

IEEE Standard Test Procedure for Thermal Evaluation of Systems of Insulating Materials for Random- Wound AC Electric Machinery

IEEE Power and Energy Society

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Rotating Machinery Committee
of the
IEEE Power and Energy Society

Approved 5 December 2015

IEEE-SA Standards Board

Abstract: The standard test procedure for the thermal evaluation and qualification of electrical insulation systems (EISs) for random-wound ac electric machinery, where thermal degradation is the dominating aging factor, is described. The relative thermal performance of a candidate EIS is compared to that of a reference EIS. Insulation systems for such machinery with input voltage of up to 600 V at 50/60 Hz are described in this standard. A statistical method for establishing a relative life-temperature relationship for an insulation system is also described. To have any significance, the reference insulation system must be supported with adequate field service data. Evaluation of insulation systems for use in air-cooled, random-wound ac electric machinery with “usual service conditions” is this procedure’s intent. This procedure, on its own, does not cover insulation systems such as exposure to conducting contaminants, radiation, inverter applications, or operation in oils, refrigerants, or other media that potentially degrades insulating materials.

Keywords: ac electric machinery, IEEE™, insulation system, random-wound, thermal evaluation

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Introduction

This introduction is not part of IEEE Std 117™-2015, IEEE Standard Test Procedure for Thermal Evaluation of Systems of Insulating Materials for Random-Wound AC Electric Machinery.

This standard provides an evaluation of the thermal capability of an unsealed random-wound insulation system. Other aging factors—electrical, mechanical, and environmental—are also known to be important. Test procedures for evaluating those factors, both individually and in combination with each other, will be pursued by other working groups.

This standard was updated in 2015, with specific limitations noted here:

- Consideration of uprating for usage to 1000 V was discussed, but not implemented in the 2015 version. This was due to concerns about uprating without adequate test data. Publications and data collection of testing up to 1000 V should be completed prior to placing it into an IEEE standard.
- The use of a condensation chamber is listed herein. There is a round-robin study pending that will investigate the alternate use of a humidity chamber for testing. At present this standard remains with the wording of condensation chamber.

Comments on, and suggestions for the improvement of, this standard are welcome, and should be sent to the IEEE Standards Board (see Participants).

Acknowledgements

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1. Overview

1.1 Scope

This is a standard test procedure for the thermal evaluation and qualification of electrical insulation systems (EISs) for random-wound ac electric machinery, where thermal degradation is the dominating aging factor. This procedure compares the relative thermal performance of a candidate EIS to that of a reference EIS. This standard covers insulation systems for such machinery with operating voltage of up to 600 V at 50/60 Hz. This standard provides a statistical method for establishing a relative life-temperature relationship for an insulation system. To have any significance, the reference insulation system must be supported with adequate field-service data. This procedure is intended to evaluate insulation systems for use in air-cooled, random-wound ac electric machinery with “usual service conditions.” This procedure, on its own, does not cover insulation systems such as exposure to conducting contaminants, radiation, inverter applications, or operation in oils, refrigerants, or other media that potentially degrade insulating materials.

1.2 Purpose

The purpose of this standard procedure is to classify insulation systems in accordance with their temperature limits by test, rather than by chemical composition. This test procedure has been prepared to outline useful methods for the evaluation of systems of insulation for random-wound stators of rotating electric machines. The motorette procedure described is used for the evaluation of EISs.

1.3 General conditions

The concepts implemented in this recommended practice are based on IEEE Std 99TM.¹

The intent of this procedure is to classify candidate insulation systems by comparing them to reference insulation systems in machines with service-proven performance. Temperature classification of insulation systems are designated 105 °C, 130 °C, 155 °C, 180 °C, 200 °C, 220 °C, 240 °C, and above 240 °C, previously referred to as temperature classifications Class A, B, F, H, N, R, S or C categories, respectively (see [Annex A](#) for further information). It is expected that the several insulating materials or components that form any insulation system to be evaluated by these procedures will first be screened by the appropriate test procedures for each type of material. Thermal indices for discrete insulating materials can be obtained by following the procedures shown in IEEE Std 98TM.

Thermal indices of insulating materials cannot be used to classify insulation systems. They are to be considered only as screening tests for this system test.

1.4 Methods of evaluation

This test procedure describes test models suitable for use in random-wound insulation tests. The procedure recommends a series of heat exposures to which the test models may be subjected to represent the cumulative effects of long service, using accelerated aging parameters. Procedures are given for applying periodic voltage checks preceded by periods of mechanical stress and moisture to establish the end point of insulation life by electric failure.

To obtain an acceptable statistical average, for each chosen temperature of heat exposure, an adequate number of samples should be carried through the test procedure until failure occurs. It is important that the tests on the samples be performed at a minimum of three different aging (exposure) temperatures for each insulation system to be evaluated.

After the final results of the tests are known and the test life hours have been projected to a rated temperature, the ratio of the aging (exposure) hours of the candidate EIS compared to the aging (exposure) hours of the reference EIS can provide a rough measure of the service life expectancy of the candidate system in relation to that of the reference system.

Based on the current state of the art in terms of test procedures, no accurate prediction of actual service life can be made from test results alone. This procedure will permit approximate comparisons only, and cannot be relied upon to completely determine the merits of any particular insulation system. Such information can be obtained only from the experience of extended service. By following the general procedures outlined herein, the temperature classification in which any candidate insulation system belongs can be determined.

2. Normative references

The following referenced documents are indispensable for the application of this document, i.e., they must be understood and used. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1, IEEE Recommended Practice—General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation.^{2,3}

¹Information on references can be found in [Clause 2](#).

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³IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

IEEE Std 98, IEEE Standard for the Preparation of Test Procedures for the Thermal Evaluation of Solid Electrical Insulating Materials.

IEEE Std 99, IEEE Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment.

IEEE Std 101, IEEE Guide for the Statistical Analysis of Thermal Life Test Data.

NEMA MG 1, Motors and Generators.⁴

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary: Glossary of Terms and Definitions*⁵ should be consulted for terms not defined in this clause.

condensation chamber: A device with an atmosphere of high (95%–100%) relative humidity that is designed to produce visible condensation on the windings.

motorette: The model suitable for use in insulation evaluation testing, with a simulated stator slot system.

3.2 Abbreviations and acronyms

EIS electrical insulation system

4. History

4.1 Background information

A wide variety of synthetic electrical insulation materials are available for application in electric machinery and apparatus. As there is a growing tendency either to rely solely on these materials as electrical insulation or to employ them with the historic materials in novel combinations, there is a corresponding increase in the problems associated with the selection and evaluation of insulations. Consequently, a complete insulation system must be evaluated rather than testing only the individual insulating materials.

Many of the specifications regulating the use of insulation materials were written before the advent of the newer synthetics and were based upon experience gained with the old materials over a long period of time. Difficulties arise, therefore, when an effort is made to classify these new materials or combinations for insulation purposes under IEEE Std 1 as well as supplementary documents IEEE Std 98 and IEEE Std 99.

Current synthetic materials exhibit a wide range of properties, but the following must be considered:

- a) It is not feasible to classify them on the basis of their chemical composition alone.
- b) Second, it is not desirable to wait and acquire the knowledge required to classify them solely on the basis of experience.
- c) In addition, composite systems of insulation, in which materials of different temperature classes are used in different parts of the structure, may give satisfactory service at temperatures higher than nor-

⁴NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

⁵*IEEE Standards Dictionary Online* subscription is available at: <http://ieeexplore.ieee.org/xpls/dictionary.jsp>.

mally permitted for the lowest temperature component, and, conversely, compatibility or other problems may arise whereby the highest temperature component is rendered unsuitable for use at its classified temperature.

This test procedure has been prepared to outline useful methods for the evaluation of systems of insulation for random-wound stators of rotating electric machines. It is expected that the several insulating materials, or components making up any insulation system to be tested will first be screened in accordance with specific test procedures for each type of material. Normally, materials that have given acceptable performance in these separate screening tests are included in the system evaluation tests outlined in this procedure.

This procedure is intended to evaluate insulation systems for use in “usual service conditions” with air-cooling. It has also been a useful tool for evaluating systems for special requirements where machines are enclosed in gas atmospheres, subjected to strong chemicals or metal dusts, or submersed in liquids. However, these special requirements are beyond the scope of this test procedure.

4.2 Methods of evaluation

The test procedure includes two principal sections.

