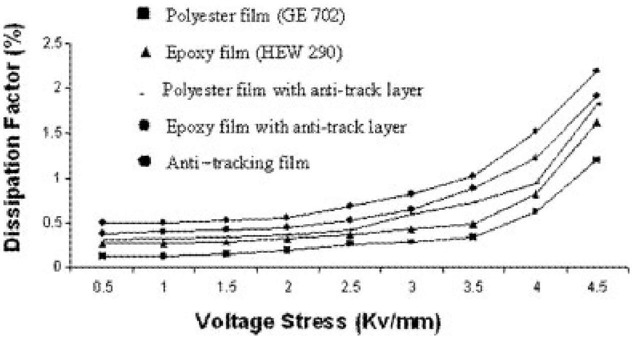


Figure 3 Change of dissipation factor with voltage stress for GE 702, HEW 290, antitracking varnish, composite films of polyester (GE 702) and epoxy (HEW 290) coated with antitracking varnish.

called arc resistance. The comparative tracking index and arc resistance of antitracking varnishes, GE 702, HEW 290 and antitracking varnish (with dielectric constant 4.8) applied on GE 702 and HEW 290 films were measured by a comparative tracking index tester (Model: CTIT from SCR Elektroniks, India) and arc resistant measuring instrument (Model: 113094-01 from Lectromec) respectively, at room temperature on ms panels with six layers of antitracking varnish (see Table V).[7]

Determination of thermal class

Many helical coils were made from aluminum wire (1-mm diameter) having coil with 6.3-mm diameter and 75-mm length with loops in both ends of the coils. Helical coils were washed with acetone and alcohol solution and then given double layers with antitracking varnish having dielectric constant of 4.8. Three hot air ovens were set at 200, 220, and 240°C, and 60 helical coils with antitracking layer were hung in each oven for accelerating thermal ageing. In the end of a time-temperature cycle (prescribed in Table VI), five coils were taken out from the oven and let them cool down to room temperature. Helical coil bond strength of each coil was measured in a universal testing machine (Model: Instron 5582) following ASTM D2519-07 method[21] and average value was recorded for each cycle (see Table VI). The thermal aging and bond strength testing after the end of a cycle at a specified temperature were continued until bond strengths were reduced to just or below 50% of the initial value (See IEC 60216 in Refs. 22,23). The time in hours to 50% loss of initial value of bond strength at each temperature was precisely calculated[12] from the plot of time versus helical coil bond strengths (Fig. 4). The Arrhenius type plot of logarithm of time versus inverse of absolute temperature to 20,000 h line gave temperature class of the antitracking varnish to 191.22°C (Fig. 5).

RESULTS AND DISCUSSIONS

Structure of the varnish and optimum antitracking property

The carboxylic groups of isophthalic, terephthalic, and linoleic acids were reacted with the hydroxylic groups of glycols and the branching of the polymer chain was restricted by linoleic acid.[2] The excess hydroxylic groups from both glycols were then reacted with the same groups of silicone intermediates. Thus, the structure of the alkyd polymer was that 2–3 glycols were linked to either aromatic acids or silicone intermediates by ester or Si—O—C bonds, respectively.

Para tertiary amyl phenol, bisphenol-A and formalin were reacted to make a resole type resin which was heat reactive. The structure of the phenolic resin contained many —CH_2OH groups and these groups were very reactive at high temperature with themselves or with the alkyd resin.[3] The phenolic resin was also very soluble with alkyd resin in solution and in semisolid state.

