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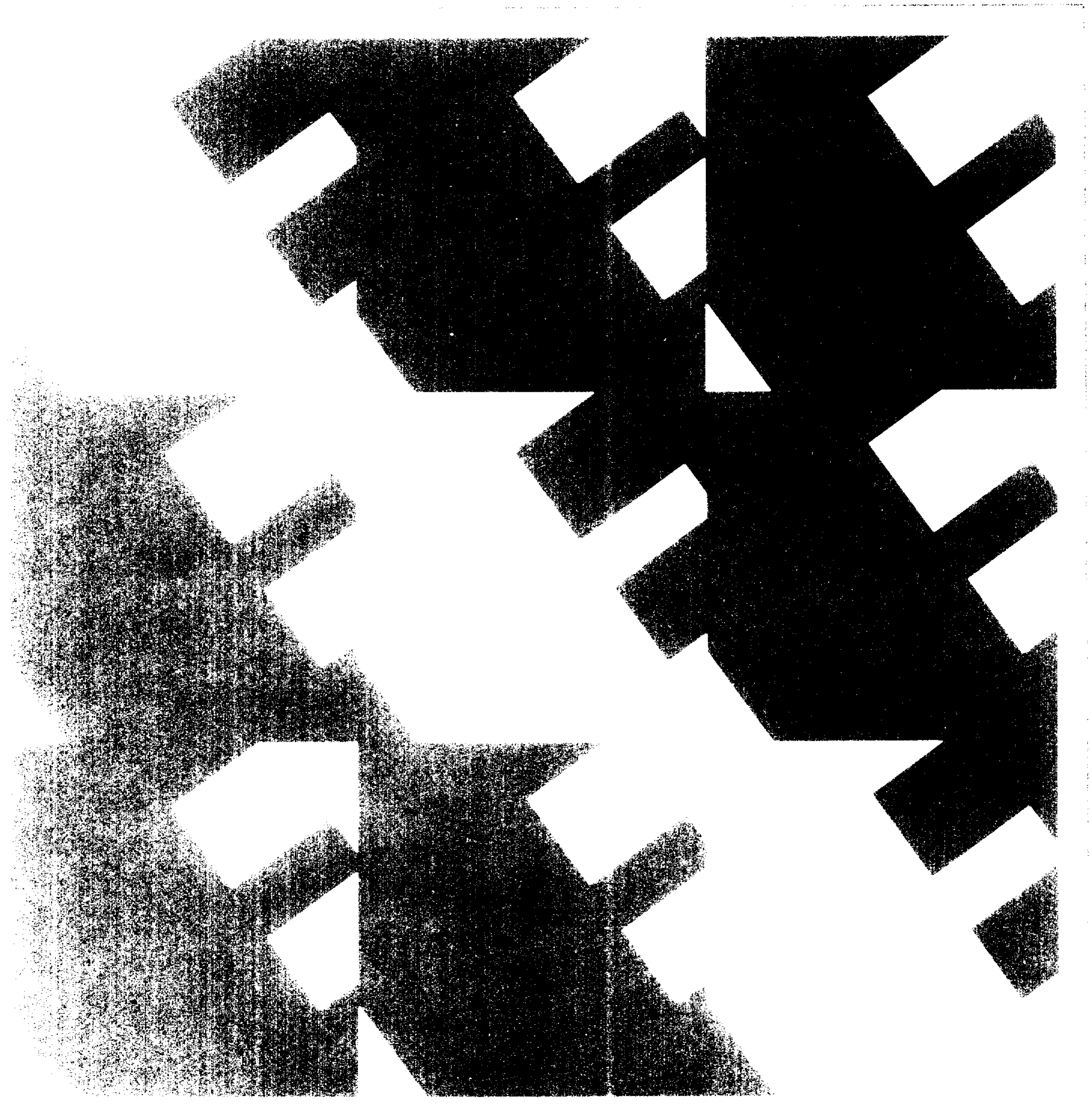
IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10 000 hp)



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IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery

(5 hp to less than 10 000 hp)

Sponsor

Rotating Machinery Committee of the IEEE Power Engineering Society

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Foreword

(This foreword is not part of IEEE Std 432-1976 Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10 000 hp))

The purpose of this guide is to present information necessary to permit an effective evaluation of the insulation systems of medium and small rotating electrical machines. Such an evaluation would serve as a guide to the degree of maintenance or replacement which might be deemed necessary and also offer some indication of the future service reliability of the equipment under consideration.

To fulfill these functions the following should be reviewed:

(a) service conditions reducing insulation life,
(b) insulation systems in general use,
(c) visual inspection methods,
(d) insulation maintenance testing principles,
(e) electrical insulation tests,
(f) methods for cleaning insulation structures.

This publication was prepared by a Working Group of the Rotating Machinery Committee of the IEEE Power Engineering Society. The Working Group membership was:

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APPENDIX

An American National Standard

IEEE Guide for Insulation Maintenance for Rotating Electrical Machinery

(5 hp to less than 10 000 hp)

1. Scope

This insulation maintenance guide is intended to apply in general to industrial air-cooled rotating electrical machines rated from 5 hp to 10 000 hp.

The procedures detailed herein may be found useful for other types of machines.

2. The Significance of Maintenance

Rotating electrical machines are complex structures which are subjected to mechanical, electrical, and thermal stresses of varying magnitude. Of the various components, the insulation systems are the most susceptible to aging or damage due to these stresses. The service life of an electrical machine will, therefore, largely depend on the serviceability of the insulation systems.

Where reliability is of concern, adequate inspection and testing programs are advocated to assure the equipment is maintained in satisfactory condition to minimize the possibility of in-service failure.

The experience and data obtained from regular maintenance inspection and testing programs can, in addition to providing an evaluation of the present condition of the piece of equipment, give some indication of long-term trends and probable need for future repair or replacement.

The extent to which a maintenance program is pursued will depend largely on the operator's own experience and philosophy, but should also take into account the importance of service reliability for the equipment. Where high service reliability is required, a regular maintenance program involving periodic disassembly and knowledgeable visual examination of the equipment together with the application of electrical tests of proven significance is strongly recommended.

