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IEEE Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines

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Foreword

(This Foreword is not a part of IEEE Std 434-1973, IEEE Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines).

The Rotating Machinery-Insulation Subcommittee, Power Engineering Society, IEEE, has been actively developing functional testing guides during the past two decades for rotating machines under the authorization of IEEE Std 1-1969, General Principles for Temperature Limits in the Rating of Electric Equipment. In 1965, the working group assigned to develop a test procedure for machines rated at 50 to 2000 hp and below 6600 V completed their task. After more than a decade of work by two working groups, a revised test procedure was issued in December, 1966 as IEEE Std 275-1966, Test Procedure for Evaluation of Systems of Insulating Materials for AC Electric Machinery Employing Form-Wound Preinsulated Stator Coils.

It has become the custom at these working group meetings to devote a short time to the consideration of functional test procedures for larger machines than those included within the scope of IEEE Std 275-1966 . With the discharge of the old working group, a new task force was established at the February, 1965 meeting of the Rotating Machinery Insulation Subcommittee. Its charter was: "To review available means of functional evaluation of insulation for large, high-voltage machines, and report on the feasibility of standardizing test procedures for this purpose." This report was favorable and was accepted at the February, 1966 meeting of the Insulation Subcommittee. At the same time, the task force was reconstituted as a regular working group to prepare a suitable guide for the functional testing of this class of machines.

Over the past six years, five drafts of the new guide have been prepared and the final version successfully balloted through the Insulation Subcommittee, the Rotating Machinery Committee, and the Standards Committee of IEEE with no negative votes or unresolved comments.

There was considerable doubt in 1965 that an IEEE standard could be written for insulation functional evaluation of large, high-voltage machines. Many thought the effort was premature and that ten years or more would be spent by working groups before a useful, acceptable document could be written.

It is recognized that this standard does not describe all of the functional tests currently in use by manufacturers of large, high-voltage rotating machines, and that these additional tests may be essential to a complete evaluation and classification of a new insulation system. The tests described in the guide are, however, in widespread use and are generally performed prior to the newer, more complex and less generally used model tests which have recently been described in technical papers. A period of experience with this guide and the continued rapid development of new test methods will enable a revised edition to be developed within a few years.

Active participants in the present document will continue their IEC roles in Technical Committee 63 (Insulation Systems) and Technical Committee 2 (Rotating Machines) by transmitting IEEE viewpoints to these international organizations.

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IEEE Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines

1. General

1.1 Purpose

The purpose of this guide is to describe classification test methods which may be used to compare insulation systems in use, or proposed for use, in large high-voltage rotating machines.

1.2 Scope

1.2.1

The tests outlined in this guide are applicable to the insulation systems used in coils of generators, motors, and synchronous condensers operating at 6600 V and above.

1.2.2

The basic ingredient of these insulation systems is usually mica combined with reinforcing, bonding, and impregnating materials. This guide is based on the experience of the industry with micaceous systems; any evaluation of nonmicaceous systems should, however, consider the requirements of this guide.

1.3 General Considerations

1.3.1 Factors Causing Deterioration

1.3.1.1

The factors causing deterioration of insulation in large high-voltage machines are temperature, voltage, thermomechanical forces, electromechanical forces, and environment.

1.3.1.2

In order to determine the effect of these factors on insulation systems in a reasonable length of time, it is necessary that the tests be accelerated; however, the more acceleration, the less the test conditions resemble service conditions. The procedures outlined in the guide represent a compromise between too much acceleration and too long a test period.

1.3.2 Types of Tests

1.3.2.1

In the following sections of this guide, tests are described to determine the effects of various deteriorating influences. Section 2 covers thermal aging; Section 3, voltage endurance; Section 4, thermomechanical forces, and Section 5, electromechanical forces.

1.3.2.2

The interactions between the factors causing deterioration of insulation are provided for in the separate tests of this guide by maintaining all factors at normal service levels except for the one factor being accelerated. This does not preclude use of a periodic overvoltage test between stress exposure periods to determine an end point or a comparison voltage-endurance test of stress-aged test samples with new samples.

