UDC 621.313.13.048

RECENT INSULATION SYSTEM FOR LOW VOLTAGE ROTARY MACHINES

Matsutaroh Minami
Yuhji Ishii
Hideto Fukumori
Hiroshi Noda
Yoshitaka Nishiwaki
Masao Maeda

I. INTRODUCTION

Low voltage rotary machines are used in all areas of industry and recently, rèsponding to the electronic control, the improved heat resistance, increased size, and high reliability under various environmental conditions are demanded. Under these conditions, the reliability demanded of insulation is steadily increasing. Therefore, wide studies must be added to material application techniques and insulation treatment techniques and then, insulation must be amply evaluated as a system. Insulation for low voltage induction motors and DC motors is introduced here for reference purposes.

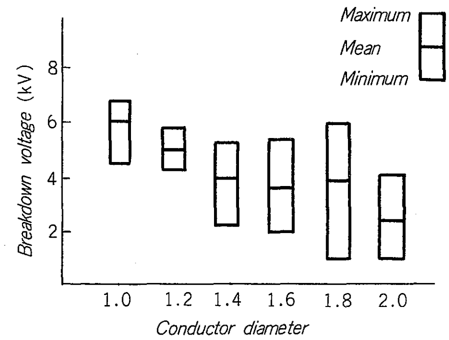

Fig. 1 Distribution of breakdown voltage of enameled wires

II. INSULATION FOR LOW VOLTAGE INDUCTION MOTOR

The trend in insulation for low voltage induction motors is toward a rise of the thermal classification from the present standard Class E to Class B and Class F and improvement of the durability under environmental conditions accompanying the diversification of the operating environment. On the other hand, to establish a high reliability insulation system, selection of superior quality material suited to manufacturing and fabrication techniques, grasping of the operating environment factors, and selecting the insulation system according to these factors are necessary. The points which should be given special consideration in material and insulation selection and durability under environmental conditions will be described below.

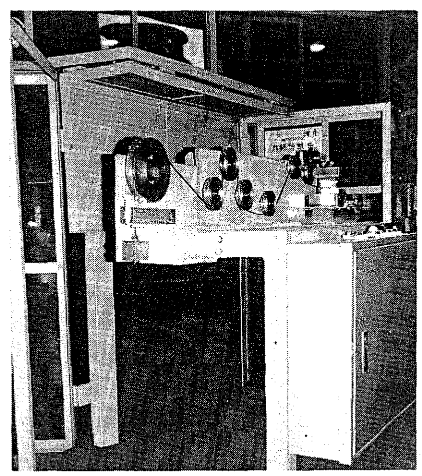

Fig. 2 Continuity test equipment for enameled wire

1. Selection of material

In the manufacture of motor windings, the coil winding process is becoming mechanized, varnish treatment process is being performed on a production line, and other rationalizations are progressing. When these rationalizations are implemented, quality must be stable and superior durability against mechanical stress are necessary in applying various materials. The wire is important material in a low voltage induction motor. The points which should be considered in selection will be discussed here by taking wire as an example.

The distribution of the breakdown voltage of a 1 m sample of various diameter wire by the continuity testing equipment is shown in *Fig. 1* as an example of enamel wire quality control. According to this figure, the defect of the enameled layer tends to increase as the conductor diameter of enamel wire becomes larger, depending on the kind of wire. This also applies to the effect by length. The relationship between breakdown voltage and electrode area (wire length) is $V_l = V_0 - K \cdot \log l/l_0$ (V_0, V_l are the breakdown voltage when the sample lengths are l_0, l) within a certain range. Therefore, we have established standards at the characteristic level in the conductor diameter and length directions to maintain product quality. JIS (Japanese Industrial Standards) testing is insufficient since the sample length is small, we perform receiving inspection by equipment which continuously checks the defects of long samples such as that shown in *Fig. 2*.

The breakdown voltage distribution after manual winding of polyester wire (Type 1) and winding using a certain kind of winding machine is shown in *Fig. 3* as an example of mechanical deterioration in winding work. Moreover, a simple varnish processed Class E insulation model was manufactured using these enamel wires and Motorette tests basing on IEEE Std. 117 were performed. The test cycle was heating (190°C – 2 days) – vibration (1.5 G for 1 hour) – moisturizing (40°C 95% RH for 3 days) – voltage check (between wires: 200 V for 10 minutes). The life time (between wires) distribution obtained is shown in *Fig. 4*.