It should be recognized that some over-potential tests may be damaging to insulation in marginal condition. Where there is uncertainty, consultation with the manufacturer is recommended. This is implicit in setting up any maintenance testing program.

3. Service Conditions Reducing Insulation Life

As has been stated, electrical machines and their insulation systems are subjected to mechanical, electrical, and thermal stresses which give rise to many deteriorating influences, the most significant of which are:

(a) **Thermal aging.** Normal load/temperature deteriorating influence on insulation.

(b) **Overtemperature.** Unusually high temperature from causes such as overload, high ambient temperature, restricted ventilation, etc.

(c) **Overvoltage.** An abnormal voltage higher than the normal service voltage such as caused from switching or lightning surges.

(d) **Contamination.** This deteriorates electrical insulation by actually conducting current over insulated surfaces, or by attacking the material reducing its electrical insulating quality or its physical strength, or by thermally insulating the material forcing it to operate at higher than normal temperatures. Included here are:

wetness or extreme humidity
oil or grease
conducting dusts and particles
nonconducting dusts and particles
chemicals of industry.

(e) **Physical damage.** This contributes to electrical insulation failure by opening leakage paths through the insulation. Included here are:

physical shock
vibration
overspeed
short-circuit forces
erosion by foreign matter
damage by foreign objects
thermal cycling.

(f) **Ionization effects.** Ionization which may occur at higher operating voltages is accompanied by several undesirable effects such as chemical action, heating, and ionic bombardment. (See Appendix.)

4. Insulation Systems in General Use

4.1 Insulated Parts. Insulation is present in various machine components but the complexity of the structure is such that no attempt is being made here to describe these in detail. However, such detailed information plus knowledge of modes of insulation failure permit more meaningful evaluation.

4.1.1 *Armature Winding.* For the purpose of this guide, the armature winding can be considered to be the main current-carrying winding, usually the stator in ac machines and the rotor in dc machines, including associated leads where applicable. The armature coils usually have wire, turn, and ground insulation.

DC armatures have commutator insulation, while insulated wedges, blocks, and other insulated mechanical supports are common to both ac and dc machines.

4.1.2 *Field Windings.* The fields of ac machines are either salient or cylindrical-pole type, while in dc machines they comprise stationary coils. In all cases, they have turn and ground insulation, insulated mechanical supports, and lead insulation. AC machines, in addition, would have collector ring insulation.

4.1.3 *Brush Rigging.* Both ac and dc machines may have insulated brush rigging.

4.1.4 *Core and Frame Assembly.* The principal insulation components in this assembly are the insulation between laminations in the core and insulation on through bolts (when used).

4.1.5 *Other Parts.* Insulation is sometimes used on bearings and other parts.

4.2 Armature Winding Insulation

4.2.1 *Wire Insulation.* The individual wires of armature coil conductors are usually insulated with organic resin films or fibers, paper, cotton, asbestos, glass or polyester glass fiber, or mica in various forms. (Note that the alternative term "strand" is used for these components in IEEE Std 56-1958 (reaff 1971) (ANSI C50.25-1972.))

4.2.2 *Turn Insulation.* Groups of wires forming a single conductor may be insulated and held together with insulating tapes including cotton, fiberglass, films, papers, micas, etc. Individual wire insulation, as described in Section 4.2.1, may also be used as turn insulation, including those applied as liquid resin coatings or as applied by taping with various materials such as cotton, fiberglass, films, papers, micas, etc.

4.2.3 *Ground Insulation.* Ground insulation is generally defined as that insulation intended to actually insulate the current carrying components (such as the coils, the commutator, the slip rings, and connections thereto) from the non-current carrying components (such as the core iron, the shaft, and other structural members).

Ground insulation takes on many different forms depending on the type of machine, intended use, and ambient conditions, design, temperature class, and manufacturer's standard practice.

Ground insulation is generally a dry-type multi-layered system comprising various insulating materials bonded and filled by different processes. Mica or micaceous products are generally preferred in high-voltage machines for at least a part of the ground insulation system. However, the more recent developed materials have also proven acceptable. On low-voltage machines, many different materials have proven acceptable, consistent with the machine's temperature classification.

4.2.4 *Commutator Insulation.* A commutator is a cylindrical assembly of wedge-shaped copper segments separated from each other and ground by insulation which is usually micaceous. This structure is mechanically locked together by various techniques including vee grooves, cones and support rings at commutator bar ends, steel shrink rings and ring insulation on the commutator surface, high-tension fiberglass bands deep in grooves in the commutator surface, or as on many small-size units, compression molded with a high-strength molding compound.

4.2.5 *Support Insulation.* Support insulation, such as blocks, slot wedges, etc, are usually made from wood, compressed laminates of fiberous materials, polyester, or similar felt pads, impregnated with various types of bonding agents.

4.3 Field Windings

4.3.1 *AC Machines.* The rotating field coils whether of the salient or cylindrical pole type, usually have a cell-type ground insulation. Many organic and inorganic materials are used.

Turn insulation on wire-wound coils usually incorporates a thin insulating layer on the conductor itself including those applied as liquid-resin coatings or as applied by taping with various materials such as cotton, fiberglass, films, papers, micas, etc.

Various forms of strip material with resin bonding are used on strap-wound coils of both salient pole and cylindrical rotors.

4.3.2 *DC Machines.* The stationary field coils of dc machines are constructed similarly to ac field coils, except they need not be built to withstand the effect of centrifugal forces. DC field coils usually are a complex assembly of exciting and commutating coils each fitted over a pole piece and insulated from it. Some coils comprise multiple windings.

4.3.3 *Collector Lead and Ring Insulation.* The insulation used on current collector rings must be adequate both for support and to provide adequate creepage to the grounded shaft. Again, a wide choice of materials is available.

4.4 Brush Rigging Insulation. The insulated components on brush rigging are generally made from molding compounds laminated boards or tubes made from paper, cotton, or glass fibers suitably bonded and impregnated. Moisture-resistant surfaces are most important for these items.

4.5 Core and Frame Assembly

4.5.1 *Stator Core Interlaminar Insulation.* Stator cores are built up from thin laminations insulated from each other to reduce core losses. A variety of thin insulating films, such as core-plate varnish, water-glass, and other chemical deposits, are used. On very small machines or where the volts per turn in the stator winding are low, the metallic oxides produced during annealing process may be adequate, though coatings formed from chemical treatment are also used.