- a) [Clause 5](#) describes types of specimens to be used for testing as well as recommending a series of exposures to heat, vibration, and moisture, to which the specimens (motorettes) may be subjected to represent cumulative effects of long service under accelerated conditions. Procedures for applying periodic voltage checks to establish the end point of insulation life are also given.
- b) [Clause 6](#) describes similar procedures when actual motors are used as test specimens.

It is recommended that for each particular system to be evaluated a suitable type of a specimen, namely a motorette or a complete motor, be selected and then an adequate number of these be subjected to repeated cycles of heat, vibration, moisture, and electrical stress as outlined in [5.2](#) of this procedure.

An adequate number of samples to obtain a good statistical average, in no case less than 10 motorettes or five motors, should be carried through the test procedure until failure occurs for each chosen temperature of heat exposure. It is recommended that the tests be carried through on the indicated number of specimens for at least three different test temperatures for each insulation system to be evaluated. To promote uniformity in the results, [Table 1](#) provides six possible ranges of exposure requiring from 1 d to 32 d per given temperature that are appropriate for making these tests.

The number of cycles and the total number of hours of heat aging to the end of life for the average of each group of samples and for each of the test temperatures are then reported as the final results of the tests. The extrapolated regression line obtained for a new insulation system is determined from these data according to the procedure in IEEE Std 101. The motorette or motor life from an *accepted standard system* must be used as the criterion to determine the new thermal rating for the insulation system from the plot. A control set of test units using an established insulation system should be used so that a comparison of the new system to the old system can be made. As indicated in [5.2](#), the combined effects of the heat, vibration, moisture, and electrical stresses imposed on the insulation during these tests are intentionally made more severe than those normally found in service at the same temperature. Therefore, the life of any given insulation system in these tests will be shorter than that to be expected in actual service at a comparable temperature.

This procedure permits approximate comparisons only and cannot be relied upon to completely determine the merits of any particular insulation. Such information can only be obtained from extended service experience. In the course of time, however, it is expected that enough data may be obtained from tests of this kind to establish a normal number of hours of heat aging before failure that will be representative of each of the standard temperature classes of insulation systems.

5. Motorettes

5.1 Insulation test specimens

5.1.1 Motorette general construction

This subclause suggests appropriate test specimens for evaluating insulating systems that may be usefully subjected to the exposures outlined in 5.2, to simulate their behavior in service. It is considered that one type of motorette, as defined in the following, will adequately represent random-wound machines of both fractional and integral horsepower of 600-V rating or less. Other types of specimens will be required to represent machines with operating voltages other than 600 V and with other than random-wound insulation systems. Procedures for evaluating such other types of insulation fall outside the scope of this standard. (See IEEE Std 1107-1996 [B15]⁶ and IEEE Std 1776 [B16].)

5.1.2 Motorettes

The model shall be made to embody all of the elements and should be, as nearly as possible, representative of a complete winding insulation system. Specifically, it is recommended that for the purposes of testing random-wound motor insulation a motorette be employed, as shown in Figure 1, Figure 2, and Figure 3. At least 10 motorettes shall be subjected to each of a series of test exposures outlined in 5.2.

Figure 1 shows typical components of a motorette before final assembly, while Figure 2 shows the assembled motorette, and Figure 3 shows the motorette frame dimensions. Each of these components should be subjected to separate screening tests to establish uniformity and normality before they are assembled. For example, a number of representative samples of the wire, slot, and phase insulation, as well as wedges, all of which may be broken down by ac high-potential tests or other means. It should be recognized that the number of tests that are required to establish the acceptable temperature limit in service will increase greatly, if the performance of individual components varies over a wide range. Therefore, everything possible should be done to assure that the individual components are uniform and representative of the materials used in actual service.

The finished motorette consists of a rigid supporting metal stand with four suitable stand-off porcelain insulators bolted to one end and with a slot portion, made from an inner and outer plate, bolted to the other end. The supporting stand has holes for mounting the fixture during vibration testing. The slot sections are fabricated from US Standard #16 gauge (1.52 mm [0.060 in]) steel sheets such as AISI 1010 cold rolled steel. The assembled slot portion contains two coils of magnet wire insulated from ground by slot insulation, insulated from each other by phase insulation, and held in place with slot wedges. These components are typical parts used in actual motors. The coils are each wound with two parallel wires (bifilar wound) so that conductor-to-conductor electrical tests may be made. They can be machine wound on pins or forms, as in ordinary shop practice.

In special cases, the construction and processing procedures may be modified to simulate the intended use.

5.1.3 Preparation of motorettes

5.1.3.1 Overview of preparation

The following is a detailed description of the preparation of the motorette test samples for this standard test method. This motorette description is based on historic industry-wide testing. As noted in the last sentence of 5.1.2, modifications may be made to more clearly simulate the intended use, provided the control and candidate test specimens are modified in the same manner. The methodology for testing of multiple materials on one motorette specimen has not been standardized and has not been established as part of this standard.

5.1.3.2 Components used in motorette construction

The components used in motorette construction are as follows:

⁶The numbers in brackets correspond to those of the bibliography in Annex B.

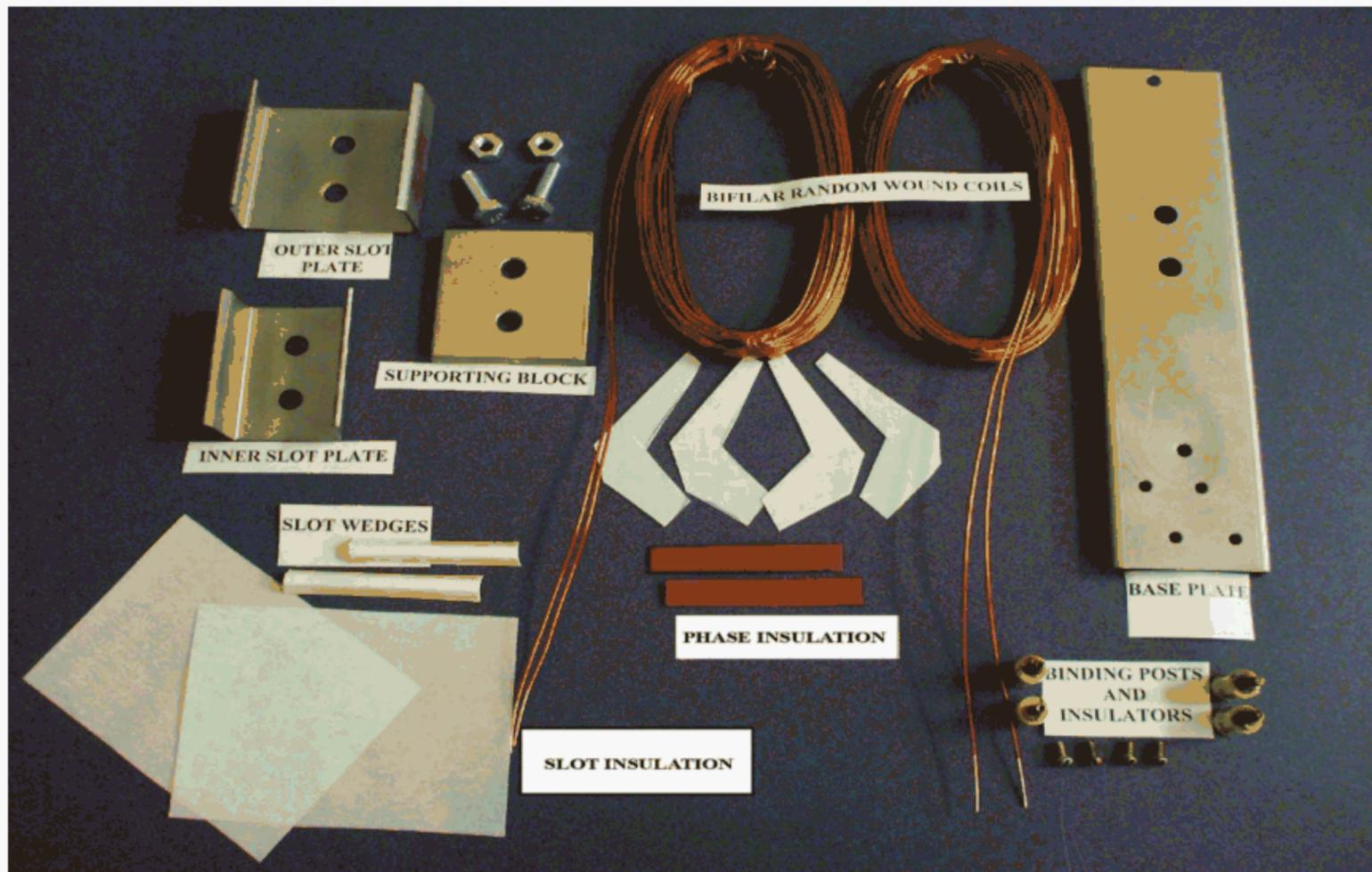


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Figure 1—Components of motorette before final assembly

