A REPORT OF THE PROPOSED IEEE TEST PROCEDURE FOR THE EVALUATION OF INSULATION SYSTEMS FOR ELECTRONIC POWER TRANSFORMERS

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PREFACE

To implement the changes made in AIEE Standard No. 1, the AIEE charged its technical committees with the responsibility for developing test procedures for the thermal evaluation and classification of insulation systems used in electric equipment. These test procedures are to be in general accord with IEEE Standard No. 1 and its supplements. The principal objective of these test procedures is to enable the performance of new and old insulation systems to be compared directly in a practical way and in a reasonable time, plus providing a sound basis for introducing new insulation systems into service.

A number of test procedures have been developed and published. One such procedure is "The Proposed AIEE Test Procedure For Evaluation Of Insulation Systems For Specialty Transformers." A review of this test procedure revealed that the procedure did not entirely satisfy the needs of electronic transformers. The Electronic Transformers Materials Subcommittee set out in 1961 to modify the specialty transformer test procedure to better apply to electronic power transformers.

Specialty transformers generally have their primary windings connected to secondary distribution circuits of 600 volts or less, and they supply power to lighting systems, machine tools, and other power loads. Electronic transformers usually terminate into or are energized from electronic devices. Electronic transformers may be of the power type wherein their losses are significant and are dissipated as heat, or they may be circuit elements which handle relatively low currents but may be subjected to high voltage stresses including d-c, pulses, and even transients. Most electronic transformers are small compared to specialty transformers, and in general, they are operated in significantly different and often varying environments.

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This test procedure was prepared by the Materials Subcommittee for the Electronic Transformer Committee.

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INTRODUCTION

The intent of this test procedure is to establish a uniform method by which the life of electronic transformer insulation systems can be compared. Thermal degradation has been chosen to be the major factor affecting the life of insulating materials. Other environmental factors, such as vibration, thermal shock, and moisture, have been included in the test procedure to simulate operating conditions. These factors have been chosen in such a way as to develop and disclose promptly any significant weaknesses during the temperature aging of an insulation system.

This test procedure is offered as a guide for preparing samples, conducting tests, and analyzing results. This information is presented in the following three principal sections:

Section 1. Insulation Test Specimens.
This section describes the types of insulation specimens suitable for use in the evaluation tests.

Section 2. Test Cycle.
This section recommends the test cycle for use in the insulation evaluation tests. The cycle consists of a series of exposures to heat, vibration, thermal shock, moisture, and voltages to

which the test specimen may be subjected to represent the cumulative effects of long service, under ac-
1. celerated conditions. Information is included for selecting varying test conditions for several different transformer applications.

Section 3. Interpretation of Data.
2. This section gives information on establishing the criteria of failure, methods for analyzing test results, and a guide for interpreting test
3. results.

It is recognized that some transformers may have special requirements other than those included in the procedure. In these cases, special tests should be added to the test cycle. It is all-important that when insulation systems are compared, the test samples must be subjected to
4. precisely the same test cycle.

The test procedure provides a statistical method for establishing a life-temperature relationship of an insulation system. This life-temperature relationship is relative. To have
5. any significance, it must be backed up with adequate field service data or be compared to similar life test data of insulation system with known service reliability.

SECTION 1

INSULATION TEST SPECIMENS

Whenever possible, actual transformers should be used for the thermal evaluation of insulation systems. In the case of small electronic transformers, they are the simplest, most direct, and least expensive test specimens. Some guides that can be used in selecting these specimens are given in Section 3. IV.

In those cases where the actual transformer is too large to use as test specimens, a reduced size specimen may be used. The lack of experience with large transformers prevents the establishing of a standard test model. In the use of reduced size specimens, adequate consideration should be given to all the conditions and environments affecting the life of the simulated transformer. Each situation may involve a number of different arrangements to adequately cover the various combinations of conditions affecting the performance of the insulation system. It shall be the responsibility of each testing laboratory to select and use suitable models. Full and complete design information on the model shall be published at the time of presenting test data.

Whether the test specimens are transformers or models, consideration should be given to the following items when designing and building the specimens:

1. The materials used for the various components of the specimen should be identical with those used for the actual transformers. It is recommended that only insulating materials on which life data is available be used in system evaluations. Everything possible should be done to assure that the individual components are uniform, and representative of the materials used in actual service.

2. Insulation thickness and creepage distances should be appropriate for the voltage class and industry or equipment standards or practices.