Failure of interlaminar insulation is rare, except where precipitated by external causes. Among these are mechanical damage due to foreign objects or vibration, excessive heating due to power arcs created by winding failure or excessive losses in the finger plates of large machines.

Such damage can initiate a complete machine failure. Careful inspection of the core condition is, therefore, mandatory whenever the machine in question is out of service for maintenance purposes.

5. Visual Inspection Methods

To achieve maximum effectiveness from a visual inspection program, it should be directed initially to those areas which have been shown by previous experience to be most prone to the forms of damage or degradation caused by the influences listed in Section 3 of this guide.

The most significant items to which inspection should be directed, and possible findings are listed below.

5.1 Armature Winding

(a) Deterioration or degradation of insulation resulting from thermal aging due to cumulative time temperature effects. Examination of coils might reveal general puffiness, swelling into ventilation ducts, or a lack of firmness of the insulation, suggesting a loss of bond with consequent separation of the insulation layers from themselves or from the winding conductors or turns.

(b) Girth cracking or separation of the ground wall. This is most likely to occur on machines having bar-type stator coils greater than about 12 ft (4 meters) in length and having asphaltic-type bonds. Particular attention should be paid to the areas immediately adjacent to the ends of the slots. Where considerable cracking is observed, it is recommended that the wedges at the ends of the slots be removed, if possible, for inspection as dangerous cracks may also have occurred just within the slots.

(c) Contamination of coil and connection surfaces by substances which adversely affect insulation strength, the most common being carbon dust, oil, or moisture contamination.

(d) Abrasion or contamination of coil and connection surfaces from other sources, such as chemicals, abrasive, or conducting substances. Such effects are aggravated in the case of motors used in adverse atmospheric industrial applications, such as chemical plants, rubber mills, and paper manufacturing facilities.

(e) Cracking or abrasion of insulation resulting from prolonged or abnormal mechanical stresses. In stator windings, looseness of the bracing structure is a certain guide to such phenomenon, and can itself cause further mechanical damage if allowed to go unchecked.

(f) Eroding effects of foreign substances embedded or lodged against coil insulation surfaces. Particularly damaging are magnetic particles which vibrate with the effects of the magnetic field in the machine.

(g) Insulation deteriorating due to corona discharges in the body of the machine or end windings in the higher voltage ratings. These are evident by white, gray, or red deposits, and are particularly noticeable in areas where the insulation is subject to high electrical stresses. Some experience is required to distinguish these effects from powdering which can occur as a result of relative vibratory movement between hard surfaces as can be caused by loose-end winding structures.

(h) Loose slot wedges or slot fillers, which, if allowed to go uncorrected, may themselves cause mechanical damage or reduce the effectiveness of stator coil retention against short circuit and other abnormal mechanical forces.

(i) The effects of overspeeding may be observed on dc armatures by distortion of the windings or commutator risers, looseness or cracking of the banding, or movement of slot wedges, if any.

(j) Commutators should be checked for uneven discoloration which can result from short-circuiting due to the breakdown of insulation between bars, and for pin holes and burrs resulting from flashover.

(k) The risers (the connection straps between commutator bars and coils) may collect carbon deposits to cause electrical leakage and subsequent failure.

5.2 Field Windings. In addition to insulation degradation from causes similar to those listed in paragraph (a) of Section 5.1, close attention should be paid to the following in field windings:

(a) Distortion of coils due to the effects of abnormal mechanical, electrical, or thermal forces. Such distortion might cause failure of insulation between turns or to ground.

(b) Shrinkage or looseness of field coil washers. This permits coil movement during periods of acceleration and deceleration with the probability of abrading turn insulation and breaking or loosening of connections between coils.

(c) In cylindrical pole rotors (defined as "round-rotor" in ANSI C42.10-1957), evidence of heating of wedges at their contact with the retaining ring body, and "half-mooning" or cracks on the retaining rings can be caused by high circulating currents due to unbalanced operation or sustained single-phase faults close to the generator, such as in the leads or generator bus.

The condition and tightness of end-winding blocking, signs of deterioration or movement of the retaining ring insulating liner due to the above effects and any other looseness should be noted.

Powdered insulation in air ducts is evidence of coil movement. Red oxide at metallic joints is evidence of movement of metal parts.

The tightness of field lead connections and condition of collector and collector-lead insulation should be checked.

5.3 Brush Rigging. Insulation supporting the brush rigging should be checked for evidence of flashover, or carbonized leakage paths.

5.4 Core and Frame Assembly. In the assembly previously grouped together in Section 4.5 as the Core and Frame Assembly, the following items are considered to be the most significant:

(a) **Stator core.** A close examination should be made at the bore surface for evidence of damage due to rubbing between the stator and rotor due to stator displacement, by foreign objects or loose laminations in the bore, or by burning of laminations following coil failure.

Whenever several laminations have become short-circuited due to these effects, the possibility exists that excessive local heating might arise, exaggerating the problem by affecting the interlaminar resistance in the environment of the original fault with danger of further overheating, leading eventually to coil insulation damage.

Where such damage is widespread and concern might be felt regarding the adequacy of subsequent repairs, a loop test is recommended. This test, which will be detailed in a subsequent section of this guide, and in the Appendix should identify any local hot spot.

Loose or broken ventilation duct separators or fingers can engender further difficulties either by creating further core looseness or by impact of the loose pieces with coil insulation.

Overheating of the end finger plates is evident by discoloration of the paint or components in the areas affected. Abnormal overheating can lead to thermal degradation of the insulation between laminations with consequent short-circuiting and damage to the adjacent coil insulation.

(b) **Stator insulated through bolts.** Where these are fitted, examination of the insulated washer and associated pieces is indicated, together with verification of tightness and locking of the nuts.

(c) **Bearing insulation.** This is only available for adequate examination during a complete disassembly program and should always be cleaned at that time.

6. Insulation Maintenance Testing Principles

There is included in this maintenance guide a list of available electrical tests which are each designed to detect particular areas of weakness. Note that all tests are not applicable to all machines.