- a) *Wire:* Coils shall be prepared as bifilar windings made from 18 AWG magnet wire with heavy film coating. Bifilar wound means that two separate wires are wound into the coils at the same time.
- b) *Slot insulation:* A sheet of slot insulation shall be slit into rolls of 70 mm (2 3/4 in) width. The material may be cuffed 3.2 mm (1/8 in) on each side making a final width of 64 mm (2 1/2 in). This allows 4.8 mm (3/16 in) to project from each end of the slot.
- c) *Phase insulation:* A sheet of phase insulation shall be cut into pieces, two pieces for each motorette, 13 mm (1/2 in) by 76 mm (3 in) strips and one circular piece 64 mm (2 1/2 in) in diameter with a hole 38 mm (1 1/2 in) in diameter in the center. This allows 6.4 mm (1/4 in) overlap on the rectangular pieces. The circular pieces are cut in half and the two halves placed in the end turns.
- d) *Slot wedges:* The slot wedges shall be cut from preformed U-shaped stock. The wedges are 9.5 mm (3/8 in) wide at the base and 76 mm (3 in) long. One end of the wedge is rounded to insure easy passage through the slot.
- e) *Tubing:* Insulated tubing of sufficient size to go over the lead and of sufficient length to cover the lead from the center of slot portion of the coil to the terminal stud may be added to the motorette, only if it is to be considered part of the insulation system.
- f) *Tie cord:* Tie cord material of sufficient length to tie the coil and leads together may be used as an optional process aid.
- g) *Binding tape:* Typically, 13 mm (1/2 in) electrical tape is used to hold bifilar wound coils as an optional process aid.
- h) *Insulating varnish:* Electrical grade insulating varnish or impregnating resin shall be used if the varnish/resin is to be considered as part of the insulation system.

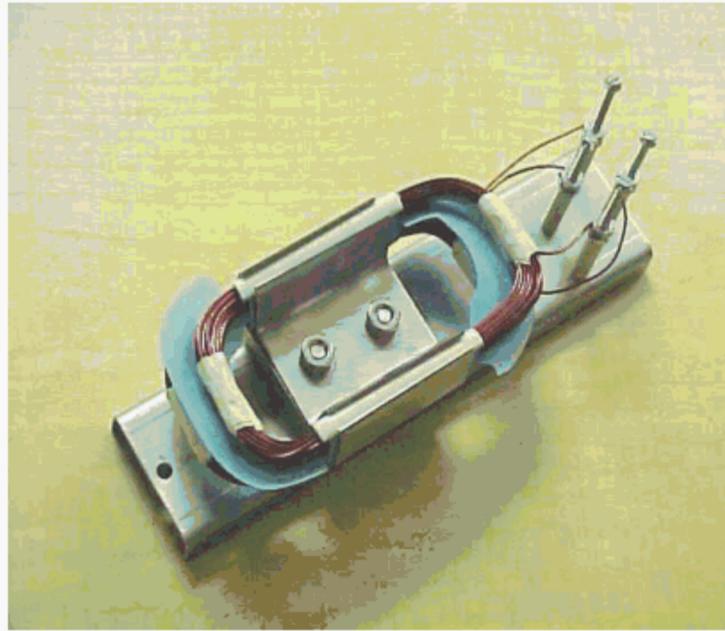


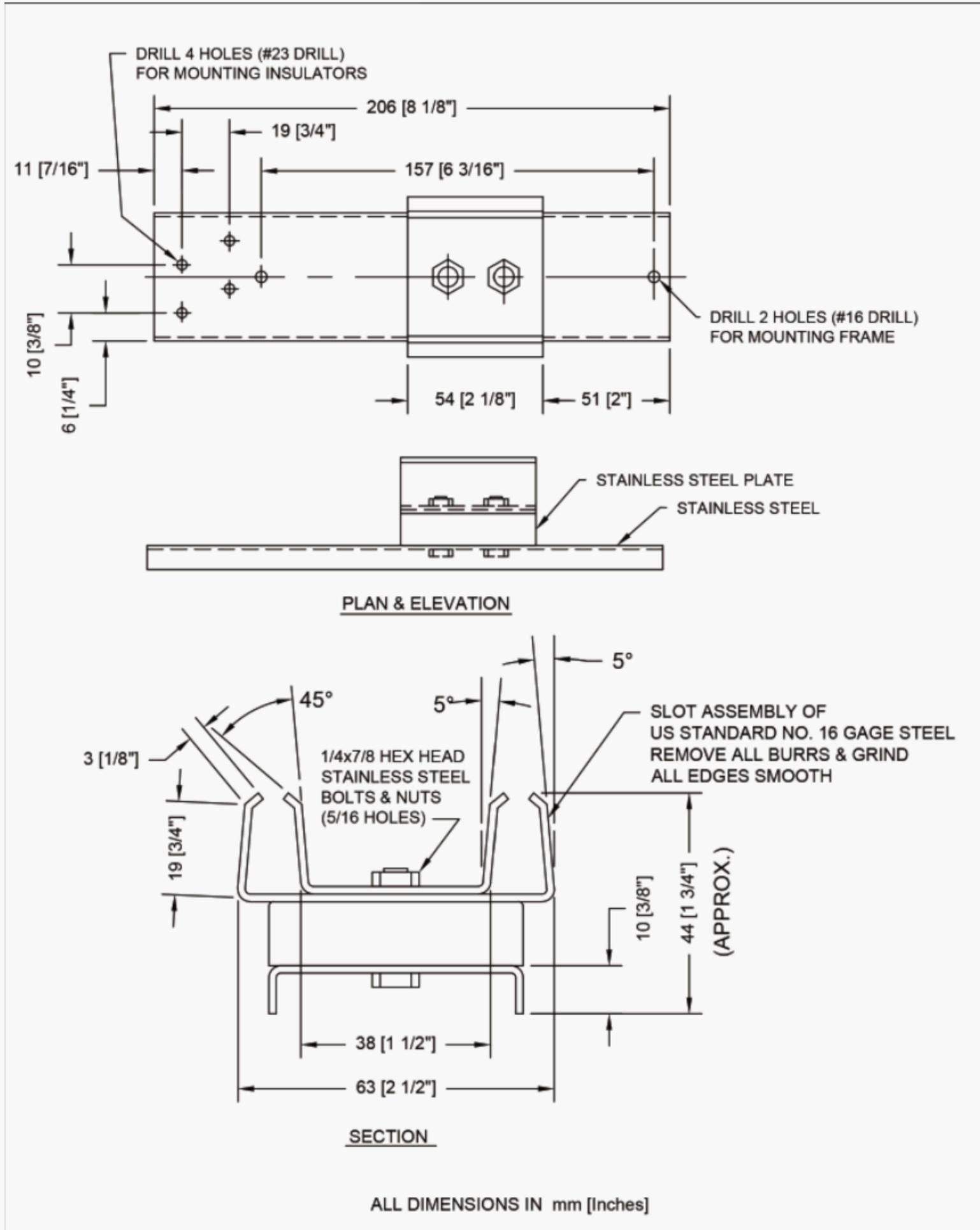
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Figure 2—Completely assembled and varnished motorette

5.1.3.3 Motorette assembly

The motorette assembly shall be as follows:

- a) Before assembly, each metal component of the motorette is immersed in a solvent composed of equal parts of toluene and denatured alcohol for at least 30 min. Each part is removed from the solvent, rinsed with fresh solvent, and wiped with a lint-free cloth. The motorette metal parts are carefully assembled, ensuring that the slot portions are equal in width and sides parallel. A simple device for this is to cut two wooden blocks equal in width to the slot portion and center the slot by placing the blocks in the slot portion prior to tightening slot hold down bolts.
- b) Winding coils shall be wound with two parallel wires on forms as in ordinary shop practice. Each coil is composed of 20 turns of wire wound 2 in hand or 40 wires. Since there are two coils in each slot, this means each slot has 80 wires. The coils are tightly wound in the form of an oval with parallel sides extending the length of the slot portion approximately 64 mm (2 1/2 in). The parallel sides are separated by 44 mm (1 3/4 in). The round end of the oval is a 44 mm (1 3/4 in) diameter semicircle. The dead ends of each coil are brought out and separated by 4.8 mm (3/16 in). The active ends of the coil are separated and taped with one layer of binding tape brought above and below each lead, or tied using tie cord. The leads exit the coil in the center of one of the semicircles.
- c) The slot insulation shall be cut from the strip in the form of a 64 mm (2 1/2 in) square and bent to fit the slot. This allows the sheet insulation to be folded under the wedge. It will project 4.8 mm (3/16 in) from each end of the slot. The slot insulation is inserted in the slot portion with extreme care so that equal amounts extend beyond each end of the slot.
- d) The slot insulation shall be folded back at the top of the slot to act as a feeder to ensure that the magnet wire is not abraided upon placement in the slot. The bottom coil is inserted in the slot with the dead coil ends down and the lead extensions at the top of the coil. After the bottom coil is in place, the phase insulation is inserted, and care is taken to ensure that the sides of the phase insulation within the slot completely cover the bottom coil. If the phase insulation within the slot is too large, the edges are folded upward toward the top of the slot. The phase insulation is adjusted to provide an equal border over the bottom coil. The bottom coil ends are not bent since the edges of the slot insulation would be ruptured. The top coil is inserted in the same manner as the bottom coil but with the dead coil end up and lead extension down. The top coil is adjusted to maintain the same border as the bottom coil, ensuring that the wires of the top coil do not slip around the phase insulation.



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Figure 3—Motorette frame dimensions

- e) The leads are carefully measured to terminate at the insulators. The last 13 mm (1/2 in) of the lead is stripped of enamel and tinned at the end with solder before connection to the insulated terminals. The leads of the bottom coils are connected to the inside insulators and the top coils to the outside insulators for consistency. The slot insulation is cut even with the top of the slot. The ends of the slot insulation are lapped over the coil and the wedge is inserted on the top of the slot insulation.
- f) The coils are checked for insulation resistance as desired and given a voltage check as recommended under 5.1.3.5. If found to pass this test, the motorette is then treated with electrical insulating varnish.

5.1.3.4 Varnish treatment cycle for motorettes

The varnish/resin manufacturer should provide specific details for the treatment cycle. An example of a varnish treating cycle is as follows:

- a) The units are preheated to anneal the wire and remove moisture.
- b) The varnish is brought into the laboratory at least 3 h before use and adjusted to a temperature of $23\text{ }^{\circ}\text{C} \pm 1.1\text{ }^{\circ}\text{C}$ ($73\text{ }^{\circ}\text{F}, \pm 2\text{ }^{\circ}\text{F}$). The viscosity of the varnish is measured and the varnish adjusted to give the viscosity recommended by the manufacturer. The unit is placed in varnish with the slot section in a vertical position with the connections up. It is allowed to remain submerged for 15 min.
- c) The units are removed from the varnish by mechanical means at the rate of 102 mm (4 in) per minute to assure an even coating, unless recommended otherwise by the varnish manufacturer.
- d) The units are allowed to drain with the slot section in a vertical position, connections up, and away from the dip tank, so as to prevent washing by solvent fumes. The unit is drained for 15 min or longer, per the varnish manufacturer's recommendation.
- e) The motorettes are placed in an oven with the slot section in a vertical position and connections up, and the varnish cured as in the manufacturer's recommendation.
- f) The motorettes are removed from the oven and allowed to cool.
- g) This is repeated as above for the required number of dips and bakes.

5.1.3.5 Electrical check of motorettes

After assembly and after varnish curing, a screening test shall be performed on the motorettes using a 400-Vac conductor-to-conductor potential with a 50-mA circuit breaker to denote failure. In addition, a 2000-Vac phase-to-ground screening test shall be used.

5.1.3.6 Motorette rack mounting

The motorette mounting, for ease of handling, can be made as follows: ten motorettes were bolted to a rack (13 mm [1/2 in] thick rigid aluminum has proven quite successful). This rack can have metal removed between motorettes so that air circulation is not impeded. The rack shall be sized to fit the ovens and condensation chamber drawers and be capable of being bolted to the vibration table. Some use shorter mounting racks of 5 motorettes each, for ease of handling due to lighter weight and smaller length.

5.2 Test exposures for motorette testing

5.2.1 Stress factors

It is the purpose of this subclause of the test procedure to specify appropriate exposures to heat, mechanical stress, moisture, and electrical stress, concurrently, or in repeated cycles that shall represent the cumulative deteriorating effects of service on insulation materials and systems on an accelerated basis.

Extensive experience with other tests of this general nature has indicated that most of the deteriorating effects of service can be reasonably approximated by such a sequence of exposures to high temperature, mechanical stresses, moisture, and voltage, as outlined herein.

The best results are obtained when the sample is first thermally aged, then exposed to mechanical stress, and finally exposed to moisture followed by voltage (thus applying electrical stress over the weakened insulation). An overnight room-temperature drying period is recommended before the next thermal aging cycle.

It is recognized that ovens provide the most convenient means of obtaining high temperatures. This method of aging subjects all the parts of the insulation system to the full temperature, while in actual service a large proportion of the insulation may operate at considerably lower temperatures than the hottest spot temperature. For this reason, the life in oven aging at a given hot-spot temperature should be expected to be shorter than in actual service.

It is recognized that failures resulting from abnormally high mechanical stresses or voltages are generally of a different character from those failures that are produced in long service. For this reason, the mechanical and electrical exposures recommended are only moderately above those normally met within service. The temperature and moisture exposures are intentionally made more severe than usually met within service, in order to shorten the required time for testing.

5.2.2 Thermal exposure

Table 1⁷ lists the suggested temperatures and corresponding times of exposure in each cycle for insulating systems for the different estimated values of the limiting hottest spot temperature. For example, the recognized 105 °C, 130 °C, 155 °C, and 180 °C (A, B, F, and H) classes of insulation would normally be tested at the times and temperatures shown in those columns of the table, respectively. To permit use of available ovens in different laboratories, a range of exposure temperatures are given in the table. Either the time or the temperature or both may be adjusted to make the best use of facilities.

The oven used for motorette tests shall be of the forced-air baffle type with ventilation to obtain uniform temperatures, such as listed in ASTM D5374 [B2]. The selected temperature should be controlled to ± 2 °C up to 180 °C and ± 3 °C from 180 °C to 300 °C after heat up for the aging portion cycle.

Motorettes are subjected to the nearest temperature corresponding to the 32-d exposure period that is necessary to provide a minimum 5000-hr mean life and to at least two of the other temperatures. In addition, at least 10 samples (motorettes) shall be carried through successive cycles of exposure at each of the test temperatures until failure occurs.

It is intended that these temperature exposures shall be obtained by placing the specimen in enclosed ovens, with just sufficient ventilation or forced convection to maintain temperatures uniform over the specimens. The cold specimens shall be placed directly in preheated ovens, so as to subject them to a uniform degree of thermal shock in each cycle. Likewise, the hot specimens shall be removed from the ovens directly into room air, so as to subject them to uniform thermal shock on cooling as well as on heating.

In certain cases, materials age more rapidly when the products of decomposition remain in contact with the insulation surface, whereas other materials age more rapidly when the decomposition products are continually removed. It is, therefore, desirable that the conditions of ventilation and temperature be precisely maintained for tests on other specimens with which the test materials are to be compared. If the insulation in actual service is so arranged that the products of decomposition remain in contact with it, the test specimens should then be designed in the same way, so that the oven ventilation will not remove these decomposition products.

⁷Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

Table 1—Temperature and exposure guide (estimated hot-spot temperature range)

Exposure temperature	Aging (temperature exposure) cycles (in days) for various insulation classifications in °C						
	105 °C (days) (A)	130 °C (days) (B)	155 °C (days) (F)	180 °C (days) (H)	200 °C (days) (N)	220 °C (days) (R)	240 °C (days) (S)
310 °C							1
300 °C							2
290 °C						1	4
280 °C						2	8
270 °C					1	4	16
260 °C					2	8	32
250 °C				1	4	16	
240 °C				2	8	32	
230 °C				4	16		
220 °C			1	8	32		
210 °C			2	16			
200 °C		1	4	32			
190 °C		2	8				
180 °C	1	4	16				
170 °C	2	8	32				
160 °C	4	16					
150 °C	8	32					
140 °C	16						
130 °C	32						

NOTE 1—The above schedule is based upon an approximate “ten-degree” rule for insulation deterioration, which states that the life of the insulation is reduced one-half for each 10 °C rise in temperature.