3. The arrangement of the different components, such as conductors, insulation, supporting members, spacers, shields, and ground, should duplicate electrically, thermally, and mechanically the conditions existing in the actual transformer.

4. The design and construction of the specimens should be representative of the prevailing engineering practices and manufacturing procedures and processes.

5. Provisions should be made for making electrical tests on the various insulation components.

6. If self heating is used, provisions should be made in the specimen for heating.

SECTION 2

TEST CYCLE

The test specimens shall be subjected to a repeated test cycle, consisting of the following parts, in the order given in Table I. Where indicated, specific values for some of the test conditions will be found in Table III., which provides varying degrees of severity for different applications.

It is recognized that for some equipment there may be special requirements, other than those represented in this Test Procedure, such as ability to withstand surge tests, d-c polarizing voltages during moisture exposure, etc. For these cases, special tests should be formulated and added to the test cycle recommended herein.

It is also recognized that, depending on the test facilities available, the type of specimen employed, and other factors, slight variations in the methods of exposing the specimen may be necessary. It is all-important that, when any two different materials or insulation systems are compared; the test specimens of each shall be subjected to precisely the same exposures and other conditions of test. Unless otherwise specified, tests shall be carried out at normal room temperature and humidity.

I. Dielectric Proof Test

A. Initial Proof Tests - All test specimens shall be given an applied and induced potential test prior to the first cycle of the test procedure. These tests shall be made under the conditions of and at the voltages recommended by applicable standards for the type of electronic transformers involved.

Equipment for which no acceptable standard test is available may be tested according to the following recommended procedure at approximately room temperature and in normal humidity.

1. Applied-Potential Test

a. The applied-potential test shall be made by applying between each winding separately, and all other windings and ground, a 60-cycle voltage from an external source. The winding under test shall be shorted on itself during the test. All other circuits and metal parts shall be grounded during the test.

b. The duration of the applied-potential test shall be for one minute at the value specified in (c) below.

c. The RMS test voltage shall be $\sqrt{2}$ times normal working voltage plus 1000 volts. The RMS test voltage shall be applied at a rate not to exceed 1000 volts per second. (The working voltage is defined as the maximum peak voltage stress that may occur under normal rated operation across the insulation being considered. This insulation may be between windings or between winding and case or core.)

2. Induced Potential Test

a. The induced-potential test shall be made by applying across the terminals of any suitable winding a voltage that will stress the turn and layer insulation at a peak value twice their normal working voltage but will not stress inter-winding, winding-to-core, or other insulation to voltages higher than that specified in 1. (c) above. A frequency higher than normal is usually required to avoid core saturation during this test.

b. The duration of the induced-potential test shall be the same, measured in cycles, as for a 120-cycle per second one-minute test, except that it shall not exceed 60 seconds. These equivalents, for purposes of standardization, are as follows:

Frequency Cycles	Duration of Test Seconds
120 or less	60
180	40
240	30
360	20
400	18
900	8

B. Proof Test During Test Cycle - Applied and induced potential tests are not normally made during the test cycle. Overvoltage tests made during the test cycle may influence the time to failure of the samples. They are usually used to locate and determine the causes of failure. It is recommended that current be monitored as a means of determining failure.

II. Temperature Aging

A. Temperature aging of test specimens shall be done either by internal heating or a combination of internal heating and elevated ambient.

B. Internal heating shall be done by exciting the test specimen at rated voltage and causing current to pass through the conductors until the desired test temperature is attained. When conservation of power and simplification of test setup is important, the specimen may be loaded in a buck-boost or opposition arrangement.

C. For transformers normally operating in ambients of 40°C or below, the test specimen shall be aged in an ambient temperature between 20°C and 40°C. Transformers normally operated in ambient temperatures above 40°C shall be tested in their normal operating ambients.

A heat run box of the type shown in the Appendix, may be used where ambient temperatures above room temperature are required.

Transformers which normally operate in a temperature of 40°C or below shall be thermally aged in still air with cooling by natural convection.

Heat run boxes used to maintain ambients above 40°C may have the air within the box recirculated by a fan to eliminate hot spots and maintain essentially constant temperature throughout the box. A minimum of exchange air from outside the box, consistent with maintaining the required ambient, should be permitted. Air flow should be baffled if necessary to prevent air blowing directly across the test specimen.