Some electrical tests set up a potentially damaging situation. *Where there is uncertainty* it is recommended that the manufacturer be consulted.

The tests are given in synopsis form in this guide but further details are given in the Appendix and in the appropriate IEEE standards to which reference is made.

Insulation evaluation tests can be roughly divided into the following two categories:

(a) Tests to discern existing weaknesses or faults.

(b) Tests which give some indication of expected service reliability.

The tests have been grouped accordingly in the following sections of this guide. Their classification in this manner is not considered inflexible and selection of maintenance tests will depend on the user's own philosophy, performance records, production, and economics. The user is encouraged to discuss his findings with the manufacturer for their interpretation and trends.

7. Tests to Discern Existing Weakness

7.1 Insulation-Resistance Tests at Low Voltage. These tests are usually made on either all or parts of an armature or field circuit to ground. They primarily indicate the degree of contamination of the insulating surfaces or solid insulation by moisture and other conducting influences and will not usually reveal complete but uncontaminated ruptures.

Insulation resistance tests are based on determining the current through the insulation or across its surfaces when a direct voltage is applied. The current is dependent on the voltage and time of application and also on the area and thickness of the insulation and on temperature and humidity conditions during the test.

IEEE Std 43-1974 outlines a recommended practice for insulation resistance testing together with corrections to be made for temperature and humidity conditions. Recommended values for minimum insulation resistance for safe operation are also given in IEEE Std 43-1974.

The insulation resistance test is mainly used to determine insulation condition with respect to contamination prior to application of an overvoltage test.

7.2 Dielectric Absorption Test. Dielectric absorption testing involves a determination of insulation resistance as a function of time. This test is also made on all or parts of an armature or field circuit to ground.

IEEE Std 43-1974 outlines test procedures and equipment for the standard method, which is usually made at a test potential of 500 to 5000 direct volts. Tests at higher potentials are frequently made usually using the voltmeter–ammeter method of resistance determination.

During this test the potential is held until the insulation resistance stabilizes or for a period of 10 min. The slope of the time resistance characteristic gives information on the relative condition of the insulation with respect to moisture and other contaminants. This slope is expressed as the ratio of the 10 to 1 minute values of insulation resistance and is termed the "polarization-index" (PI). This value is useful in comparing the results of tests of prior years on the same machine or in comparing the insulation characteristics of other machines.

Further details of these tests together with suggested acceptable polarization indices for certain insulation systems are contained in the Appendix to this guide.

7.3 Overvoltage Tests. Overvoltage tests are used to obtain assurance concerning the minimum strength of the insulation. Such tests are made on all or parts of the circuit-to-ground insulation of the armature or field winding.

Many users of large rotating machines apply overvoltage tests periodically, generally at the beginning of the overhaul of related equipment. This allows for the detection and possible repair of insulation weaknesses during the scheduled outage.

Overvoltage tests should be applied wherever possible to each phase in sequence, the remaining two phases not under test being grounded. In this way, the insulation between phases (or lines) is also tested. This is only practical, however, where both ends of each phase are brought out to separate terminals, as is usually the case in generators. Except for the larger horsepower ratings, most motors have either three or four leads brought out, precluding a test between phases.

The level of overpotential which should be applied will depend to a very large extent on the type of machine involved, the degree of exposure to overvoltages, and the level of serviceability required from the machine in question. It should, however, be sufficiently searching to discern any weakness or incipient weakness in the insulation structure which might lead to service failure.

Overvoltage tests may be performed either by alternating or direct voltage methods. The values of test voltages usually are selected as follows:

(a) For 60 Hz tests the overvoltage may be related to the rated machine voltage, and tests in the range of 125 to 150 percent of the line-to-line voltage are normal. For test procedures refer to IEEE Std 4-1968 (ANSI C68.1-1968).

Equipment for making overvoltage tests at very-low frequency (0.1 Hz) has become commercially available, which tends to be less in cost and weight and smaller in size than equivalent 60 Hz equipment. See IEEE Std 433-1974.

(b) Similarly for dc tests, the overvoltage is recommended as a function of the rated machine voltage multiplied by a factor to represent the ratio between direct (test) voltage and alternating (rms) voltage. The recommended value is from 125 to 150 percent rated alternating voltage × 1.7. For test procedures refer to IEEE Std 95-1962.

It should be recognized that if the windings are clean and dry, overvoltage tests may not detect defects which are in the end turns or in leads remote from the stator core.

7.4 Interturn-Insulation Tests. Where the adequacy of the insulation between adjacent turns is of concern, tests to check its condition are advisable.

In many cases, the interturn insulation on motor coils is fibrous in nature. This effectively provides a physical separation of the turns of the order of 0.010 to 0.025 inches (0.025-0.0635 centimeters) for motors, and the electric strength between the turns is essentially provided by the gas contained between these fibers, if not contaminated.

To provide a useful service in checking the adequacy of the insulation between turns, the test level selected must be greater than the minimum sparking potential of the gas at the minimum permissible spacing. The test potential will frequently, therefore, be several times normal operating volts per turn. A test of about 500 V rms per turn is considered average for a new machine, while for maintenance tests, potentials of one-half to two-thirds of the new coil turn test, eight to ten times normal operating volts per turn, are usually considered adequate to provide insurance from the possibilities of marginal insulation.

The normal operating volts per turn are often up to about 30 V for motors, while turbine and water-wheel generators are substantially above that value.

The test methods used are forms of surge comparison tests. A steep-front surge is applied to all or part of a winding, or by induction to individual coils within a winding. The resultant waveforms are viewed on an oscilloscope screen and interpretation of the patterns or amplitude permits detection of short-circuited turns.

The surge-comparison test applied directly to the winding terminals is limited, in the case of windings consisting of many coils in series, by the magnitude of the voltage which can be applied to the ground insulation without exceeding its specified test voltage. This limitation can be overcome by placing a multi-turn surge coil in the bore over the coil to be tested and by applying directly into it a voltage appropriate to the induced volts per turn required in the stator coil. See Ref [15] in the Bibliography for detailed information on surge-comparison testing.