1.3.2.3

The tests described in this guide are normally conducted in air, since in this way they can be performed simply and without danger. It is recognized that the windings of the largest machines operate throughout their lifetimes in an atmosphere of hydrogen. Although testing in a hydrogen atmosphere is more complex than testing in air, mechanisms of insulation breakdown for some materials may be significantly different than in air. Nothing in this guide should be construed as preventing testing in hydrogen atmosphere if it is believed that this factor may be important in providing more realistic test results.

1.3.3 Environmental Influences

1.3.3.1

These influences include gas atmosphere, moisture, oil vapor, carbon dust, brake dust, and other contaminants. Separate tests are not included in this guide but may be added later. Large machines often have closed cooling systems which permit control of contaminants. The environment of the test station is likely to be more severe than that inside the machine in its effect on insulation. It is expected that the insulation system evaluated will withstand normal environments and contaminants.

1.3.3.2

Tests for insulation systems designed for use in open ventilated machines, where contaminants may be present, may include these substances in the test environment.

1.3.4 Interrelationship of Tests

1.3.4.1

Each effect should be tested separately; that is, additional samples should be used for each part of this guide.

1.3.4.2

This procedure does not preclude using a preaged test specimen, obtained by subjecting sufficient numbers of test samples to appropriate sections of the subguides, to determine the effect of that aging factor on some other insulation-system deteriorating stress.

1.3.5 Test Samples

1.3.5.1

The samples should be actual production or prototype bars or coils or sections, including all insulation components of the finished winding. A typical sample would be constructed with stranded insulated conductors, including transpositions if used, to provide a bare bar without turn or ground insulation, with dimensions of approximately 1/2 in × 2 in × 48 in long. (1.27 cm × 5.08 cm × 121.92 cm). Since many machines will use a much larger cross section, it may be desirable to build specimens with other dimensions.

1.3.5.2

Samples of multiturn bars or coils should include the turn insulation.

1.3.5.3

Thicknesses of the ground wall should be used which are representative of the voltage class to be studied. It has been found that thicknesses from 0.100 in to 0.300 in (0.254 cm to 0.762 cm) are representative of the voltage classes in use.

1.3.5.4

If electrical measurements are to be used as criteria of insulation system degradation, appropriate electrodes should be applied to the specimens.

1.3.5.5

For discussion and definition of terms used in this guide, refer to the IEEE Std 100-1972 (ANSI C42.100-1972), IEEE Dictionary of Electrical and Electronic Terms, or the latest revision thereof.

1.4 Interpretation of Results

1.4.1

Comparisons between two insulation systems tested in different laboratories may not be meaningful unless all factors are very carefully controlled. Comparisons based on tests of different systems made in the same laboratory should be significant. It is desirable that tests be aimed, as far as practical, at producing results expressable in terms of absolute, rather than relative life expectancy, but the greatest value may be obtained by comparing a new with a service-proven insulation system for the same classification of machinery.

1.4.2

The end point, or determination of when a sample has failed, may be voltage breakdown, loss of mechanical strength, or other criterion or combination of criteria. The same standards should, of course, apply to all samples.

1.4.3

In the analysis of results, no single test procedure is capable of providing the information needed to make a dependable classification of the insulation systems used in large high-voltage rotating machines. The proper weighting to be applied to the results and interpretations of the several tests in this guide must depend on the specific type, size, and duty cycle of rotating machine in which the insulation system is to be used.

2. Thermal Aging

2.1 Purpose

The purpose of this section is to describe a test method by which insulation systems for large high-voltage machines can be compared in their ability to withstand thermal exposure.

2.2 Scope

2.2.1

It is generally recognized that insulation systems are limited by the operating temperature in the length of time that they are able to perform the intended insulating function. The thermal life of an insulation system is an inverse function of the operating temperature to which it is exposed. The loss in ability to insulate will usually be evident by a change in the electrical characteristics or a change in the mechanical characteristics, either of which can impair the operation of the machines.

2.2.2

By exposing representative specimens of various insulation systems to accelerated aging temperatures, comparative evaluations can be made.

2.3 Test Specimens

Refer to Section 1.3.5 for test-specimen description.

2.4 Test Exposure

2.4.1

The test specimens should be placed in ventilated air-circulating ovens which can be regulated in temperatures to approximately ± 3° C. It is recognized that many of the machines on which these insulation systems are used do not operate in an air environment, but generally this test procedure is used to generate comparative data and not absolute life curves.