According to these figure, deterioration by winding of the enamel wire coating has a direct effect on life. Therefore, we have been selected and checked the quality of enameled wires by the windability test equipment that simulated the machine winding of an actual coil, and developed and improved the winding machine suited to manufacturing work.

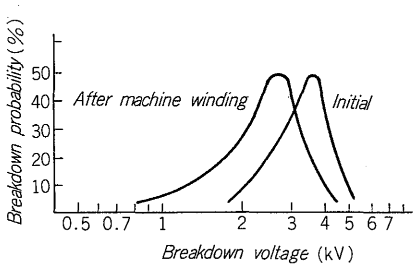

Fig. 3 Distribution of breakdown voltage of polyester enameled wires

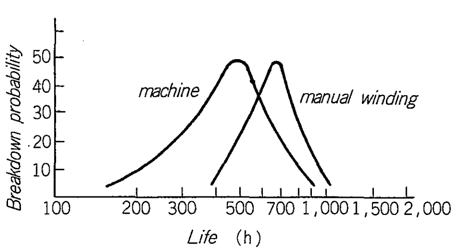

Fig. 4 Distribution of thermal life curves by motorette test

2. Selection of insulation system

For selection of the insulation system, after the homogeneity of the material and manufacturing deterioration occurring in the coil manufacturing process are studied, a some insulation systems are selected by the heat resistance test of the enamel wire, varnish, sheet material, etc. and compatibility test by combining these, and then evaluation of the life of the insulation system is performed

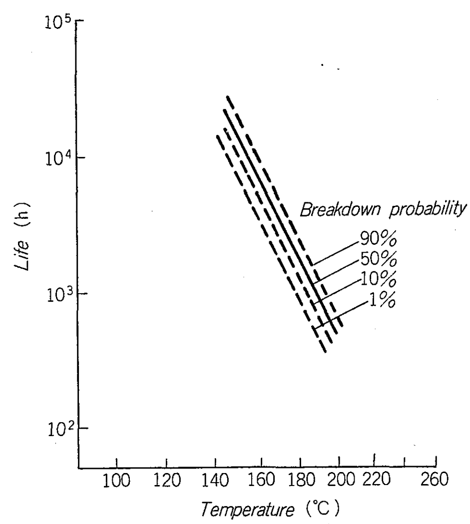

Fig. 5 Thermal life curves by motorette test

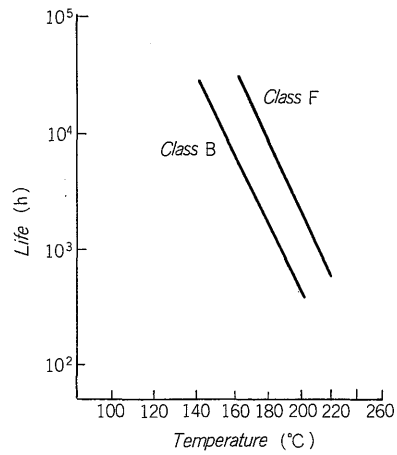

Fig. 6 Thermal life curves by motor test

by Motorette with part of IEEE Std. 117 modified or functional evaluation test with the actual machine. These tests must be performed according to the test conditions approximated actual operating states and life must be estimated by statistical processing of the results.

The Motorette test results for Class B insulation system are given in *Fig. 5*. The life time of motors is variations, therefore, it is dangerous to select the insulation system and manufacturing system by only the mean life by a 50% probability. Actually, the distribution of life curve can be represented by a logarithmatic normal distribution, and life must be estimated at a breakdown probability of 1% or less, for example, after confirming that the relationship between life and breakdown probability is flat at each temperature. The thermal life characteristic based on IEEE Std. 177 for an actual Class B, F insulation system machine whose insulation system was selected in this manner is shown in *Fig. 6*.