7.5 Slot Discharge and Corona-Probe Tests. The slot discharge test is made for the single purpose of checking the adequacy of the ground connection between the conducting surfaces and the core. If surface discharging exists it is important that it be detected as accelerated deterioration of the ground wall insulation may be produced by it. This test is usually only applicable to machines having operating voltages in excess of 6000 V.

The corona probe test is intended to be an indicator and locator of unusual ionization about the insulation structure. The ability of this test to discriminate between harmful and acceptable levels of general ionization phenomena such as occur in high-voltage windings has not yet been demonstrated but is under study.

Further details of these tests are given in **Appendix and Refs [17] and [20] in the Bibliography of this guide.**

7.6 Rotor Winding Impedance Test. Measurement and comparison of the impedance of rotor windings and individual coils provide a useful way of detecting and locating turn-to-turn faults. This test is sometimes made in the factory and can also be used as a maintenance test. The field winding is energized with low-potential alternating voltage (such as 120 V) at conventional frequency. Current is observed with respect to voltage across various coils. With the field coils connected in series, similar coils should have a comparable voltage drop.

Comparison of voltage drop of similar field coils will permit detection of shorted turns. A fault between turns not only reduces the total effective turns, but a short-circuited turn produces further reduction in impedance. The test is suitable for cylindrical rotors of turbine generators and for multiple fields of other machines.

An impedance test can be made on the complete field winding, across the collector rings, with the generator being driven at rated speed.

Shorted turns of a minor nature, unlike shorted turns in the stator may not necessarily require immediate reinsulation. Rotors have been known to operate for years with a few random short circuits between successive turns in the rotor winding. However, should subsequent periodic impedance testing show the shorting to be progressive in nature, reinsulation would be necessary to assure reliable operation.

If the rotor has brushless excitation the manufacturers' instructions should be reviewed carefully before making impedance tests.

8. Tests to Give Indication of Expected Service Reliability

8.1 Insulation Power Factor Tests. These tests are mainly useful on the larger high-voltage machines (6000 V or higher).

The power factor of the insulation from the winding to core may be measured by special bridge circuits or by the volt–ampere–watt method. Equipment is available which is especially designed for such tests.

The power factor of the stator insulation will be affected by the test voltage, the type of insulation, temperature of the insulation and moisture, and voids in the insulation. It is also affected by conditions external to the main insulation, such as the condition of the outer wrapper or slot liner, and the type of corona control used. Because of the effect of external conditions, it is usually impossible to correlate the power factor of machine insulation with its dielectric strength.

Increasing power factor on the same machine over a period of time is believed to denote a general deterioration of the insulation. The normal power factor increase with age is usually small for machines having corona control treatment on the slot part, whereas the increase is very evident on machines having coils with organic slot liners.

Power factor values on complete windings are an average of the insulation of all coils. When the coils in a machine can be individually tested, power factor can be used to compare the amount of deterioration among coils which have been operating at different voltages, e g, between line coils and neutral coils.

The change in power factor of the stator insulation as the test voltage is raised from some low value to operating voltage may be indicative of the amount of ionization loss in or adjacent to the insulation. It is believed that an increase in ionization loss over a period of years indicates an increase in the size and number of voids and, hence, is an indication of mechanical deterioration within the insulation. Reference is made to IEEE Std 286-1975, Ref [7].

8.2 Controlled Overvoltage Test (dc). A controlled overvoltage test is one in which the increase of applied direct voltage is controlled, and measured currents are continuously observed for abnormalities, with the intention of stopping the test before breakdown occurs. This test is often referred to as a "direct-current leakage test" or a "step-voltage test."

Methods of conducting the test and interpretation of the results are detailed in IEEE Std 95-1976 "Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Direct Voltage." The methods described have been found applicable to equipment of smaller size and lower voltage.

IEEE Std 95-1976 was developed to provide uniform procedures for:

(a) Performing high direct-voltage acceptance tests and routine maintenance tests on the main ground insulation.

(b) Analyzing the variations in measured current so that any possible relationship of the components of these variations to the condition of the insulation can be more effectively studied.

Many operators have found this test to be a useful maintenance tool, although there is some controversy in the interpretation of the test results, plus the fact that breakdown sometimes occurs without prior indication by current measurement. The operator is urged to study IEEE Std 95-1962 to derive significant benefit from controlled overvoltage testing.

8.2.1 *Alternative Method of Controlled Overvoltage Test.* An alternative test method, which has been adopted by some users is the "graded-time test," detailed in the Appendix to IEEE Std 95-1962.

In this test, an attempt is made to linearize the time-dependent absorption current with the total leakage current and thus obtain a more significant impression of the behavior of the insulation when subjected to increased voltage steps.

This method is an expedient to shorten the time of conducting the test which would be required to allow the absorption current to essentially disappear during each voltage step. This phenomenon is also discussed in [19, pp 46, 47] of the Bibliography.

An alternate analysis of the graphical solution is presented in Ref [13] of the Bibliography by using a set of templates for proportioning magnitude of leakage current and determining time schedule for the test.

9. Other Special Tests

In addition to the tests outlined above, there are a number of other special tests the use of which would normally be dictated by conditions observed during the visual inspection program. Some of the more frequently used of these tests and a summary of their performance are as follows.

9.1 Stator Core Interlaminar Insulation Test. In cases where several core laminations have been short-circuited by the causes referred to in Section 5.4, repairs will usually be required to restore the interlaminar insulation.

An effective test can be made by inducing in the stator core a flux at rated frequency at approximately the flux density in the core corresponding to 105 percent of rated voltage.

This can be done by installing a temporary coil passing through the stator bore and then around one side of the frame. This coil should be insulated from the core and frame and be braced securely in position. A single-turn search coil is also wrapped around the core and connected to a voltmeter.

Methods of calculating the search-coil voltage and ampere-turn requirement are given in the Appendix.

9.2 Interturn Short Circuits on Cylindrical Pole Rotors. In addition to the impedance measurements referred to in Section 7.6 of this guide, several other tests are available by means of which short circuits between turns of cylindrical pole rotors can often be detected. Among these are the following:

(a) The flux distribution over the rotor body surface, when a potential of 120 V 60 Hz is applied to the collector rings, is observed by a test coil connected to a galvanometer, as described in Ref [18]. The test coil is arranged to span adjacent rotor teeth and is usually placed on the part of the rotor body close to the coil retaining rings. The magnitude and sign of the voltage induced in the coil for each pair of teeth is plotted. The flux pattern shows a significant change in magnitude and sign whenever a short circuit exists in the slot being tested.