D. The test temperature is that of the hottest spot in the specimen windings. The relationship of the hottest spot temperature to the average winding temperature or to the temperature of an embedded detector shall be determined for each type of specimen under test. The test temperature shall be controlled within plus or minus 3°C.

E. Normal operating voltage stresses should be used in the test specimen during aging. Other than normal voltage stresses might effect the end of life.

F. The test specimen should be tested at their normal rated frequency. The frequency will effect the life of insulation if corona or dielectric heating is present. Therefore, it is important to test at rated frequency to bring in any effects of dielectric heating or corona deterioration.

G. The temperature aging should be done at a minimum of three different temperatures. From a statistical approach, it is suggested that a minimum of six duplicate specimens be tested at each temperature. The lowest test temperature should be 30°C to 60°C above the expected limiting insulation temperature. The other temperatures should be separated by intervals of 15°C or more. The shortest aging time should not be less than 300 hours and the longest time should not be less than 3000 hours. Table II illustrates typical exposure temperatures for the various classes of insulation.

H. The specimens shall be switched "on" for 20 hours and "off" for four hours in each 24-hour period. While "off" the temperature of the sample shall be reduced to within 5°C of its ambient temperature, even if forced cooling is required. This test shall be repeated four times for a total of 80 accumulated hours of temperature aging.

III. Mechanical Stress

After temperature aging, each specimen or test model shall be vibrated. For non-military type transformers, the specimens shall be vibrated as shown in Table III.

Specimens representing military type transformers shall be vibrated in simple harmonic motion for a period of 15 minutes. The amplitude of vibration shall be 0.03 inch (0.06 inch maximum total excursion) and the frequency shall be varied uniformly between the appropriate limits of 10 and 55 cycles per second (cps). The entire frequency range from 10 to 55 cps and return to 10 cps shall be traversed in approximately one minute.

The specimens shall be mounted using suitable mounting apparatus to assure that the mounting is free from resonance over the test frequency range and that the motion occurs parallel to the axis of the coils. The vibration test should be made at room temperature, with normal humidity, and without any applied voltage.

IV. Thermal Shock

After temperature aging and mechanical stress, each specimen or test model shall be placed in a low temperature chamber maintained with ± 5°C of the value and for the duration of Table III. The units should be approximately room temperature immediately prior to placing in the cold chamber. No voltage should be applied to the test sample during this exposure.

Moisture Exposure

After temperature aging and mechanical stress, and thermal shock, each specimen or test model shall be exposed for the duration and to the atmosphere specified in Table III. No voltage should be applied to the test sample during this exposure.

SECTION 3

I. Criteria of Failure

The criteria by which a test specimen is considered to have failed should be fully defined prior to the start of the test. An adequate test should be included in the test cycle to detect when a failure occurs. For example, fuses can be used if current is selected as the failure criteria. The use of more than one criteria of failure will tend to make the interpretation of the test results more difficult. It is recommended that only one criteria be used.

The cause of all test specimen failures should be determined. If it can be established that a failure was not within the insulation system under test, the data should not be included in the analysis. If a failure is not within the insulation system and it can be repaired without disturbing the insulation system, the specimen should be put back on test. For example, a lead joint may open during the test. Since lead joints are usually not a part of the insulation system and if it can be conveniently repaired, the joint should be repaired and the specimen put back on test.

II. Method for Determining the Average Life

When all the test specimens have failed, the average life at each exposure point should be calculated. It is recommended that the average life be a logarithmic average (anti-logarithm of the average of the logarithmic lines). The standard deviation of this life and the 95 percent confidence limits of this life should be calculated using logarithmic life values and by statistical methods. From these values, an indication of the accuracy of the average life values at each exposure temperature can be determined.

Methods for processing thermal aging data are given in AIEE No. 1F.

III. Extrapolation of Data

The calculated regression line and the 95 percent confidence band can be used to determine the life and corresponding temperature for other than the test points. The extent to which data may reasonably be extrapolated is limited by these requirements:

A. The calculated regression line must plot as a straight line on the coordinates specified in section 3, V.D.

B. The life to be expected at a lower temperature which may be extrapolated from data taken at higher temperatures must be considered to be anywhere between the upper and lower confidence limits existing at the desired temperature.

IV. Application of Results

It is quite impractical to evaluate every transformer model and rating built by a manufacturer and the use of a prototype design is very desirable. Also, it is known that life test data can be applied with reasonable confidence to similar and prototype designs providing that extreme care is taken to control the range of the extrapolation. The following conditions are offered here as guides for applying specific life test data to other designs. These similarities may be revised as data is collected and experience is gained in conducting these tests.