NOTE 2—In order to obtain an average number of heat cycles between 8 to 20 test cycles: a) If no samples fail by the end of the 8th cycle, the heat aging period of the test cycle is doubled, and b) If 3 or more samples fail by the end of the 4th cycle, the heat aging period of the test cycle is halved.

5.2.3 Mechanical stress exposure

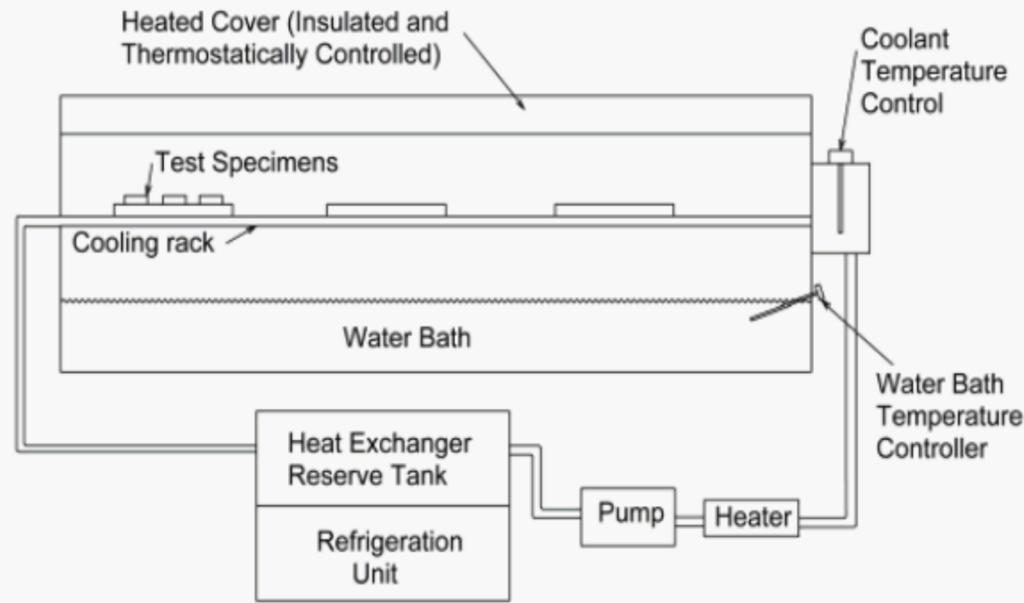
Following each cycle of temperature exposure and after cooling to room temperature, each specimen shall be subjected for a period of 1 h of mechanical stress. The following is the preferred method of applying mechanical stress to motorettes: each motorette shall be mounted on a shaker table and operated for a period of 1 h with a 60-Hz oscillating motion, with a double-amplitude (peak to peak) of approximately 0.20 mm (8 mils). The motorettes shall be mounted so that the motion occurs at right angles to the plane of the coils, allowing the coil ends to be free to vibrate as they would under radial end winding forces in an actual motor. This vibration test shall be made at room temperature and without applied voltage.

5.2.4 Moisture exposure

After each cycle of mechanical stress exposure, each specimen shall be exposed for at least 48 h to an atmosphere of high (95% to 100%) relative humidity to generate uniform and visible condensation on the winding. No voltage shall be applied to the specimen during this period. The test chamber shown in [Figure 4](#) and [Figure 5](#) is an example, and it, or its equivalent is recommended for moisture exposure with visible condensation on the motorettes.

[Figure 4](#) is a schematic block diagram illustrating the basic principle employed [B18]. The specimen rack in its drawer as shown in [Figure 5](#) is refrigerated by means of a circulating coolant (water), which is thermostat-

ically controlled to maintain a specified temperature differential between the specimens and the surrounding chamber air. This differential is independent of normal room ambient variations. Since both the heated water bath and the coolant are thermostatically controlled, this independence is limited only by the capacity of the system. Temperature control is not lost in the event that the room ambient should rise to a temperature above that of the water bath. The heat lost to the refrigerated rack keeps the water within the control of the heater, thus allowing the balance of temperatures to be maintained. In case the room temperature should fall below that of the cooling rack, the control is again preserved by the heat supply of the water bath heater. In contrast to a conventional plus-dew chamber, this balancing effect between the heating and cooling systems eliminates the necessity for the chamber to be in a temperature-controlled room. The interior of the chamber should be so



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Figure 4—Block diagram illustrating basic principle of condensation chamber

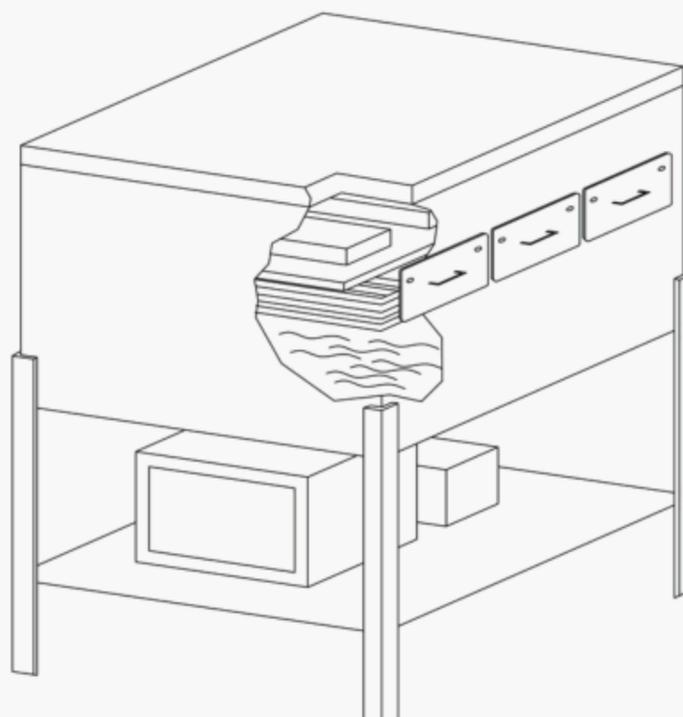
designed that all motorette specimens would be located in the same position with respect to the distance above the water bath and below the roof of the chamber. This is done so that each specimen is equally influenced by such factors as radiating surfaces, air temperature, and degree of relative humidity.

When the test chamber is maintained utilizing the temperatures shown in [Table 2](#), uniform condensation will occur.

Table 2—Condensation chamber conditions

Condensation chamber location	Temperature
Water bath temperature	30.0 °C
Motorette coil temperature	24.0 °C
Chamber air temperature (25 mm (1 in) above motorettes)	25.0 °C
Center underside chamber roof	28 °C –29 °C

[Figure 5](#) shows a cutaway view of the condensation chamber. After the desired moisture exposure, the specimens are removed for electrical testing. They are covered with an acrylic box to retain moisture on the samples. The electrical testing shall commence immediately upon removal from the chamber. The motorettes are connected to a voltage test stand by cables.



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Figure 5—Artist's cutaway view of the condensation chamber

5.3 Voltage checks for motorette testing

5.3.1 Recommended check voltages for motorette testing

Each motorette shall be carried through repeated cycles of the thermal aging, mechanical stress, and moisture exposure in sequence until failure occurs. In order to check the condition of the samples and determine when the end of life has been reached, an ac voltage check shall be applied after each successive exposure to moisture as shown in [Table 3](#).

Table 3—Check voltages for testing motorettes

Expected line-to-line voltage in service (rms volts)	Check voltage for testing (rms volts at 50/60 Hz)		
	To ground	Between windings	Between conductors
110–600	600	600	120

The voltage between conductors is chosen to be well above the maximum service voltage across a single turn of the winding and to be adequate to break down the air space between wires in the presence of moisture.

Following each exposure to moisture, the voltages shall be applied for a period of 10 min, while the specimens are still wet from exposure and near room temperature. The applied voltage is held successively for 10 min using the circuit arrangement shown in [Figure 6](#); first between the parallel-wound conductors, then from phase to phase, and finally from all coils to ground. Alternately, all of these voltages may be applied simultaneously, by the circuit arrangement shown in [Figure 7](#). However, if these voltages are applied simultaneously the voltages from winding to winding and winding to ground may not be exactly equal. Therefore, care should be taken to adjust the voltages to make the lowest one equal to the required test value. It is suggested that surge protectors be included in the test circuit to eliminate high-voltage spikes.