Thus the linoleic chains of the polymer reduced the possibility of polymer chain to be oxidized at elevated temperature, silicone segments increased

TABLE V
Tracking and Arc Resistance of Varnishes

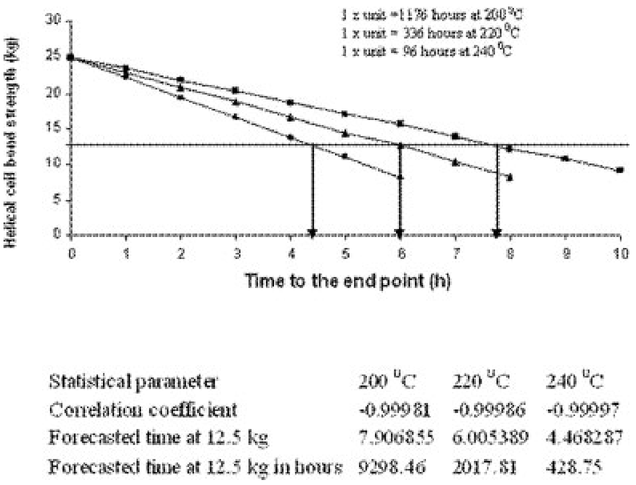
Name	Tracking resistance (CTI in volts)	Arc resistance (s)
Antitracking varnish (dielectric constant 3)	250	280
Antitracking varnish (dielectric constant 3.5)	300	280
Antitracking varnish (dielectric constant 4.8)	350	300
Antitracking varnish (dielectric constant 5.7)	400	320
Antitracking varnish (dielectric constant 6.2)	450	330
Alkyd resin without pigments	160	280
Glyptal 1201 red	280	480
GE 702	120	160
HEW 290	120	160
Anti-tracking varnish on GE 702	300	300
Antitracking varnish on HEW 290	300	300

TABLE VI
Change of Helical Coil Bond Strengths after Thermal Ageing

Number of cycle completed	Helical coil bond strength (kg) at 200°C (1 cycle = 49 days)	Helical coil bond strength (kg) at 220°C (1 cycle = 14 days)	Helical coil bond strength (kg) at 240°C (1 cycle = 4 days)
Initial	25	25	25
1	23.45	22.91	22.24
2	21.84	20.81	19.43
3	20.38	18.73	16.64
4	18.62	16.67	13.88
5	17.10	14.48	11.04
6	15.66	12.74	8.12
7	14.01	10.37	
8	12.11	8.32	
9	10.81		
10	9.22		

the hydrophobicity such that resistance of the polymer chain to humidity was remarkably increased.[2] The phenolic resin has increased the resistance of the dry polymer films to be attacked by acid and alkali.

Antitracking varnishes having different values of dielectric constant were applied on GE 702 insulation films on ms panels separately and each panel was evaluated over a range of voltage stress and temperature for dissipation factors (see Figs. 1 and 2) at 60 Hz. Interestingly, voltage endurance of the composite films has reduced with the increase of dielectric constant of the applied antitracking layer on GE 702 as observed from the start of the sharpness of the slope of dissipation factor versus voltage stress. On the other hand, with the increase of temperature, the dipoles of the insulation orient under the influence of electric field and at a critical temperature these dipoles align to form conducting paths in the insulation. It is called hot spot.[5] The hot spot temperature was observed from the plot of dissipation factor versus temperature in Figure 2. The more the value of dielectric constant, the lower the value of the hot spot temperature was also. Thus an optimum value of dielectric constant of the antitracking varnish was selected at 4.8–5 such that voltage endurance and hot spot temperature would not be changed much. The dielectric constant of GE 702 alone and coated with antitracking varnish (having dielectric constant 4.8) was 2.8 and 3.8, respectively. A great change of dielectric properties such as dissipation factor versus temperature and dissipation factor versus voltage stress was observed when the dielectric constant had been increased. So, we have selected the optimum dielectric constant of the antitracking varnish to 4.8–5 such that the dielectric



Statistical parameter	200 °C	220 °C	240 °C
Correlation coefficient	-0.99981	-0.99986	-0.99997
Forecasted time at 12.5 kg	7.906855	6.005389	4.468287
Forecasted time at 12.5 kg in hours	9298.46	2017.81	428.75

Figure 4 Change of helical coil bond strength after ageing at different temperatures for anti -tracking varnish and correlation coefficient at each temperature.

