



UL 1446

STANDARD FOR SAFETY

Systems of Insulating Materials – General

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UL Standard for Safety for Systems of Insulating Materials – General, UL 1446

Seventh Edition, Dated November 11, 2016

Summary of Topics

This new edition of UL 1446 reflects the latest approval date as an ANS and includes the following changes in requirements:

- ***Clarification of the terms magnet wire and enameled magnet wire.***
- ***Harmonization of ovens used for thermal aging in UL 1446.***
- ***Clarification of the terms encapsulant and potting compound.***
- ***Clarification of the terms phase insulation and interwinding insulation.***
- ***Addition of IEC winding wire insulations to Appendix A.***

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated September 23, 2016.

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Comments or proposals for revisions on any part of the Standard may be submitted to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at <https://csds.ul.com>.

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INTRODUCTION

1 Scope

1.1 These requirements cover test procedures to be used in the evaluation of Class 120(E) or higher electrical insulation systems (EIS) where the thermal factor is the dominating aging factor. These requirements also cover the investigation of the substitution of non-electrical insulating materials (NIM) components of insulation in a previously evaluated insulation system and also the test procedures to be used in the evaluation of magnet wire coatings, magnet wires, and varnishes.

1.2 These requirements for the evaluation of an EIS do not establish thermal ratings for/or alter established thermal ratings for individual components.

1.3 These requirements do not cover insulation systems exposed to radiation or operating in oils, refrigerants, soaps, or other media that potentially degrade insulating materials.

1.4 When any performance aspect of an end-product requirement is not covered by this standard, the applicable standard shall be used.

1.5 These requirements do not cover electrical insulation systems where transient overvoltages or partial discharge are present. Such electrical insulation systems shall be evaluated to the appropriate standard for the application. Such standards include, but are not limited to the Test Procedure for Thermal Evaluation of Insulation Systems for Dry-Type Power and Distribution Transformers, Including Open-Wound, Solid-Cast, and Resin-Encapsulated Transformers, IEEE C57.12.60.

2 Units of Measurement

2.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

3 References

3.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

3.2 IEC test methods are the preferred test methods with the ASTM methods presented as technically equivalent except where noted in Table 3.1. If a designation for a test method is followed by an alternate or equivalent designation, in [brackets], the latter method can be considered technically equivalent, though not necessarily identical, and might yield somewhat different numerical test results.

Table 3.1
Test methods

ASTM Standards
ASTM D1676, Standard Test Methods for Film-Insulated Magnet Wire
ASTM D2307, Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire
ASTM D2519, Standard Test Method for Bond Strength of Electrical Insulating Varnishes by the Helical Coil Test
ASTM D3145, Standard Test Method for Thermal Endurance of Electrical Insulating Varnishes by the Helical Coil Method
ASTM D3251, Standard Test Method for Thermal Endurance Characteristics of Electrical Insulating Varnishes Applied Over Film-Insulated Magnet Wire
ASTM D5642, Standard Test Method for Sealed Tube Chemical Compatibility Test
ASTM E178, Standard Practice for Dealing with Outlying Observations
IEC Standards
IEC 60172, Test Procedure for the Determination of the Temperature Index of Enamelled and Tape Wrapped Winding Wires [ASTM D2307, Standard Test Method for Thermal Endurance of Film-Insulated Round Magnet Wire]
IEC 60317, Specifications for Particular Types of Winding Wires (all parts) [ASTM D1676, Standard Test Methods for Film-Insulated Magnet Wire]
IEC 60455-2, Resin Based Reactive Compounds Used for Electrical Insulation – Part 2: Methods of Test
IEC 60455-3, Resin Based Reactive Compounds Used for Electrical Insulation Part 3: Specifications for Individual Materials (all sheets for individual resins) [ASTM D3251, Standard Test Method for Thermal Endurance Characteristics of Electrical Insulating Varnishes Applied Over Film-Insulated Magnet Wire]
IEC 60493-1, Guide for the Statistical Analysis of Ageing Test Data – Part 1: Methods Based on Mean Values of Normally Distributed Test Results
IEC TR 60493-2, Guide for the Statistical Analysis of Ageing Test Data – Part 2: Validation of Procedures for Statistical Analysis of Censored Normally Distributed Data [ASTM E178, Standard Practice for Dealing with Outlying Observations]
IEC 60851, Winding Wires – Test Method (all parts)
IEC 61033, Test Methods for the Determination of Bond Strength of Impregnating Agents to an Enamelled Wire Substrate [ASTM D2519, Standard Test Method for Bond Strength of Electrical Insulating Varnishes by the Helical Coil Test]
IEC 61857, Electrical Insulation Systems – Procedures for Thermal Evaluation (all parts)
IEC 61858-1, Electrical Insulation Systems – Thermal Evaluation of Modifications to an Established Electrical Insulation System (EIS) – Part 1: Wire-Wound Winding EIS [ASTM D5642, Standard Test Method for Sealed Tube Chemical Compatibility Test]
IEEE Standards
IEEE 1, Recommended Practice – General Principles for Temperature Limits in the Rating of Electrical Equipment and for the Evaluation of Electrical Insulation
IEEE 99, Recommended Practice for the Preparation of Test Procedures for the Thermal Evaluation of Insulation Systems for Electric Equipment
IEEE 101, Guide for the Statistical Analysis of Thermal Life Test Data
NEMA Standards
NEMA MW 1000, Magnet Wire

4 Glossary

4.1 For the purpose of this standard, the following definitions apply:

4.2 APPARENT THERMAL INDEX – The unadjusted thermal index of an insulation system derived from a regression analysis of that system's thermal aging data, usually higher in value than the system's rated temperature class.