Experience has shown that this prolonged time of voltage application in the wet condition is necessary to detect failures. Many of the failures are found along wet surfaces, with gradual building up of the leakage current, which could not occur in the usual one-minute test. Any such failure in any component of the insulation system constitutes failure of the entire sample and fixes the end point of the life.

It is recognized, that by applying the voltages recommended in [Table 3](#), which are fixed by the intended voltages in actual service, markedly different periods of life may be obtained for the same insulating materials, depending on the insulation barriers and lengths of the creepage paths employed.

As this indicates, the test procedures recommended are adapted to prove the reliability of the insulation proposed for a given temperature, for high humidity, and for a given voltage.

Other tests⁸, besides the test where an applied voltage of frequency 50/60 Hz is applied, may be employed to check deterioration of the specimens. These may be provided for in future revisions of this test procedure. They are not considered sufficiently positive or uniform in their indications to warrant their inclusion at this time.

It is desirable to take periodic (relatively nondestructive) measurements of insulation quality during the course of the tests on a part of the samples, such as insulation resistance, power factor, or corona intensity or all three at some overvoltage. By noting changes in such qualities and correlating them with the time before final failure occurs, much can be learned about the nature and the rate of deterioration of the insulation, and greater confidence in the reliability of the final results can be established.

One of the most significant factors in the experience of testing motorettes is that of the behavior variations of the circuit breakers used to detect failure. It is strongly recommended that failure be determined by pre-calibrated electromechanical overcurrent breakers set at 0.5 A and 0.75 A rather than by neon light protectors.

5.4 Failure criteria for motorette testing

The opening of a circuit breaker, whose size and trip time are specified in [Figure 6](#), shall indicate failure in any of the voltage check tests. Minor spitting and surface sparking should be recorded but do not constitute a failure.

Any failure in any component of the insulation system constitutes failure of the entire coil and fixes the end of life.

The end of insulation life shall be considered to have occurred at the mid-point of the exposure time between the two consecutive applications of diagnostic tests, i.e., the one during which failure was observed and the preceding application of diagnostic test with no failure. For example, failure on the 11th cycle yields 10.5 cycles of life.

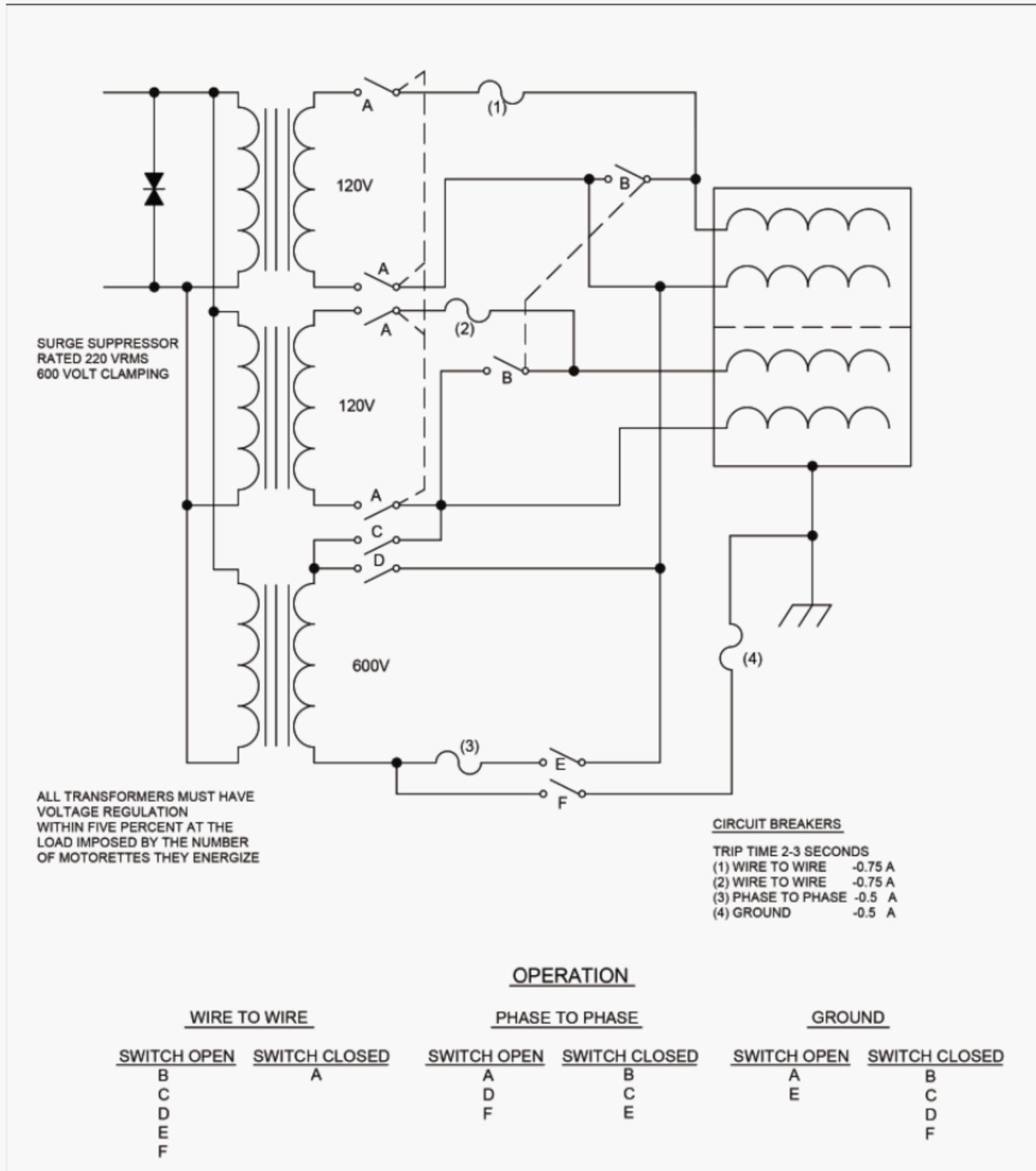
6. Motors

6.1 Test procedure for motors

This subclause lists the procedure for testing of insulation of complete motors. It utilizes the analysis of IEEE Std 101 in order to arrive at a rating of the insulation system into the Classes 105 °C, 130 °C, 155 °C and 180 °C (A, B, F, and H, respectively) as defined in [Annex A](#).

The insulation systems tested under [Clause 6](#) consist of complete systems assembled in actual motors. The motorette testing in accordance with [Clause 5](#) involves a simplified and highly standardized winding that the effects of normal manufacturing processes do not constitute a variable in the tests. On the test in [Clause 6](#) for motors, the dimensions of components and the manufacturing processes of winding and shaping do affect the test results. For comparison of systems employing different materials, the variations in manufacturing processes should be reduced to an absolute minimum when producing the two systems to be compared. These tests are also of value to a manufacturer in the development of their design processing methods.

⁸These include alternative methods and procedures for applying various types of voltages to detect changes in the test specimens.