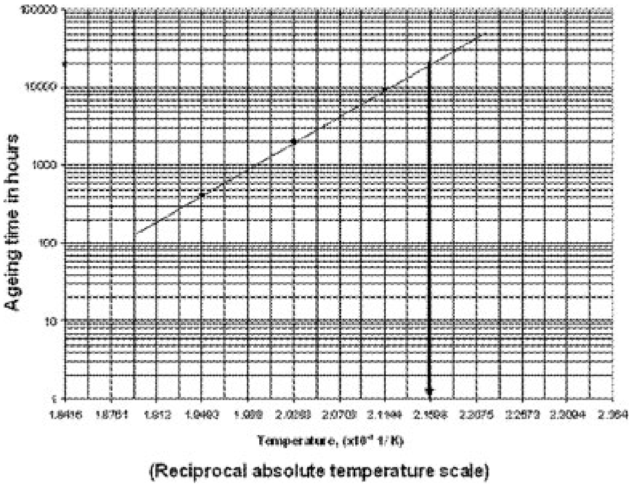


Figure 5 Thermal endurance curve for antitracking varnish-logarithm of time versus reciprocal of temperature plot. The extrapolation of the Arrhenius plot to 20,000 h meets x-axis at 2.15.

properties of the main insulation were affected little. As a result physical, electrical, antitracking, and thermal properties were evaluated for the antitracking varnish having dielectric constant of 4.8.

Studies of physical properties

The viscosity of the antitracking varnish is 500 cps suitable for application by brush and it can be reduced to 250 cps by addition of xylene suitable for spray application with dry film thickness of 40–50 μm in a single layer. The dry film is very compatible with polyester and epoxy films with respect to chemical nature and electrical properties.

Titanium dioxide, cadmium sulfide, and red iron oxide have very high dielectric constants of 110, 56, and 18, respectively. Cadmium sulfide and iron oxide are also semiconducting materials with very low band gap of 2.42 and 0.72 eV, respectively. The former generates positron and the later electrons easily on excitation of their molecules by light or heat energy. Whenever dust particles, humidity, chemical vapors, etc., are deposited on the insulation surface, they accumulate both positive and negative charges and start making tracking path in the core insulation under the electrical stress of the machines. The positron generated from cadmium sulfide and electrons from iron oxide consume the negative and positive charges respectively, of the tracking agents and titanium dioxide catalyzes this redox reaction. The ratio of cadmium sulfide and red iron oxide was determined (given in Table II) to achieve a preselected color, glaze and light, and weather fastness. On the other hand, different weight ratios of titanium dioxide were used in antitracking varnishes to see the effects of extra films with high dielectric constants on the core insulation and to determine the optimum one.

All the pigments are very stable in high temperature and the resin layer retains both color and glaze for a long time. The dry film is very flexible and this reduces the cracking of the surface due to heating and cooling cycles of the coils. Storage stability of the varnish is also good. It is a solvent-based varnish and has a high flash point of 42°C.

Studies of electrical properties

Since the antitracking coating will be exposed to outdoor such that the polymer films will come to the contact of humidity, dust, different solvents, acids, and alkali in industrial motor application, the dry film of the antitracking varnish having dielectric constant 4.8 was thoroughly investigated.[7] We have seen that treatments of the antitracking films in boiling water, transformer oil have changed the electrical properties such as volume resistivity, dielectric strength, dielectric constant very little. The antitracking varnish having dielectric constant of 4.8 was applied on both polyester and epoxy-based main insulation to see any changes of dielectric properties under voltage stress. The dissipation factor of the main insulation is changed little over a voltage range (see Fig. 3). Further, to see any incompatibility of antitracking varnish with other resins on ageing at elevated temperature, dissipation factors of the composite films of GE 702 and red varnish were measured and it has changed very little in the range of 0.04–0.06 at 180°C over a period of 6 months. The varnish is an insulating varnish for small motors and generators as it has also good electrical properties. It can also be used as industrial coating for high temperature application.