2.4.2

The specimens should be aged in an unrestrained condition. Here again, it is recognized that in service the coils would be confined by the stator slots, but for generating comparative data, no restraint is recommended. If support is desired, refer to Section 4 of this guide.

2.4.3

The coils shall be supported in the oven in such a way that the entire coil surface is exposed to the air.

2.4.4

In order to make comparisons of insulation systems which are statistically sound, at least three temperatures should be used. Aging temperatures in the range of 120 — 200°C are recommended as being sufficiently accelerated for the types of machines involved here.

2.4.5

Since the periodic measurements involved and described below will necessitate destruction of the samples, it is recommended that at least five samples be tested at any point in time. Sufficient samples should be used initially to provide for all the periodic checks which will be made.

2.5 Measurements

As noted above, periodically, specimens will be removed and subjected to various tests which can then be plotted as a function of time. Some of the measurements which can be made are as follows:

2.5.1

2.5.1.1

Short-time electric strength, either at room temperature or at operating temperature, can be measured. A one minute step-by-step test is recommended. This is a destructive test.

2.5.1.2

The physical dimensions of the specimens can be measured. This is a nondestructive test.

2.5.1.3

Tangent delta (dissipation factor) and capacitance can be measured as a function of a voltage at various temperatures. This is a nondestructive test. Reference should be made to IEEE Std 286-1968, Recommended Practice for Measurement of Power Factor Tip-Up of Rotating Machinery Stator Coil Insulation, or the latest revision thereof.

2.5.1.4

Specimens can be subjected to longtime exposure to voltage after thermal aging periods. Reference is made to Section 3 of this guide. It should also be recognized that it may be desirable to combine thermal aging with voltage-endurance exposure.

2.5.1.5

Physical integrity is perhaps one of the most important requirements for these insulation systems and it is recognized that a test to measure some mechanical property is desirable. This may involve such things as removal of the insulation and preparation of test specimens for mechanical tests thereof, or subjecting the test bar to some mechanical load. No exact test can be described at this time, but reference is made to Section 4 of this guide. Section 4 was included because of recognition of the importance of physical integrity.

3. Voltage Endurance

3.1 Purpose

The purpose of this section is to establish the principles involved in the voltage-endurance evaluation of insulation systems for high-voltage rotating machines. Since several different approaches are being followed in industry, a specific test method is not completely defined. An outline of the parameters that must be considered and the variables that must be controlled in performing this type of evaluation is presented.

3.2 Scope

3.2.1

This section of the guide covers the testing of insulation systems at voltages higher than normal operating stress in order to accelerate the degrading effects of electric stress. By conducting tests at different voltages, a relationship of life versus stress may be plotted. Although this relationship cannot be accurately extrapolated to obtain an expected life at operating stress, different insulation systems tested under the same conditions can be compared over the range of test voltages.

3.2.2

In order that the voltage endurance may be evaluated separately, accelerated mechanical or thermal degradation is not included in this test. The samples are tested at room temperature or at normal service temperature. Care must be taken that dielectric losses at high stress do not raise insulation temperatures excessively.

3.3 Time Dependence of Electric Strength

3.3.1

Electric strength of solid insulation under ac stress depends on time of exposure at a given stress level. The breakdown mechanism probably varies with time. Four conditions are postulated in the literature.[1] At short times, such as impulse, the breakdown value is the intrinsic electric strength. This may be theoretically defined as the condition of instability resulting when conduction electrons gain energy from the field faster than they lose energy to the lattice.

3.3.2

With longer exposure time, in the order of minutes, the failure mechanism is called *streamer breakdown*..[2] The ambient medium breaks down at the edges of the high voltage electrode and the local field at the tip of the discharge channel is much greater than the average field — perhaps approaching the intrinsic breakdown strength. Local partial breakdown occurs, which propagates through the dielectric, resulting in a complete failure.

3.3.3

Thermal breakdown may occur at still longer times. This is caused by an instability resulting when the rate of internal heat generation at some point in the dielectric exceeds that at which the heat is conducted away from it.

[1]BAKER, W.P., Electrical Insulation Measurements, New York: Chemical Publishing Company, 1969. pp 6275.
[2]BAKER, W.P., Electrical Insulation Measurements, New York: Chemical Publishing Company, 1969. pp 6275.