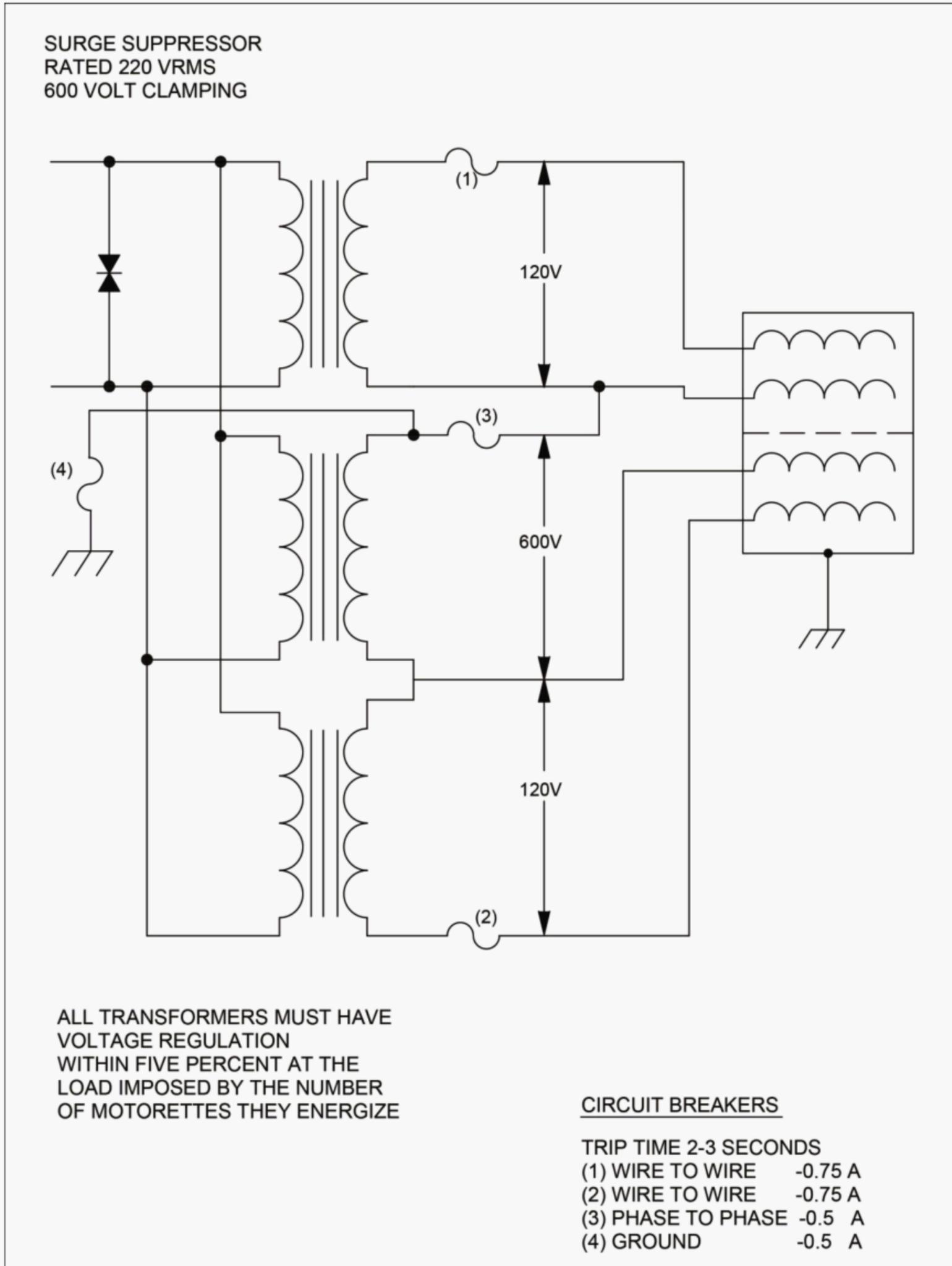
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Figure 6—Test circuit for successive proof testing

Due to a wider variation in manufacturing processes and methods of testing motors, it is exceedingly difficult to compare motor tests of one facility to those of another. It is the intent of this procedure to compare motor insulating systems within one manufacturing and testing facility.

6.2 Motor models

The models will consist of complete motors. A motor design may be modified to increase mechanical life, restrict ventilation, or increase the temperature rise, provided no changes are made in the insulation system and its immediate environment.



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Figure 7—Test circuit for simultaneous proof testing

6.2.1 Number of samples for motor testing

At least five motors are carried through each test as a group for each temperature being tested.

6.2.2 Screening tests for motor testing

To eliminate defective units, the motors shall be screened, first by visual inspection and then by subjecting them to a high potential test (see 12.3 in NEMA MG 1) and a repetitive surge test (surge comparison test⁹).

Any of the following tests may be used as additional screening tests:

- a) Corona starting voltage
- b) Dissipation factor and capacitance measurements
- c) Insulation resistance measurements
- d) Phase balance
- e) Current leakage to ground

The voltages in the above tests are applied in such manner as not to reduce the insulation life of the acceptable motors. If in any one of these tests the values obtained for an individual motor vary widely from the mean, the reason for the variation shall be investigated to be sure that the motors are adequately uniform.

6.3 Test exposures for motor testing

6.3.1 Aging factors

This subclause specifies appropriate exposures to heat, mechanical stress, moisture, and electrical stress concurrently or in repeated cycles, which will represent the cumulative deteriorating effects of service on insulation materials and systems on an accelerated basis.

The most meaningful results are obtained when the sample is thermally aged, exposed to mechanical stress, and finally exposed to moisture followed by voltage (thus applying electrical stress over weakened insulation).

It shall be realized that greater mechanical stress and higher concentration of the products of decomposition occur during tests at higher than normal temperature. Also, it is recognized that failures from abnormally high mechanical stress or voltages are generally of a different character from those failures, which are produced in long service.

Furthermore, the temperature and moisture exposures are intentionally made more severe than usually met within service. Hence, the life predicted at the system temperature rating¹⁰ will be much lower than for normal operation at that rating. Also, because of variations in control of these extraneous factors, comparison between laboratories is difficult.

6.3.2 Thermal aging

Table 1 lists the suggested temperatures and corresponding times of exposure in each cycle for insulating systems of different classes. This table is based on a constant number of cycles to failure regardless of test temperatures¹¹. Either the time or the temperature or both may be adjusted to make the best use of facilities.

⁹Example tests can be found in 12.5 of NEMA MG-1 or IEEE Std 522 [B14].

¹⁰See IEEE Std 1 for more detailed analysis.

¹¹Since experience has shown that the life of a system may be affected by the number of aging cycles, the average number of cycles should not be less than 8 nor more than 20. To assure that this average falls within this range, the procedure explained in the footnote of Table 1 is followed. However, when only five or six motors are tested at one temperature, the cycle length is halved if two (in place of three) samples fail by the end of the fourth cycle.

Test temperatures shall be measured by the resistance method. Thermocouples may be installed for purposes of control. Temperature should be controlled to ± 2 °C up to 180 °C and ± 3 °C from 180 °C to 300 °C after heat up for the heat-aging portion cycle. If the average temperature of any one motor deviates from the group being run at a common temperature by more than 2 °C, it should be so recorded and analyzed. The mode of heat generation is dictated by the type of motor being used and the laboratory equipment available.

Higher-than-normal winding temperatures may be obtained by increasing motor losses, such as larger than normal air gaps, superimposing a dc current on the ac current, starting and reversing each motor, restricting ventilation, or increasing the temperature of air surrounding the motor. During the heat-aging portion of the cycle, the motors are run continuously at normal voltage and frequency with an electrical control that automatically starts and stops or reverses the rotation of the motors at intervals as outlined in 6.3.3. Other acceptable means of temperature control include automatic voltage variation, adjustment of the surrounding air temperature, superimposition of a dc current on a normal ac current, or combinations thereof. The heat-up time is to be considered as part of the thermal aging period while the cool-down time is not.

For any system being evaluated, tests are made for at least three different temperatures. The lowest test temperature should be no more than 25 °C above the system temperature rating. The highest temperature test should be at least 40 °C above lowest temperature test, and temperature points should be selected to give approximately equal temperature intervals. The average life at the highest temperature shall be no less than 100 hr.

6.3.3 Mechanical stress

Mechanical stress is generated in motor testing (Clause 6) by the normal vibration of the motor running with additional starts or reversals or both. There is a mechanical shock from starting or reversing; vibration at twice line frequency, increased by reducing the rotor diameter; and large forces are present in the windings as a result of the high currents during starting and reversing of the motors. Mechanical shock during start/stop is higher for motors with smaller diameter rotors. Integral horsepower motors should have a lower number of starts per day as the power rating increases. Therefore considerations should be made as to the method and frequency of the mechanical shock for this testing. Additional information can be found in NEMA MG 10 [B24]. These mechanical forces occur during the test at elevated temperatures.

The test motors should either be solidly mounted or mounted on shock pads that will give a uniform amount of shock to all motors. The mounting method shall be reported, and comparison of systems should be made only on a constant method of mounting. Single-phase motors shall have at least 250 start-stop operations each day of the heat-aging portion of the cycle¹². Polyphase motors shall have at least 1000 starts or reversals each day of the heat-aging portion of the cycle¹³.

6.3.4 Moisture exposure

Moisture is used to make dielectric tests more discerning of physical and thermal damage. The presence of condensed moisture on windings results in a direct electrical path by filling cracks and porosities in the insulation with water. The resultant current flow then causes the breaker to trip, indicating failure. This is why condensation on the coils is critical for uniformity of testing.

¹²The starting winding of a single-phase motor normally operates at a much higher current density than the main winding during starting. At each start it may reach a temperature of 10 °C to 30 °C higher than the main winding, and the magnet wire which is normally smaller than the main winding wire is subjected to high currents. In order to insure that the correct emphasis is placed on the main winding portion of the insulation system, excessive numbers of starts should not be employed.