(b) In another test method, an ac voltage is applied to the collector rings and the induced voltage in the test coil is read on a vectormeter. An iron-cored coil is used on the rotor body or an air-cored coil can be used in the end windings.

10. Cleaning Instructions

Proper maintenance of electrical equipment requires periodic visual examination of the machine and its windings, together with electrical and thermal checks. Insulation surfaces should be examined for cracks as well as for accumulations of dirt and dust to determine required action. Lower than normal insulation resistance can be an indication that conductive contaminant is present. This may be carbon, salts, metal dusts, or virtually any dirt saturated with moisture. These can develop a conductive path to produce shorts or grounds with subsequent failure. Cleaning is also advisable if heavy accumulations of dirt and dust can be seen, or are deduced to be restricting ventilation as manifested from excessive heating.

With no visual, electrical, or thermal evidence that dirt is present, cleaning should not be initiated, since more harm than good may result.

If harmful dirt accumulations are present, a variety of cleaning techniques are available. The one selected will depend on:

(1) the extent of the cleaning operation to be undertaken;
(2) the type, rating, and insulation structure of the machine involved.
(3) the type of dirt to be removed.

10.1 Field Service Cleaning (Assembled Machines) Dry Dusts. Where cleaning is required in the field and complete disassembly of the machine is unnecessary or not feasible, dry dirt, dust, or carbon should first be picked up by a vacuum cleaner to prevent the redistribution of the contaminant. A small nonconductive nozzle or tube connected to the vacuum cleaner may be required to get closer to the dusty surfaces or to enter into narrow openings as between commutator risers. After most of the dust has been removed, a small brush can be affixed to the vacuum nozzle to loosen and allow removal of dirt more firmly attached.

Suction must always be used to remove dust produced within a machine, such as in the stoning of commutators, collector rings, or the seating of brushes.

After the initial cleaning with vacuum, high-velocity air pressure not to exceed 35 to 40 $\mathrm{lbs/in}^2$ may be used to remove the remaining dust and dirt. If compressed air is used, an exhaust must be provided so that dirt will be removed from the machine. Indiscriminate blowing may produce mechanical unbalance of an armature or rotating field by redistribution of dirt.

Compressed air used for cleaning must be clean and free of moisture or oil. Air pressure or velocity must be adequately controlled to prevent mechanical damage to the insulation.

10.2 Oily Dirt. The presence of oil in the atmosphere results in oily surfaces in the machine which attract and firmly hold any entrained dust. Neither suction nor compressed air are particularly effective in removing this dust, so that only accessible areas can be cleaned. As much of the dirt as possible is first removed by wiping with clean dry rags.

For areas not readily accessible, a "shoe shine" technique works well, wherein one end of a rag is poked into one opening and is drawn out through another by means of a hooked wire, and the two ends are drawn alternately back and forth. This process is continued until a clean cloth thus applied stays clean. The cloths should be changed very frequently in any wiping operation; otherwise the dirt or contamination picked up by the cloth may simply be transferred to another, perhaps, previously uncontaminated area. The cloths should be lint free.

To simplify removal of oily waste, solvents are commonly prescribed, but the technique of applications as well as the type of solvent is critical. Liquid solvent should not be applied to the armature of a dc machine without consulting the manufacturer.

Liquid solvents do a fine job of washing away oil accumulations, but this same liquid will carry surface contamination (conductive dusts such as metals, salts, carbon, etc) into cracks, crevices, interstices, etc, or these can be drawn in by capillarity. It is next to impossible to remove the contaminants from such inaccessible areas. If these openings are at the commutator, either at banding grooves or at the mica cone or at the commutator shell, the commutator will acquire shorted bars as the liquid solvent evaporates but leaves the conductive contaminant. A dead short may not always be produced, but scintillation has been observed when voltage was applied to a machine "cleaned" with liquid solvent. Low insulation resistance readings are quite often encountered after the liquid solvent has deposited conductive contaminants on or in porous or irregular structures, such as the mica segment insulation or the cone ends behind the commutator risers, etc.

Any solvent application should be to a wiping rag — or the "shoe shine" cloth — but these should be barely moistened and not wet. Where dirt is heavy, repeated wipings may be required. The area immediately behind the commutator risers is one most difficult to clean and very often found badly contaminated.

As an insulation system ages and embrittles in service, whether it be an ac or dc machine, cracks will develop due to shrinkage, vibration, thermal expansion, and contraction of adjacent or contained structures. Liquid-solvent cleaning of a machine containing such an insulation system could well carry conducting contaminants into these openings to cause a creepage path between turns, phase windings, or to ground. Weakness in the ground-insulation system can be checked by the use of an insulation tester, provided it has a voltage output of sufficient magnitude to reveal such weakness. Without special testing equipment such as a comparison surge tester, problem areas, such as between coils and turns which could result in an in-service failure, cannot be exposed.

Where oil-saturated dirt has been subjected to operational heat for sustained periods, a chemical reaction takes place. In this reaction, oil is first converted to a varnish-like material which is still susceptible to solvent cleaning, though more slowly. Continued heat causes the oil to form a coke-like material which is extremely difficult to soften by solvents. Removal of the coke-like material usually requires more drastic action, including service-shop disassembly and reconditioning.

10.3 Carbon Brush Precautions. When the dampened-rag procedure is to be used in cleaning brush rigging or slip rings, the carbon brushes must be removed prior to any cleaning attempt; otherwise, the brushes may absorb the solvent and some of these, particularly chlorinated solvents, may produce poor commutation. Since this removal impairs the brush fit, each brush should be marked for replacement in the same holder from which it was taken.