3.3.4

Finally, for times approaching the service life, breakdown is due to erosion by discharges and electrochemical attack. Stress on air voids in the insulation structure may break down the gas, producing ions and electrons which are attracted to the instantaneous cathode and anode surfaces in the void. Both types of charged particles are sufficiently energetic to break chemical bonds in the insulation surface. In addition, corrosive and conducting chemical products form by various reaction mechanisms, which dissolve or combine with condensed water vapor to contribute to breakdown.

3.4 Test Specimens

3.4.1

Refer to Section 1.3.5 for test-specimen description.

3.4.2

Refer to Section 1.3.4 for interrelationship of tests.

3.5 Preparation of Test Specimens

3.5.1

Sections of bars or coils to be used should be cut to a suitable length and all the strands in the conductor electrically connected together.

3.5.2

The electrode should encircle the whole circumference, and sample lengths chosen to provide an area of at least 60 in^2 (387 cm^2) on the outer surfaces. Full slot length, in the case of a complete coil or bar, may also be used. The electrode should be painted to achieve perfect contact without air spaces. Slot paint must be overwrapped with foil or wire, or silver paint may be used. Tests should include a guard gap in the extended area to facilitate measurement of the dissipation factor of the sample at intervals during the testing period. While on voltage-endurance test, the gap is shorted out with conducting material wrapped around the bar. If test bars are mounted in a fixture, the electrode should extend about 1/2 in (1.27 cm) beyond the edges of the fixture.

3.5.3

The edges of the electrode area must be effectively graded to prevent failures at the edge due to high-voltage stresses resulting from field distortion. The grading system may consist of suitable paint or stress relief cones. Electrodes and grading paint should be renewed periodically if deterioration occurs.

3.5.4

The samples may be mounted in a fixture to simulate the conditions that the bar would experience in the slot of a machine.

3.6 Application of Heat

3.6.1

If the samples are to be tested at elevated temperatures, several methods are available. They may be placed in a hot air-circulating oven, heated by internal electric units or oil circulation, or clamped between heated platens.

3.6.2

Temperature control to within ± 3° C of the selected temperature is considered satisfactory.

3.7 Application of Voltage

3.7.1

Power-frequency voltage is applied to the samples, regulated ± 3% or better without distorting the sine wave. Actual voltage regulation should be reported in the results. To obtain a complete picture of voltage endurance, the time-to-failure should range from 1 min to 10 000 hr. Several methods may be used to determine the electric strength over this time range, as listed in the following sections. Results of tests made by different methods on the same system generally fall on a straight line on a semilog or log-log plot.

3.7.2

Step-by-step increasing voltage. (Refer to ASTM D149-64 (1970) paragraph 6.1.3. When this standard is superseded by a later edition approved as an American National Standard, the latest approved revision shall apply.)

3.7.2.1

Time intervals generally used between voltage steps are 1 min, 1 hr, 1 day, and 1 week. Equivalent breakdown is found by subtracting from the observed breakdown a fraction of the voltage on each step, determined from the table:

Percent of Time Step Held at Breakdown Voltage	Percent of Voltage Step to Subtract from Breakdown Voltage
0 – 9	100
10 – 22	80
23 – 40	60
41 – 65	40
66 – 99	20

Example:

On 1 hr test with 5 kV steps, specimen fails after 42 min at 65 kV

42/60 = 70 percent of time step

Subtract 20 percent of voltage step = 0.2 × 5 = 1 kV

Equivalent 1 hr breakdown = 64 kV

3.7.3

Fixed voltage. (Refer to ASTM D2275-68.)

3.7.3.1

Test voltage is applied continuously until sample failure.

3.7.4

Steady voltage rise. (Refer to ASTM D149-64 (1970), Paragraph 6.1.2. When this standard is superseded by a later edition approved as an American National Standard, the latest approved revision shall apply.)

3.7.4.1

Starting at an initial stress above zero, voltage is increased continuously at a fixed rate of rise to failure.

3.8 Recording of Results

3.8.1

A widespread variation in test life for any particular voltage stress level is expected. Therefore, a statistically significant number of failure times must be obtained (at least 10 for each voltage level).