¹³Often the electrical loss during reversal is used to maintain the elevated temperatures, in which case the number of reversals may greatly exceed 1000 per day. At the highest temperature test the total time of exposure is relatively short which results in a low number of reversals during the life of the test. At the lowest temperature, the time of exposure may be 16 to 20 times as long as that of the highest level. This wide variation in total number of starts may affect the slope of the time-temperature curve. It is recommended that the number of reversals at the low temperature be no greater than twice those at the high temperature. Other means as listed in 6.3.4 may be used to supplement the heating caused by reversal.

Resistance to ground may be plotted against time in humidity to determine length of time until moisture is effective. In place of such a plot, a humidification of 48 h shall be used.

A visible condensation shall be present on the winding during the humidification portion of the cycle. In order to insure visible condensation, the insulation system shall be at a lower temperature than the dew point of the surrounding moisture-laden atmosphere at all times. The preferable method of meeting this requirement is by use of a condensation chamber described in 5.2.4.

However, larger motors may be difficult to move and difficult to support in a condensation chamber, or the chamber may not be available. Other methods of applying moisture are to apply an enclosing hood around the motor or by using a conventional humidity cabinet. One method of obtaining an atmosphere of 100% relative humidity with condensation is by covering the floor under the hood or in the chamber with a shallow layer of water heated five to ten degrees above the chamber temperature. The base of the motor should be mounted to a body that is colder than its surrounding atmosphere to insure the insulation system is at a lower temperature than the dew point of the atmosphere. The roof of the hood or chamber should be sloped so as to drain any condensed water to the back or sides of the cabinet to prevent drip on the test samples. For totally enclosed motors, end bells should be removed or openings provided in the enclosure. No voltage is applied during the exposure.

6.3.5 Electrical stresses and test

The test motors are to be run during the heat-exposure periods at their highest rated nameplate voltage. A grounded power source should be used and the motor frame should be grounded so that normal voltage stresses are present during the entire heat-aging portion of the cycle. Start up should be made within 15 min after the moisture portion of the cycle to insure that voltage is applied with moisture present. During the heat-aging portion of the cycle, motors are subjected to line surges such as normally obtained in service by starts and reversals. The motors may be given a voltage test prior to starting each thermal-aging cycle by applying a repeated surge-impulse test to each winding or phase of the motor in turn. This test surge voltage, if used, measured from surge crest to ground shall be no greater than 22 times the line voltage. Other surge testing could be utilized, as describe in IEEE Std 522 [B14].

6.3.6 Failure criteria

The motorette testing described in [Clause 5](#), has a distinct test period and proscribed endpoint. For the motor testing in [Clause 6](#), the endpoint criteria needs to be agreed upon. Since the current is monitored throughout the aging period, one methodology to calculate the failure time, which determines insulation life, could be the precise time at which the overcurrent is determined.

The end point of the motor life in these tests is fixed by its electrical failure under rated applied voltage. Excessive currents during any portion of the heat cycle constitute a failure. Indiscriminate starting in either direction of rotation of a single-phase motor may indicate failure of the starting winding. Nondestructive tests, such as measurements of insulation resistance, and dissipation factor may be employed to check deterioration of insulation quality of the specimen or approaching failure.

6.4 Operating cycle sequence testing

6.4.1 Motor testing aging

For each of the chosen test temperatures, the period of heat exposure is selected based on [Table 1](#). After completion of each cycle of heat exposure, the motor is subjected to 48 h of moisture. Impulse-surge voltage tests and other tests may be made immediately following the moisture portion of the cycle.

Line voltage of the heat-aging portion of the cycle should be applied in less than 15 min after the moisture portion of the cycle. If this is impractical, voltage checks of [6.3.5](#) shall be applied immediately on completion

of the humidity portion of the cycle, and the heating portion of the cycle shall be started as soon as practical. If valid comparisons are to be made with data from previous tests, drying-out time shall be kept the same.

6.4.2 Heat aging

Place the motor on reversals or a start-stop sequence to heat to the aging temperature. This heat-up time is considered as part of the heat-aging time. Both the power supply and the motor housing should be grounded. After 4 h of operation at this time, it is permissible to stop the motor for standardization measurements, if desired. This may be done on the initial heat-aging run only. All subsequent measurements are then taken at the conclusion of the above steps.

6.4.3 Moisture exposure

Humidification of each motor shall be for 48 h unless a variation is permitted as a result of an investigation, as in 6.3.4.

7. Analysis of data

7.1 Data

Report the total number of hours of heat aging to the end of life, as discussed in 5.4, as well as test temperatures utilized.

7.2 Analysis

For statistical analysis of data, refer to IEEE Std 101.

7.3 Comparison

If a newly tested system (System 2) is to be compared to the reference system (System 1), the regression line of System 1 is extrapolated to its temperature rating and its mean life value is determined. The same is done with System 2 for its temperature rating. If the mean life value of System 2 is equal to or greater than that of System 1, then System 2 has, at least, the thermal reliability at its temperature rating that System 1 had at its temperature rating.

7.4 Extrapolation

It shall be understood that extrapolation carries with it a degree of uncertainty. Extrapolation from the lowest test temperature should be preferably no greater than 20 °C (30 °C maximum).

7.5 Nonlinear or dissimilar curves

Nonlinear or dissimilar thermal endurance curves may arise when insulation systems are aged over a range of temperatures that cause more than one chemical process during aging. When thermal aging data are plotted in the form of log life versus the reciprocal of the absolute temperature, the introduction of new aging mechanisms will normally be shown as a knee, or bend, in the thermal aging curve. Data from the elevated temperature region where the new aging mechanism is activated cannot be used for extrapolation to estimated service conditions. When this situation occurs, additional temperature points, beginning at least 10 °C below the lowest existing temperature point, should be obtained and used for extrapolation instead of the points above the bend in the curve. For further information regarding nonlinear data, refer to IEEE Std 101.

Annex A

(informative)

Thermal-class definitions

The following are definitions for various recognized temperature classifications of insulation systems for electrical and electronic equipment. Currently, the industry standard is to utilize the temperature, rather than the letter for the classification, i.e., Class 155 °C system, rather than the traditional Class F system.

Class 105 °C (A) insulation system: A Class 105 °C (A) insulation system is a system utilizing materials having a preferred temperature index¹⁴ of 105 °C and operating at such temperature rises above stated ambient temperature as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized system test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class A insulation system is 105 °C.

Class 130 °C (B) insulation system: A Class 130 °C (B) insulation system is a system utilizing materials having a preferred temperature index of 130 °C and operating at such temperature rises above stated ambient temperature as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized system test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class B insulation system is 130 °C.

Class 155 °C (F) insulation system: A Class 155 °C (F) insulation system is a system utilizing materials having a preferred temperature index of 155 °C and operating at such temperature rises above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class F insulation system is 155 °C.

Class 180 °C (H) insulation system: A Class 180 °C (H) insulation system is a system utilizing materials having a preferred temperature index of 180 °C and operating at such temperature rises above stated ambient temperature as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class H insulation system is 180 °C.

Class 200 °C (N) insulation system: A Class 200 °C (N) insulation system is a system utilizing materials having a preferred temperature index of 200 °C and operating at such temperature rises above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class N insulation system is 200 °C.

Class 220 °C (R) insulation system: A Class 220 °C (R) insulation system is a system utilizing materials have a preferred temperature index of 220 °C and operating at such temperatures above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has

¹⁴Temperature Index of materials as defined and explained in IEEE Std 1, is: the number that corresponds to the temperature, in °C, presented graphically, but calculated mathematically from the thermal endurance relationship of an electrical insulating material (EIM) at a specified time..

demonstrated equivalent life expectancy. The preferred temperature classification for a Class R insulation system is 220 °C.

Class 240 °C (S) insulation system: A Class 240 °C (S) insulation system is a system utilizing materials having a preferred temperature index of 240 °C and operating at such temperatures above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class S insulation system is 240 °C.

Class above 240 °C (C) insulation system: A Class above 240 °C (C) insulation system is a system utilizing materials having a preferred temperature index of over 240 °C and operating at such temperatures above stated ambient temperatures as the equipment standard specifies based on experience or accepted test data. This system may alternatively contain materials of any class, provided that experience or a recognized test procedure for the equipment has demonstrated equivalent life expectancy. The preferred temperature classification for a Class C insulation system is over 240 °C.

Annex B

(informative)

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¹⁵The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.

¹⁶IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (<http://standards.ieee.org/>).

¹⁷ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

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