10.4 Solvents. Freon TF is a good solvent for cleaning motors since it is nonflammable, has good solvency for oils and grease, but is a slow acting solvent with respect to varnishes, and has a low order of toxicity. Inhibited methyl chloroform and inhibited chlorinated hydrocarbons such as "Dowclene EC" and "Chlorother NU" are also acceptable. Nonflammable

Appendix

Amplification of Tests Described in the Guide

(This appendix is not part of IEEE Std 432-1976, Guide for Insulation Maintenance for Rotating Electrical Machinery (5 hp to less than 10 000 hp))

A1 Nature of the Deterioration Due to Voltage Stress

Electrical insulation which operates in a high-stress field is subject to deteriorating influences not present at lower stress levels.

The phenomenon, commonly called corona, can cause degradation of insulation in two ways – by chemical effects and by ion bombardment. This occurs when the voltage gradient on gas molecules in void spaces in the insulation exceeds a certain value, depending on the nature of the gas and its pressure and temperature. Oxygen molecules (O_2) in the gas space may be converted to ozone (O_3) and this forms nitrous oxide in the presence of water molecules, and attacks organic materials in the insulation. The symptoms of this kind of degradation are reddish or white deposits. This effect of corona is not present to a noticeable degree in hydrogen-cooled machines since the oxygen content is small.

The other deteriorating effect of corona is present when alternating voltage stress is high enough to ionize the gas molecules in the void spaces, thereby converting them to charged particles. During the positive half cycle of voltage, they are impelled in one direction, some of them crashing into molecules of solid insulation in the void wall. During the negative half cycle, these projectiles are driven in the opposite direction, so each cycle of ac subjects the insulation to two volleys of ionization. In certain organic insulations the oxygen and hydrogen atoms may be split from the carbon atoms, leaving the familiar dendrites or tree formations, called tracking, which are actually conducting paths of carbon.

The rate at which this type of deterioration occurs in actual insulation can vary from negligible to rapid, depending on the amount of energy present in the discharges, and where the discharges are located. The total energy being fed into a volume of insulation can be measured, but there is no simple method to determine whether it is being expended in many relatively harmless low-energy discharges, or in a few localized ones which may be injurious. This can present a difficult field test problem.

Corona existing on the outside surface of insulation does not damage insulation as rapidly as internal corona; furthermore its effects can be watched by visual inspections. In many cases, it may exist for years without even destroying the varnish coating on the insulation. Because of the uncertainty associated with internal ionization; however, it is desirable to keep this effect to a minimum.

The two common ways of determining the presence of ionization or corona are by measuring the power factor of the insulation at two voltages and noting the increase and by use of a cathode-ray oscilloscope. The first method gives a measure of the total ionization if readings are made at two voltages, one at or slightly above operating and one below any practical corona level (2 kV is commonly used). Some specifications set a limit on the power-factor difference (called tip-up) obtained in this way. If the oscilloscope is connected to an exploring coil, it can give the location of the corona, but does not tell whether it is internal or external and gives only a very rough idea of the intensity.

A2 Dielectric Absorption Test

Dielectric absorption testing involves a determination of insulation resistance as a function of time (usually up to 10 min or until insulation resistance stabilizes). This test is also used on all, or parts of, the circuit-to-ground insulation of either armature or field. IEEE Std 43-1974 outlines test procedures and equipment for the standard method, which is usually made at a test potential of 500 to 5000 direct volts.

Insulation resistance vs time curves, particularly on the higher voltage stator winding ground insulation, are sometimes made at test potentials higher than the value specified in IEEE Std 43-1974. Test voltages used vary from 500 V up to potentials well above normal operating levels. High-voltage direct-current test sets utilizing the voltmeter-ammeter method of resistance determination are usually employed.

Dielectric absorption tests are considered to be more significant than the 1 min insulation-resistance tests, particularly on the higher voltage windings, because the slope of the time-resistance characteristic gives further information concerning the relative condition of the insulation with respect to moisture and other contaminants. This slope is expressed as the ratio of the 10 to 1 min insulation resistance and is called the "polarization index" (PI). In terms of measured current at some fixed voltage, it is the ratio of the 1 to 10 min values. These ratios are nondimensional in character and aid in making comparison between insulation on machines of different physical size and in comparing with tests of prior years on the same machine.

The voltage for making polarization index checks is usually 500 direct volts. The suggested polarization index values for clean dry windings (IEEE Std 43-1974) are:

105 °C (Class A) Insulation — 1.5 or more
130 °C (Class B) Insulation — 2.0 or more

These values are considered satisfactory for the usual varnish or asphalt impregnated windings. Other new types of windings may have different polarization index values. The values of polarization index given above are for machine windings only. If the insulation resistance measurements are made with leads, cables, or surge protective capacitors connected to the machine, the values obtained do not necessarily apply to the winding alone.

A polarization index of less than 1.0 indicates a conduction current increasing with time. This normally would be an unsatisfactory condition. It might be due to a leakage path which has not been dried out. If the index is still less than 1.0 after cleaning and drying the insulation the apparatus manufacturer should be consulted.

An abnormally high polarization index from an older winding, i e, in the order of 5 or more on an insulation in the 20 year age bracket, could indicate intact, but lifeless, dried-out insulation. An "in-service" failure could result from a sudden fracture of the brittle insulation caused by mechanical shock, such as could be introduced from a short circuit on the system.

Frequently, the insulation resistance is found above the basic minimum requirements, but the polarization index is below the recommended values. This would indicate the suggested insulation resistance is too low or the polarization index values too high, as recommended in IEEE Std 43-1974. As an example, this condition sometimes occurs when testing field windings or dc armatures. Generally, a machine which has been idle for some time could be returned to service if the PI value is 1.0 or above and the insulation resistance is above the minimum requirement. The insulation resistance of a reliable winding structure should be well above the basic requirements and the PI value at least equal to or above the suggested minimum.

A3 Slot Discharge and Corona-Probe Tests

The slot discharge test is made for the single purpose of checking the adequacy of the ground connection between the conducting coil surfaces and the core. If such surface discharging exists in a winding, it is important that it be detected. Greatly accelerated deterioration of the major ground insulation is produced by slot discharges. These tests are usually only applicable to machines having operating voltages in excess of 6000 V.

Tests with a slot-discharge analyzer check the adequacy of the electric contact between the core and the stator coils for those machines having low-resistance conducting surfaces in the slot portions. This test is effective in detecting and locating the presence of surface discharge which is injurious to the coil insulation. Detection is accomplished by a simple test from the machine terminals. Discharge is located by a probe test.