3.8.2

The data may be presented as a plot of voltage gradient versus time to failure, using either a semilog or log-log plot. The results of different insulation systems can be presented and compared on the same graph.

3.9 Conclusion

Voltage endurance is a time-consuming, but necessary test. Acceleration by testing at higher frequency is under study, but conclusions are as yet insufficient to include information in this guide.

4. Thermomechanical Forces

4.1 Purpose

The purpose of this section is to describe test methods which may be used to compare the ability of insulation systems to withstand cyclic differential expansion and contraction. The systems tested may be in use or proposed for use in large high-voltage rotating machines.

4.2 Scope

Service damage from thermomechanical forces is most pronounced in machines under fluctuating load and conductor temperature. Such machines are generally conventionally cooled turbine generators, water-wheel generators, synchronous condensers, and synchronous motors, rather than directly cooled turbine generators. Functional tests for thermomechanical forces should, therefore, simulate the conditions in these types of machines.

4.3 General Considerations

4.3.1 Nature of the Deteriorating Stresses.

Differential expansion and contraction of the conductor, the magnetic structure and the insulation system can cause damage to ground insulation. The phenomenon, variously known as tape separation, girth cracks, and insulation migration, is primarily a function of:

1) mechanical characteristics of the insulation system
2) differential thermal expansion between the copper in the stator bar and the steel in the armature core
3) the number of thermal cycles
4) the degree of tightness of the winding in the slot

This separation occurs generally in the region of the bar at the end of the core. As the bar expands axially, the tape in the slot is restrained by friction with the steel, while the tape beyond the end of the slot tends to move with the conductor. This imposes a tensile shear load on the insulation which may, under some conditions, cause a separation in the tape, or girth crack. The crack is fundamentally associated with ground wall insulation weakness in tensile shear between layers of tape or between layers of mica or both. This results in slight relative motion between adjacent components in the insulation ground wall. Upon cooling, the process may not reverse to close the opening because of the inelastic nature, direction of the tape spiral, etc, of the insulation system. Successive cycles may increase the opening, or crack, until finally the opening extends through sufficient layers of mica to render the insulation unreliable.

4.3.2 Test Requirements.

A fundamental requirement of a functional test is that it ideally should have the same degrading effects as service has, by the same mechanisms, only in much shorter time. In a test for thermomechanical degradation, it is especially important to exclude degradation caused by voltage stresses or elevated temperatures significantly above service levels, except as part of a periodic proof test to determine an end point.

As thermomechanical degradation, furthermore, is caused by the interaction between the various components of the insulation system, an evaluation cannot be made of the insulation itself, but only of the entire system. The tests should, therefore, preferably be made on full-sized coils wound in slots, as in a generator, to give similar temperature gradients and which can be adjusted for control of slot clearance. The factors that might influence the degradation of the insulation during a thermomechanical functional test can be separated into three groups.

4.3.2.1 Factors that May be Adjusted to Obtain the Desired Acceleration of the Degradation

4.3.2.1.1

The frequency of the differential expansion cycles. The rate of degradation can reasonably be expected to increase about proportionally with this frequency. In order to shorten the duration of the test, this frequency should be chosen as high as practical, the limit determined by the thermal time constant of the system.

4.3.2.1.2

Tightness of windings in slots. By adjusting one end of the slot with negative clearance, the other end with excessive clearance, the rate of degradation can be increased. Caution should be used in the evaluation of the test results for different insulation systems unless actual normal slot clearances are similar.

4.3.2.1.3

The amplitude of the differential expansion cycles. An increase of the amplitude will increase the rate of degradation, but the quantitative relation is not known and may not be the same for different insulation systems. Caution should, therefore, be used in the evaluation of the results from tests with greater differential expansions than are present in service.

4.3.2.2 Factors Related to Constructional Details of the System

1) Thickness of insulation
2) Bracing and cooling of the coil ends
3) Use of supplementary materials and surface treatments such as slippery materials for assembly

4.3.2.3 Factors Unrelated to the Problem of Thermomechanical Degradation.

Factors that might cause insulation failure by mechanisms other than by thermomechanical degradation to an unknown degree should be minimized as much as possible. Two such factors should be mentioned. A common practice with large high-voltage generator models has been to increase the value of the peak of the temperature cycle when a more severe cycling is desired. However, if this change brings the insulation up to temperature significantly above that encountered in service, two undesirable factors have been introduced. First, the change of the mechanical properties of the insulation from the increase of the temperature will affect its ability to withstand the cycling, and secondly, the high temperature might cause a significant degree of thermal aging during the time needed for the test.