Since the molding process of various molding machines is complex and the time for one process is short, large load

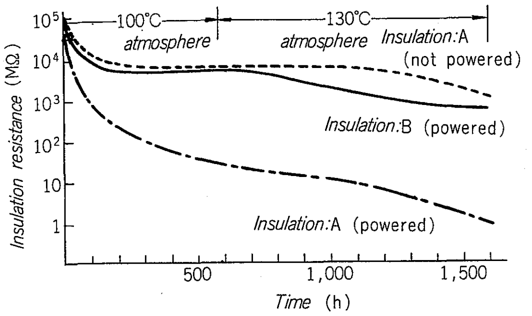

Fig. 7 Change of insulation resistance after moisture absorption during rush current test

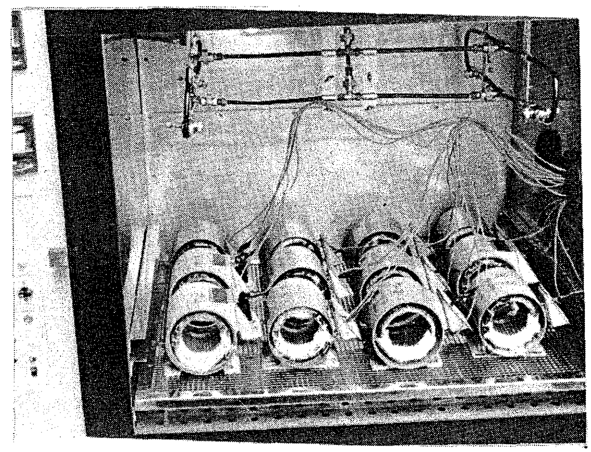

Fig. 9 Environmental test for motor insulation

fluctuations may frequently occur within a extremely short time when the mean output is low.

To improve productivity further, the trend is toward increasing the mechanical load on the coil by electromagnetic force and thermal stress. *Fig. 4* shows the change in insulation resistance in high humidity atmosphere for 30 kW class model coils when power has been applied intermittently such as 1.5 times the rated current applied for 1 second and stopped for 30 seconds, and during testing 1.5 G vibration and 120 V between conductor was applied in 100°C and 130°C atmospheres.

For machines having these severe load fluctuations we have been employed the superior insulation system which is increased the level of the enamel wire and varnish treatment.

3. Insulation under environmental conditions

With motors used under severe environments and special atmospheres, a construction corresponding to these conditions is employed, but insulation also hase an important part in such motors. Recently, the diversification of applications of conventional motors has accompanied by numerous cases of operation in high humidity, electrolyte, oil, dust, and other dirty atmospheres, therefore, an insulation system having higher reliability is being demanded.

Fig. 8 shows the aging change of the insulation resistance in various atmospheres of the stator coil of a small standard open motor, and *Fig. 9* shows the test state. The soiling of the coil end is artificial dust placed on the surface. The insulation resistance is maintained at 1000 MΩ even in an extremely moist atmosphere in this way, but when the dust on the end of the coil is severe, the insulation resistance gradually decreases, and when used in these circumstances, wet proof insulation is necessary.

Generally, when metal dust, carbon, salt, or other electrolytic materials coexist with water, the effect of voltage becomes large and tracking and arc short circuit are sometime produced by the increase in the leakage current at the weak part of the insulation layer. The effect of electrolyte of enamel wire is shown in *Fig. 10* as an example of voltage deterioration in these dirty atmospheres and the test state is shown in *Fig. 11*.

The specimen (unvarnished) was made by wrapping several turns of two parallel strands of polyester wire around a stainless steel tube over which a heat resistance film was wrapped and wrapping asbestos tape on coils.