A. The windings shall be constructed with the same materials and processes.

B. The transformers shall be similar in configuration and construction type. Typical examples are:

1. Solenoidally wound
2. Toroidally wound
3. Duolaterally or universally (honeycomb) wound
4. Metal encased
5. Encapsulated and molded, and
6. Non-encapsulated and non-encased.

C. The voltage stress across the insulation (volts per mil) shall not be more than 125% of that used in the test unit.

D. The operating frequency should be the same.

E. In extrapolating data to product wound with other wire sizes because of the effect of mechanical stresses on the insulation, consideration should be given to the wires comprising the bulk of the windings (not single layer or few turns, etc.) The extrapolations should be limited to 7-gauge sizes (2 diameters).

F. The core and coil weights shall be between 50% and 200% of the test specimen.

V. Report of Results

Similar insulation systems may be used in different equipment and under varying exposure conditions. It is imperative for the sake of clarity that the test results be identified with the conditions of test and failure criteria, as well as, the temperature classification and life expectancy.

A report of the results of the tests shall contain the following information:

A. Complete description of test sample (including insulation system).

B. Description of test cycle including dielectric tests, temperature aging, mechanical stress, thermal shock, and moisture exposure.

C. Calculated regression equation with 95 percent confidence limits.

b. A plot of regression equation and confidence limits on coordinate paper, with a logarithmic scale to represent life (hours) along the ordinate, and the reciprocal absolute temperature scale to represent temperature in Celsius along the abscissa.

REFERENCES

[1] Temperature Classes for Dry-type Transformers As Determined by Functional Tests, by Paul Narbut. AIEE Transactions vol. 72, pt. III, 1953, pp 917-921.

TABLE I. TEST SCHEDULE

Parts	Para-graph	Test	Remarks
Initial Test	I	Dielectric Proof Test	Beginning of first cycle only
Basic Test Cycle	II III IV V	Temperature Aging Mechanical Stress Thermal Shock (when specified) Moisture Exposure (or special atmosphere)	Four 20 hour periods See Table III See Table III See Table III
Complete Test	II thru V	Repeat the basic test cycle until failure Occurs	

TABLE II*

TYPICAL TEST TEMPERATURE AND CORRESPONDING ESTIMATED LIFE

Estimated Life Hours	Hottest Spot Temperature (°C) or Equivalent for Systems Expected to Operate at					
	105°C	130°C	155°C	180°C	220°C	250°C
3000	135	165	195	225	275	310
1000	150	180	215	245	300	340
350	165	200	235	270	325	375

* The temperature and times in Table II were derived from data presented by Narbut[1] in 1953. The various temperatures and times do not describe any actual insulation system. They are intended only as a guide in selecting aging temperatures.

The temperatures in Table II cannot be expected to give the same end points for all insulation systems. The life curve and end point of a specific insulation system are relative and they must be compared to similar data on a system of known reliability and service life to be significant.

TABLE III

TEST CONDITIONS IMPOSED
ON
TRANSFORMERS FOR DIFFERENT APPLICATIONS

Test	Application				
	Indoor		Outdoor	Military	Contaminated Atmosphere
	75% RH Maximum	Uncontrolled RH			
Mechanical Stress	7g minimum for 10,000 cycles	7 minimum for 10,000 cycles	7g minimum for 10,000 cycles	See Section 2 Part III	7g minimum for 10,000 cycles
Thermal Shock	None	None	-30°C for 2 hours	-55°C for 2 hours	-30°C for 2 hours
Moisture	None	48 hours in 90 to 95% RH at 5 to 10 degrees Celsius above normal room temperature.	48 hours in 100% RH plus condensation at 5 to 10 degrees Celsius above normal room temperature. After removal from humidity, the test specimens shall be held at normal room temperature and humidity for at least 20 minutes and not more than 30 minutes before continuing temperature aging.	48 hours exposure to two temperature-humidity cycles as shown in Table IV.	Duration and atmosphere as required for the specific application. Examples of contaminating atmospheres are salt or other spray, dust fog, immersion in salt or tap water, corrosive gas, or radiation. Details should be noted carefully to permit duplication.

TABLE IV · GRAPHICAL REPRESENTATION OF MOISTURE-RESISTANCE TEST