Any increase of the amplitude of the differential expansion cycles, as mentioned above under Section 4.3.2.1.3, should therefore, preferably be done without raising the average temperature of the insulation. A method with which large differential expansion can be accomplished without too high temperature of the insulation would consist of *simultaneous* heating of the conductors and cooling of the core iron, alternating with a period with no cooling nor heating, during which the system will approach an isothermal condition. This can be more easily accomplished with the test equipment described in Section 4.4.2 below.

4.4 Test Equipment

Two types of thermomechanical cycling test equipment have been applied.

4.4.1

A stack of actual core laminations, (or channels to simulate slot sides) of similar length to the cores of the machines involved, containing several full-size coil sides, and equipped with means for heating and cooling the parts and measuring the consequent movements.

4.4.2

A structure representing a short length of one or more slots of a machine, containing a short coil sample or samples which are heated and cooled, by appropriate means, while being moved to and fro by correlated mechanical means. Such a device is essentially a length multiplier, reproducing the mechanical action, at the end of a slot, of a coil side of any chosen length subjected to similar temperature cycling.

4.5 Test Specimens

Preferably, test specimens should be representative coil sides, or portions cut from them. If special test bars must be used, the cross section of the coil, insulation thickness, surface treatment, slot fillers, and wedges should be representative of a normal stator. The bracing of the coils should also be as close to actual practice as possible.

For *full-length* core model test equipment (Section 4.4.1), length of slots and of specimens must be great enough to produce movements at least equal to those which will occur in operation of the actual machine.

For *length-multiplier* test equipment (Section 4.4.2), length of specimens must suit the particular equipment, and is usually about two feet. The slot length of the equipment should preferably be not less than one foot to reproduce conditions near the end of the actual machine slot.

The normal preassembled high-potential test should be conducted on specimens prior to assembly and the conventional 60 Hz high potential test $1.17 \times (2E + 1)$ (kV) after assembly, unless clearances are too small for such a test on *length-multiplier* specimens.

4.6 Test Operation

4.6.1 Heating and Cooling.

The differential expansions in the insulation system should be accomplished by heating the conductors of the coils uniformly along their length either electrically or with hot fluid. The degrading effect of this heating can conveniently be augmented by a simultaneous cooling of the iron core, for instance with water in embedded cooling tubes. The core or simulated slot structure may be separately heated by embedded electric resistance heaters. Air blast or water cooling may be used on the coil sides, cores, and end windings. The relaxation of the system is obtained after heating of the conductors is stopped and will take place faster if also the cooling of the iron is stopped.

4.6.2 Duration of the Cycle.

A reasonable length of one cycle would be between 55 min and 95 min. For example:

1) Heat (25 – 40 min) to operating hot-spot temperature (120 – 180 °C).
2) Hold at temperature (10–15 min).
3) Cool to generator operating cold gas temperature (20 – 40 min).

4.6.3 Number of Cycles.

The number of cycles to the end point will depend upon the type of insulation tested and the severity of the test. When there is no acceleration of the degradation except for cycling, the number of cycles are normally in the order of several thousand; with acceleration, the number of cycles can be reduced by one or two orders of magnitude.

4.7 Measurements

4.7.1 Temperature.

The temperatures of at least the conductors (hot-spot and average temperature) and the iron surface in the slots should continuously be measured in order to control the thermal cycles.

4.7.2 Expansion.

The movements of the surface of the coil insulation at the ends of the slots should be measured directly with micrometers, both absolutely and relative to the iron core. It is recommended also to measure the movements of the conductors relatively to the insulation surface, for example with the use of embedded magnetic probes. Lead foils may be embedded in the insulation at various stages of taping. X-ray photographs at the beginning of the test, and at various times and temperatures during it, will then provide indication of the relative movements of various layers of the insulation and other components.