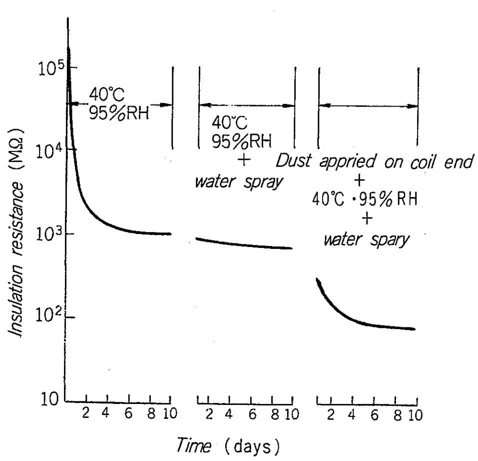

Fig. 8 Change of insulation resistance of stator coils during environmental test

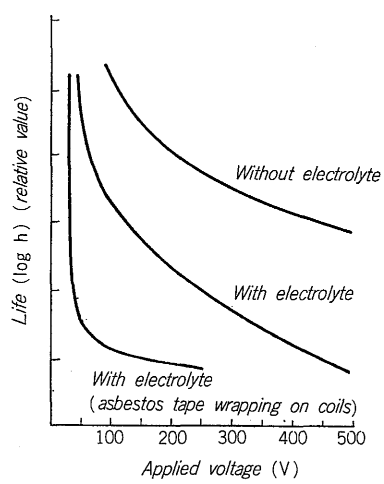

Fig. 10 Influence of voltage on life of polyester wire applied electrolyte

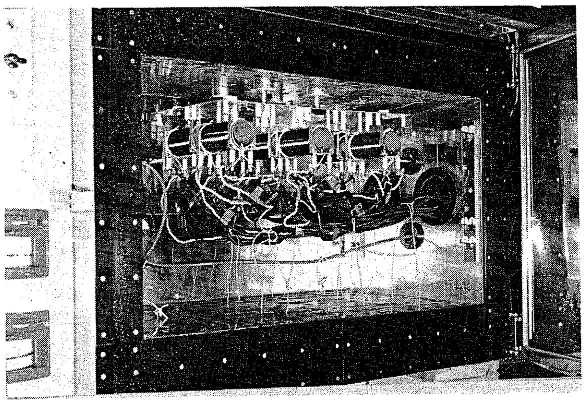

Fig. 11 Environmental test for enameled wires

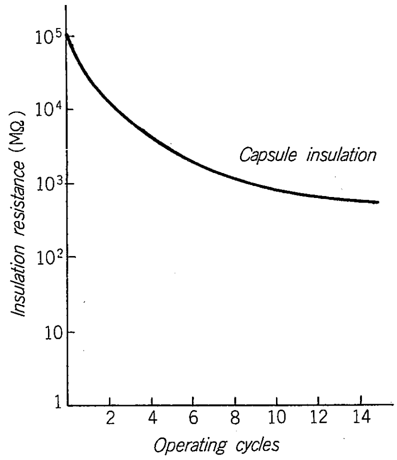

Fig. 13 Change of insulation resistance of capsule insulating motor by cutting fluid spray test

Various voltages were applied in a high humidity atmosphere and the time up to breakdown was measured. According to this test, the influence of voltage appears to be large at a high humidity atmosphere and this trend becomes more pronounced with specimens to which electrolyte is applied. Moreover, the deterioration is accelerated further when the electrolyte enters the inside of the insulation layer. Therefore, machines which are exposed to salt and other electrolytes and soiled by metal powder, carbon, and other dust, must use special environment durable insulation.

The aging change of the insulation resistance after moisture absroption (40°C 100% RH) at a IEEE Std. 117 heating conditions 200°C – 1 day cycle Motorette test for the stator winding of a environment durable insulation medium sized motor is shown in *Fig. 12*. The characteristics of a Class B standard insulation model coil are also given in this figure. The moisture resistant insulation has stable characteristics even under such severe conditions.

When there is a danger of splashing of the water soluble cutting fluid having a high direct conductivity alkali characteristic, such as motor for machine tool, epoxy wire having excellent durability for soluble cutting fluid is used and capsule insulation mainly of epoxy resin is performed. In the durability under environmental conditions test equipment, testing was performed by operating a capsule insulation motor at an 8 hours operation – 16 hours stop cycle and spraying the motor with water soluble cutting fluid (Yusiroken N 50 times water solution) under 10 minutes spray – 10 minutes stop conditions. The aging change of the insulation resistance at this test is shown in *Fig. 13*. It was found that the effect of the capsule insulation was large.

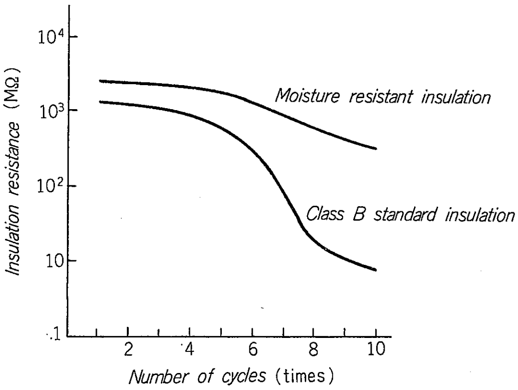

Fig. 12 Change of insulation resistance of model coils by moisture absorption

III. INSULATION OF LARGE DC MOTORS

Large mill DC motors are subject to sudden load fluctuations during operation and are frequently used under more severe electrical and mechanical conditions than other types and there are frequently cases in the installation environment where contains iron, dust, and are in high temperature, high humidity, salt, and other adverse condition. Therefore, the insulation of the motor must, of course, have superior electrical and mechanical characteristics and must be heat and environment resistant. In addition, improved thermal conduction of insulation layer or simplified maintenance are demanded. The insulation system of large DC motor has been changed from shellac-paper-mica – varnish processing → epoxy glass mica – varnish processing → mica paper composite sheet material – epoxy resin vacuum pressure impregning processing, and improved the insulation performances substantially. The epoxy resin vacuum impregnated insulation currently used at large armature coils will be described below.