Study of antitracking properties

The tracking resistance (CTI) measurement evaluates the behavior of the surface of the solid insulating materials when exposed to the effects of leakage currents that occurs when conductive contaminants are present in the surface.[5] The antitracking films had withstood the severity for a considerably high voltage of 350 V as observed from tracking resistance measurement experiment. The tracking resistances of the dry films of the modified alkyd resin without pigments, GE 702 and HEW 290 were 160, 120, and 120 V, respectively. The semiconducting pigments in antitracking varnish have enhanced the tracking resistance not only of antitracking varnish (more than 350 V) alone but also of coated films of GE 702 and HEW 290 with antitracking varnish from 120 to 300 V. The film will resist strongly to the tracking of the main insulation. The inside mechanism might be the presence of highly polar particles (titanium dioxide, iron oxide, and cadmium sulfide with dielectric constants of 110, 18, and 56, respectively) in the polymer matrix that resists leakage formation by the orientation of their molecular electrons towards the charged contaminants and minimize the voltage difference among charged contaminants (as explained earlier). Interestingly, the tracking resistance of antitracking varnish having dielectric constant of 6.2 was more than 450 V but dielectric properties of the core insulation were affected most if this varnish was used.

The arc resistance of the antitracking films is very high (>300 s) and this may be due to the very high crosslink density and the presence of silicone and phenolic moieties in the polymer. The arc could not make carbonized short circuit path easily. Since the electrodes were placed only on the top of antitracking films applied on GE 702 and HEW 290, it was expected to have similar values of arc resistance (300 s) of the composite films.

Study of thermal class

The temperature class of the antitracking varnish was determined[22,23] by IEC 60216 method. The time to 50% loss of initial values of the helical coil bond strength after thermal aging at different temperatures was determined from the Figure 4. The temperature class was obtained from the extrapolation of logarithm of time versus inverse of absolute temperature to log 20,000 line and it was 191.22°C (Fig. 5). The statistical treatment of the data for thermal endurance experimentation was performed. The correlation coefficients between time and bond strength (Table VI) at each temperature are given in Figure 4 and also forecasted time in hours to 12.5 kg bond strength are calculated from the data in Table VI. The correlation coefficient of the data (logarithm of time in hours and inverse of absolute temperature) was 0.999 and forecasted temperature class was 191.22°C.[24]

Since the cured films of the antitracking varnish contained pigments having high temperature stability and silicone modified alkyd resin, its temperature class should be high.

CONCLUSIONS

An antitracking varnish was made by judicial selection of raw materials and polymerization technique. The varnish was a solvent-based silicone modified alkyd resin with semiconducting pigments. The optimum composition of semiconducting pigments in the varnish was determined by applying a series of antitracking layers having different dielectric constants and compositions on a polyester-based main insulation. The composition (Table II) with dielectric constant of 4.8 produced maximum hot spot temperature and voltage endurance of the composite insulation (Figs. 1 and 2). The varnish was thoroughly characterized by means of physical, electrical, and thermal properties following ASTM and IEC methods. The antitracking varnish had very high tracking resistance (CTI is more than 350 V), arc resistance (more than 300 s) and temperature class (over 190°C). The tracking and arc resistance were also determined on standard polyester and epoxy-based main insulation films coated with antitracking varnish. As the testing electrodes were only on antitracking films in the measurements of tracking and arc resistance for composite films, we have also checked if any dielectric property such as dissipation factor of the main insulation was affected much. Interestingly, the dissipation factors versus voltage stress plots of pure and coated films with antitracking varnish were changed very little (Fig. 3). It is therefore, concluded that the antitracking films could save the main insulation from corona, flash-over, and tracking as the varnish has very high dielectric strength, arc and tracking resistance.

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