4.7.3 Electrical Properties.

(Such as dc resistance, polarization index, tangent delta, dielectric constant, and electric strength determined by high potential tests.) As all these properties are temperature dependent, all measurements should be made at the same temperature, conveniently room temperature. Because of the time needed to stabilize the system thermally, these measurements should not be made more frequently than would be needed to indicate a change.

Because of the long times occupied by tests (of the order of months), there is usually complete automation of temperature control and recording, and of forced mechanical movement in conductors. Self-balancing potentiometer-type instruments may be adapted for temperature recording and control of heaters and coolers, according to temperature sensors introduced in the core and the core specimens. Such an instrument may also be used to control mechanical movement according to temperature by the use of a differential transformer or equivalent device for position feedback.

4.8 Means for Acceleration of Test

The objective for the acceleration of the test must be to produce logical and consistant relationships between the intended operating conditions and the test conditions. The selection of variants must also suit the facilities of the testing laboratory and the type of insulation to be tested.

For acceleration of deterioration by the test see Section 4.3.2.1.

4.9 Interpretation of Results

4.9.1 End-Point Criteria.

The electric strength of the insulation should preferably determine the end point of the test. This is difficult on the *length-multiplier* type of model, (see Section 4.4.2) especially with short samples, for which visual examination may be the only practical end point. It is suggested to test the coils periodically with an ac voltage of 1.17 ($2E + 1$) (kV) or a dc voltage of 2 ($2E + 1$) (kV) for one minute and continue the cycling until failure occurs.

A visual examination of the coil insulation and measurements of relative motion after the cycling should be included as part of the evaluation of the insulation systems that are being compared.

If an end point has not been reached by the withstand test, specimens may be subjected to a voltage breakdown test, or a voltage endurance test, preferably together with control specimens which have not had a thermomechanical cycling test. Any significant reduction of the electric strength, as compared with the untested specimens, may be taken to indicate some degree of weakening by the thermomechanical cycling, or by the thermal cycling inherent in it. This method has been found to provide useful comparisons when other means of damage detection give little or no indication.

4.9.2 Evaluation.

Two or more types of specimens may be ranked in order of resistance to thermomechanical cycling damage, according to time to given degree of damage, or degree of damage produced in a given time or number of cycles, by the test herein described. Test conditions must be kept highly consistent to afford valid comparisons.

Test specimens should include at least one reference insulation system that is accurately representative of insulation of known service performance with respect to thermomechanical cycling deterioration.

The number of specimens of each type, which must be tested for significant results, depends upon the consistency of fabrication and processing of the specimens and of the insulation which they represent. For meaningful conclusions, statistical analysis is usually used to determine the number of samples required and to evaluate the final test data.

5. Electromechanical Forces

5.1 Purpose

The purpose of this section of the guide is to describe test methods which enable a comparison to be made of the ability of insulation systems to withstand electromechanical forces.

5.2 Scope

5.2.1

This part of the guide is preliminary since design of tests and construction of suitable models is under active technical development within the industry. Most of these models are complex large-scale devices not well suited for inclusion in a general guide.

5.2.2

This section is concerned with two effects produced by electromechanical forces which can damage insulation and cause failure. The large impact forces produced by a sudden short circuit can crack or fracture insulation. Normal current loading will produce forces which set up vibration and cause fatigue or wear of the insulation due to abrasion. The full effects of these forces are modified by the support of an end winding bracing system and the efficiency of slot wedges.

5.2.3

Short-circuit forces are usually most damaging at the slot emergence position. Vibration can cause damage in a stator slot or in the stator end winding.

5.3 Test Specimens

5.3.1

Refer to Section 1.3.5 for test specimen description.

5.3.2

Refer to Section 1.3.4 for interrelationship of tests.

5.4 Test Conditions

5.4.1

The test procedure should assume support and wedging devices to be inadequate and be designed to compare insulation systems under damaging forces.

5.4.2

The test conditions should be, as near as possible, those occurring in operation. It is not necessary to test in the normal operating atmosphere, but it is preferable to test at the normal room temperature.

5.4.3

The damage to the insulation sample will usually be visible. It is, however, advisable to use an electrical test to determine the extent of the damage. Measurement of discharges may show signs of internal changes such as void or crack formation. An overvoltage test is a sure way of indicating complete failure. This may take the form of a withstand test, a voltage endurance test, or a breakdown test.