1. Insulation system and processing method

There are two kinds of mica, which is the main coil insulation of rotary machines. One is flake mica and the other is mica paper.

As a result of overall studies on coil insulation processing methods and characteristics and economy of various kinds of thin materials, mainly paper mica, we have adopted a system which performs assembly vacuum pressure impregnation with heat resistance epoxy resin using mica paper with aramid paper or glass cloth as the backing.

In this insulation system, heat resistant epoxy resin is perfectly filled between the conductor and insulation layer, the insulation layer and core, and the exposed part of conductor is substantially reduced. Therefore, this system has features as follows,

1) Substantial improvement in thermal conduction.
2) Stronger insulation layer for electrical and mechanical stresses.
3) Since the exposed part of the conductor is limited to the vinicity of the commutator, maintenance of the insulation is simplified.

The armature insulation is composed with copper conductor insulated with heat resistant tape and above mentioned mica paper composite sheet materials as the main insulation. The coil insulated with the main insulation is inserted into the core under an adequately controlled environment and the insulation of the winding end and the various reinforcing part are bound or installed, and the amature is then vacuum impregnated with heat resistant epoxy resin. After the resin impregnated at the insulation layer is semi-cured under the pressure heating state, it is cured as an assembly in baking oven. The vacuum pressure impregnation process is outlined in *Fig. 14* and the armature of a large DC motor suspended from the impregnation tank is shown in *Fig. 15*.

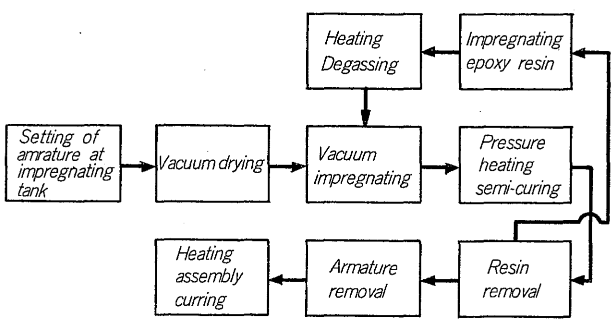

Fig. 14 Process of vacuum pressure impregnating method

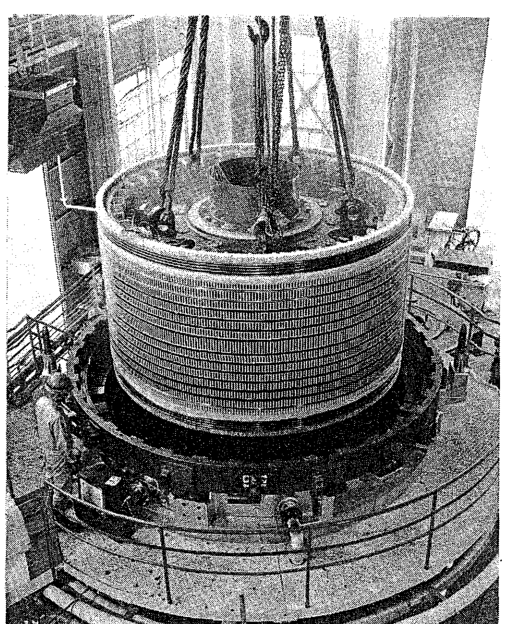

Fig. 15 Large armature under hanging up from impregnating equipment

2. Characteristics

The tanδ vs. voltage characteristics and temperature rise value of each part of the coil employing this insulation are shown in *Fig. 16* and *Fig. 17*, respectively.