Tests are made with the winding energized at the maximum normal operating stress to ground. When a discharge exists, high-frequency reflections are readily observable at the machine terminals on the cathode-ray oscilloscope.

The corona probe test is intended to be an indicator and locator of unusual ionization about the insulation structure. Such a test is sensitive in varying degrees to surface corona and unusual internal ionization. The ability of this test to discriminate between harmful and acceptable levels of general ionization phenomena such as occur in high-voltage windings has not been demonstrated, but is under study.

Ionization is accompanied by several undesirable effects, such as chemical action, the production of heat, and ionic bombardment. Continued ionization can cause charring or decomposition of the organic insulating material in the vicinity of the ionization. Severe localized ionization can lead to early breakdown of the insulation. The presence of oxygen in the area of ionization may increase the damaging effect, particularly in the presence of moisture, so that it is particularly important to locate severe ionization in insulation that operates in air or that is exposed to moisture. Inorganic insulation components such as mica and glass are not effected seriously.

The corona probe test equipment consists of three basic units: an antenna, an amplifier, and an indicator. A typical antenna is about one inch long, surrounded by an insulating housing, and mounted on the end of a long insulating handle. The antenna is connected to the amplifier by a length of shielded lead. The amplifier is one of the usual type for audio frequencies, and must reject 60 Hz and radio-frequency signals. The indicator may be earphones, an output meter, or preferably a cathode-ray oscilloscope. The corona probe is used to explore the insulation for areas of ionization while the winding is energized from a source of test voltage. The probe is particularly useful in determining the effect of the dielectric-stress gradient in the end-turn insulation.

A4 Stator Core Interlaminar Insulation Test

To induce a flux in the stator core equivalent to the operating flux at 105 percent of rated voltage and rated hertz the following data may be used:

(a) The ampere-turns required may be approximated from the table below.

(b) The search coil voltage, however, is a more significant criterion as it will enable the actual volts per turn in the stator winding to be simulated.

The search coil voltage is calculated from:

Search Coil Voltage =

$$\frac{1.05 \times \text{phase voltage}}{K_d \times K_P \times \text{turns per phase in series}}$$

where

K_d distribution factor = 0.955 for a 3-phase star or delta winding;

K_p chord factor.

From these data the number of turns and current required for the voltage source available can be calculated.

When the coil is energized, any hot spots due to short-circuited laminations will be apparent within a few minutes. Care should be exercised in entering the core of a large machine with the coil energized because of the voltage induced between laminations.

Core Density in		Ampere-Turns per	
Kilolines per Square Inch	Kilolines per Square Centimeter	Inch of Core Mean Periphery	CM of Core Mean Periphery
85	13.2	9	3.5
90	13.9	18	7.1
95	14.7	37	14.6
106	16.4	145	57.1

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IEEE Standards on Rotating Machinery

IEEE Std	Title
11-1980	Standard for Rotating Electric Machinery for Rail and Road Vehicles (ANSI/IEEE) (Revision of IEEE Std 11-1962) (Reaff 1985)
43-1974	Recommended Practice for Testing Insulation Resistance of Rotating Machinery (ANSI/IEEE) (Reaff 1985)
56-1977	Guide for Insulation Maintenance for Large AC Rotating Machinery (10 000 kVA and Larger) (ANSI/IEEE) (Revision of IEEE Std 56-1958) (Reaff 1982)
58-1978	Induction Motor Letter Symbols (ANSI/IEEE) (Revision of IEEE Std 58-1956)
67-1972	Guide for Operation and Maintenance of Turbine Generators (ANSI/IEEE) (Revision of IEEE Std 67-1963)
85-1973	Airborne Sound Measurements on Rotating Electric Machinery (Reaff 1980)
86-1975	Definitions of Basic Per-Unit Quantities for AC Rotating Machines (Revision of IEEE Std 86-1961)
95-1977	Insulation Testing of Large AC Rotating Machinery with High Direct Voltage (ANSI/IEEE) (Revision of IEEE Std 95-1962) (Reaff 1982)
112-1984	Test Procedure for Polyphase Induction Motors and Generators (ANSI/IEEE) (Revision of IEEE Std 112-1978)
113-1985	Test Procedures for Direct-Current Machines (Revision of IEEE Std 113-1973)
115-1983	Test Procedure for Synchronous Machines (ANSI/IEEE) (Revision of IEEE Std 115-1965)
116-1975	Test Procedure for Carbon Brushes (ANSI/IEEE) (Revision of IEEE Std 116-1958) (Reaff 1982)
117-1974	Standard Test Procedure for Evaluation of Systems of Insulating Materials (ANSI/IEEE)
252-1977	Test Procedures for Polyphase Induction Motors with Liquid in the Magnetic Gap (ANSI/IEEE)
275-1981	Recommended Practice for Thermal Evaluation of Insulation Systems for AC Electric Machinery Employing Form-Wound Pre-insulated Stator Coils (ANSI/IEEE) (Revision of IEEE Std 275-1966)
286-1975	Recommended Practice for Measurement of Power-Factor Tip-up of Rotating Machinery Stator Coil Insulation (ANSI/IEEE) (Revision of IEEE Std 286-1968) (Reaff 1981)
290-1980	Recommended Test Procedure for Electric Couplings (ANSI/IEEE) (Revision of IEEE Std 290-1969)
304-1977	Test Procedure for Evaluation and Classification of Insulation Systems for DC Machines (ANSI/IEEE) (Revision of IEEE Std 304-1969) (Reaff 1982)
421-1972	Criteria and Definitions for Excitation Control Systems for Synchronous Machines
429-1972	Evaluation of Sealed Insulation Systems for AC Electric Machinery Employing Form-Wound Stator Coils (ANSI/IEEE)
433-1974	Recommended Practice for Insulation Testing of Large AC Rotating Machinery with High Voltage at Very Low Frequency (ANSI/IEEE) (Reaff 1984)
434-1973	Guide for Functional Evaluation of Insulation Systems for Large High-Voltage Machines (ANSI/IEEE) (Reaff 1981)
492-1974	Guide for Operation and Maintenance of Hydro-Generators
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