5.5 Impact (Sudden Short Circuit)

5.5.1

When a machine suffers a sudden short circuit, slot insulation and end winding insulation can be damaged, but a particularly vulnerable position is where a conductor bar emerges from the slot. Unless the end winding packing and bracing system is perfect, some movement will occur in the end winding, allowing the bar to deflect. The loading on the bar in this situation will be as for a cantilever beam.

5.5.2

Fig 1 shows a test apparatus which can be used to drop a load onto a sample bar mounted as a cantilever beam. The deflection can be controlled by a suitable restraint if so desired. It is recommended that the initial height *D* of the dropping mass be held constant and that its weight be fixed. Thus, the number of blows before the test sample fails a voltage proof or withstand test can be used as a criterion for comparison of different systems. The sample bar is usually turned over after each test blow in order to alternate the direction of sample movement.

It is advisable to apply an overvoltage test after each blow using the apparatus clamp as a suitable and convenient electrode.

5.5.3

This test does not produce short-circuit conditions but is simple and reproducible and has proved useful for comparing stator insulation systems under impact loading.

5.6 Vibration

5.6.1

Damage to stator insulation, caused by electrically induced vibration, has been observed in large machines. Test facilities may be set up to reproduce that damage. Often these tests require large items of equipment. The test described here is designed to be simple and easily controlled.

5.6.2

Fig 2 outlines a possible design of an apparatus for applying a controlled oscillating load to insulation samples. The length of the apparatus and the number of vibrating heads used is variable. The test frequency can be 100 Hz or higher to accelerate the action if so desired.

5.6.3

Adjustment of the static load on the sample will make it possible to set up two conditions to a required level. The rubbing action producing abrasion of the sample surface will be influenced by the surface condition of the vibrating beam while a variable compressive load along the length of the test bar can induce fatigue in the insulation.

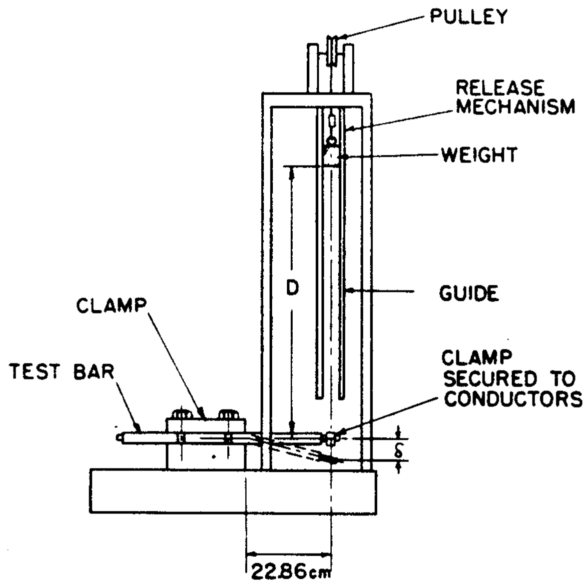

Figure 1—Apparatus for Impact Tests on Stator Conductor Bar Specimens Loaded as a Cantilever

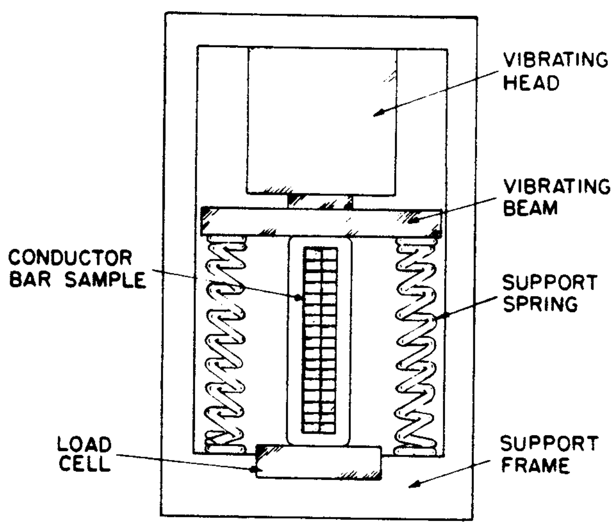

Figure 2—Apparatus for Applying Oscillating Load on Stator Conductor Bar Specimens