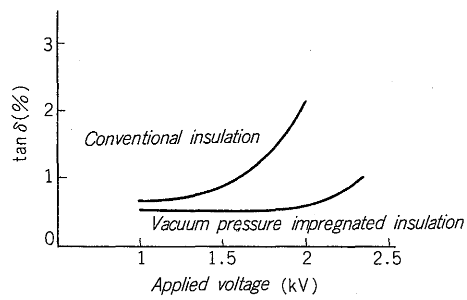

Fig. 16 tanδ vs. voltage characteristics

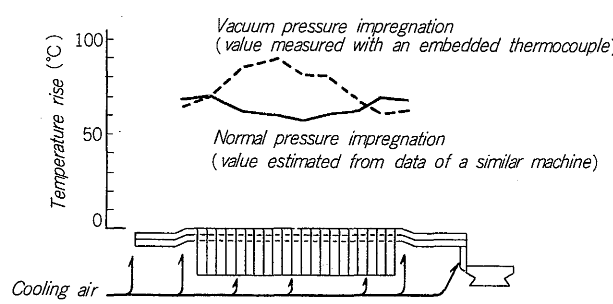

Fig. 17 Temperature distribution of armature coil

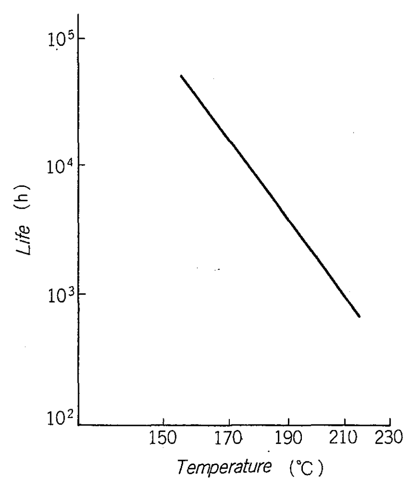

Fig. 18 Thermal life curve by Motorette test

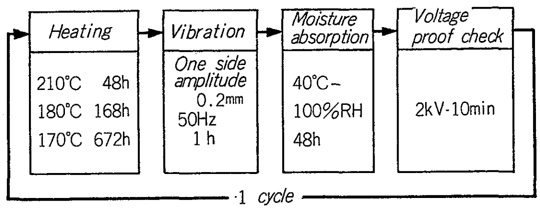

Fig. 19 Motorette test conditions

A coil insulation layer is almost void-less, and since the gap between the insulation layer and core is filled with impregnating resin, the heat dissipation of the coil is improved.

As an example impregnated armature model coil, the thermal life characteristic by Motorette test is shown in *Fig. 18* and the test conditions are shown in *Fig. 19*. This characteristic shows that the insulation system has an ample thermal life as Class F insulation.

IV. INSULATION OF RAILWAY MAIN MOTOR

Railway main motors are usually designed for the following condensed severe conditions:

1) High critical rise temperature

In IEC Pub. 349 and Japanese Railway Standards, the critical rise temperature is given as 140°C for the armature and 155°C for the field (resistance method) for Class F raily main motor. This is 55°C higher than JEC 54.

2) Severe environmental conditions

Since sand, iron dust, rain, snow, or salt enter the motor and the motor is installed to the bogey, a vibration acceleration of about 10 G is applied.

3) Severe operating conditions

The rotating speed is high, starting and stopping are severe, and an overcurrent flows at each starting and stopping. The terminal voltage of the motor is usually 375 V, but since the aerial voltage is applied to ground and the standards are different, the insulation resistance test voltage is 5,400 V when the aerial voltage is 1,500 V.

The insulation system described below is currently being used with motor used under such conditions.

1. Insulation system

Currently Class F insulation is generally used as the insulation stage. This insulation system is shown in *Table 1* and *Table 2*. Namely, two kinds of insulation are used; glass mica and aramid paper, polyimide, and other film materials. However, recently film material has come into wide use from the standpoint of cost. The impregnating resin is solventless epoxy resin and is used by concidering the impregnation process and the usage parts. Recently, main motors employing Class H insulation have been manufactured. In this case, the insulation system employs high heat resistant resin (for example, polyimide resin) as the impregnating resin. The heat resistance temperature estimated by a time up to a reduction in the tensile strength of 50% at 40,000 hours is 231°C for polyimide film and 202°C for aramid paper and both can be satisfactorily used for Class H insulation.

Table 1 Insulation systems of interpole coil

Type of insulation	Insulation system
Conductor and turn insulation	1) Bare copper wire + glass mica tape 2) Double glass wrapped copper wire 3) Bare copper wire + aramid paper tape 4) Bare copper wire + polyimide tape
Ground insulation	1) Glass mica 2) Aramid paper 3) Polyimide
Impregnating resin	Epoxy resin (vacuum impregnation)

Table 2 Insulation systems of pole coil

Tape of insulation	Insulation system
Conductor	Flat square copper wire
Insulation between layers	Asbestos Glass mica
Ground insulation	1) Glass mica tape 2) Aramid paper tape
Impregnating resin	Epoxy resin (vacuum impregnation)

2. Insulation performance

Actual motor insulations are used by combining various materials. Moreover, since various deterioration factors act on the insulation, the insulation performances are verified by evaluation tests such as those described below.

1) Armature coil insulation

The heat cycle shown in *Fig. 20* was applied by operating a completed main motor (glass mica insulation) as a motor and the temperature was then held at 180°C and operation continued. Thereafter, the motor was disassembled, the armature was removed and a water submerging test was performed with the commutator at the top. The armature was submerged in water for 48 hours and the insulation resistance was measured during this time. The insulation resistance was always over 10^4 MΩ and good results were obtained.

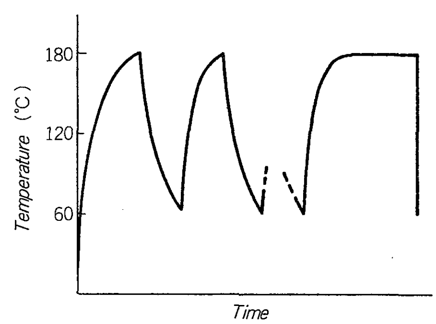

Fig. 20 Thermal cycle test pattern of armature

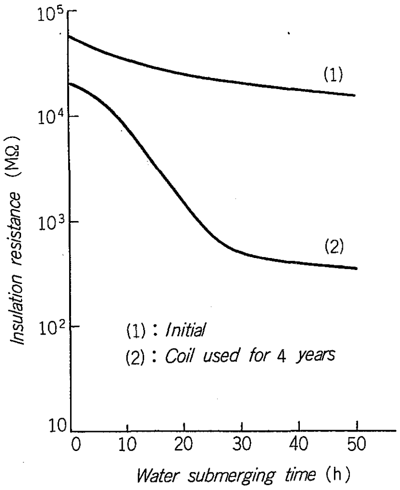

Fig. 21 Change of insulation resistance of interpole coils

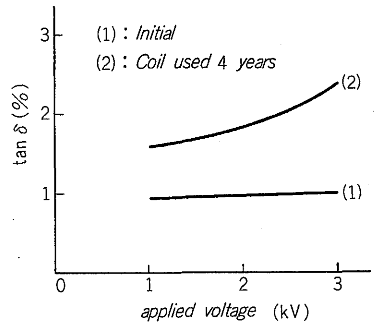

Fig. 22 tan δ vs. voltage characteristics of interpole coils

2) Stator coil insulation (pole and interpole coil)

Since the main motor was a series winding, edgewise rectangular copper conductor is generally used at pole and interpole coil. Since the insulation system is the same for both coils, the test results for the interpole coil are given below.

The results of the water submerging test using a completed interpole coil (aramid paper insulation, attached to core) are shown in *Fig. 21*. The insulation resistance was 10^4 MΩ or greater at 48 hour water submersion. The results of measurement of the tan δ vs. voltage characteristic of this coil are given in *Fig. 22*.

Fig. 21 and *Fig. 22* show the results of the same kind of water submerging test and the tanδ vs. voltage characteristics of a coil which has the same insulation system and been actually used for four years.

The insulation resistance is about the same as the initial product before water submersion, but tend to decrease the passage of submerging time. However, it is a 100 MΩ even after 48 hours and the insulation has satisfactory insulation characteristics. Japanese Railway Standards prescribe a tanδ of 5% or less at 1 kV initially and a Δtanδ (difference between 3 kV and 1 kV) of 2% or less. The characteristic of *Fig. 22* has a value which meets this standard even as an initial product.

V. CONCLUSION

The insulation performance at a motor is a main factor governing the life of the machine and, therefore, the establishment of a rational insulation system having a reliability matched to the usage objective is vital.

We are making efforts toward increasing the quality and reliability of rotary machine insulation through function evaluation, including material use evaluation, and manufacturing and fabricating techniques. Research will be conducted and efforts will be made toward the development of new insulation systems in the future.