4.3 CATALYST – A substance that alters (usually increases) the rate at which a reaction occurs without being consumed into the reaction.

4.4 CURING AGENT – A substance or mixture of substances that promote or control the reaction process and is consumed in the reaction.

4.5 CYCLE – A time period of heat exposure, which is used to induce deterioration at the specific aging temperature, followed by conditioning and diagnostic testing.

4.6 DEAD METAL – Metallic part that is at no electrical potential. With respect to the requirements in this Standard, dead metal parts are to be considered the same as if they were at ground potential.

4.7 EIS – ELECTRICAL INSULATION SYSTEM – Electrical insulating structure containing one or more electrical insulating materials (EIM) together with associated conducting parts employed in an electrotechnical device.

4.8 ELECTRICAL INSULATION SYSTEM CLASS – An agreed upon classification; refer to 6.5.5(c).

4.9 GENERAL PURPOSE MODEL (GPM) – A unit constructed in accordance with the specifications in the Standard for Electrical Insulation Systems – Procedures for Thermal Evaluation – Part 1: General Requirements – Low-Voltage, IEC 61857-1, with specific description of the GPM in the Standard for Electrical Insulation Systems – Procedures for Thermal Evaluation – Part 21: Specific Requirements for General-Purpose Models – Wire-Wound Applications, IEC 61857-21, except that:

a) The slot assembly, comprised of both inner and outer slot plates, shall be constructed of stainless steel; and

Exception: When stainless steel is not able to be used due to difficulty in material adhesion, such as an epoxy coating, or similar problem, cold rolled steel is able to be used.

b) The magnet wire shall be 18 AWG (0.82 mm²) unless unavailable, in which case any wire size 18 AWG – 24 AWG (0.20 mm²) is able to be used.

4.10 GEOMETRIC MEAN – The n^{th} root of the product of n values. Mathematically will result in the same value as the log average.

4.11 LOG AVERAGE – The antilog of the quotient, defined as the sum of the logs as the dividend, divided by the number of values as the divisor. Preferred method for calculating life but mathematically will result in the same value as the geometric mean.

4.12 SAMPLE – Actual electrotechnical products, components thereof, or non-functional models representing the product, e.g. general purpose model (GPM), used in the evaluation of an insulation system.

4.13 SYSTEM – An insulation system. See 4.7.

4.14 SYSTEM COMPONENTS – Grouped as follows:

a) ELECTRICAL INSULATING MATERIAL (EIM) (also known as Major Components) – The components of an insulation system that are relied upon to prevent a risk of electric shock or fire. Examples of this type of insulation include ground, interwinding, turn, encapsulant, and varnish. See Table 4.1.

b) NON-ELECTRICAL INSULATING MATERIALS (NIM) (also known as Minor Components) – The components of an insulation system that are used typically in mechanical or thermal conduction capacities, and are not relied upon to prevent risk of fire or electric shock. See Table 4.1.

Table 4.1
Common EIM and NIM

Type	EIM	NIM	Definition/[Comments]
Balancing Compound (Motor Term)	–	X	A material applied to a rotor to reduce vibration.
Bobbin or Core Tube (Transformer Term)	X	X	The form around which the conductor is wound. [It is an EIM when it is the sole insulation between windings and grounded or dead metal. It is a NIM when it is always provided with a supplemental EIM insulation between isolated windings and grounded or dead metal.]
Crossover Insulation	–	X	Component providing isolation between the magnet wire at the point where it enters the coil and all subsequent layers or turns of wire to the winding to which it is connected and to all other winding turns or layers. This insulation may be in sheets, films, film tapes or it may be of material inclusive to the molded coil form designed for that purpose.
Enameled Magnet/Winding Wire	X	–	Wire coated with an insulation of cured polymeric resin.
Encapsulant	X	–	An EIM, usually a molding material which is typically cast or injection molded around the electrical insulation system (EIS) and is intended to electrically insulate and protect the EIS. An encapsulant is a material used to separate the windings from components at a different voltage or from dead metal parts and also provides other safety protection. For example, be separating the windings from the metal stack. Encapsulated devices do not employ supplementary surrounding shells hence the encapsulant may function as an electrical enclosure.
End Spider (Motor Term)	X	X	The material provided between rotor laminations and the winding as it passes from slot to slot. [It is an EIM when no supplemental EIM insulation is provided between conductors and ground. It is a NIM when provided with required ground insulation or a 1/32-in (0.8-mm) minimum air space between conductors and the end spider.]
Filament Winding	X	–	Windings constructed of the type of wire typically used as lead wires.

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Table 4.1 Continued

Type	EIM	NIM	Definition/[Comments]
Fully Insulated Wire (FIW)	X	–	Enameled magnet/winding wire with sufficient build to provide Zero High Voltage Continuity Defects.
Ground Insulation	X	–	The electrical insulation between the conductor and grounded or dead metal.
Integral Ground	X	–	A coating, such as epoxy, that is fused directly to the grounded or dead metal core and serves as ground insulation.
Interwinding Insulation (Transformer Term)	X	–	An EIM placed between individual windings. [Does not apply to material used between series-parallel windings in multi-voltage transformers where the coils are physically separated by minimum safety spacing.]
Layer Insulation (Transformer Term)	–	X	The material interleaved between successive layers of an insulated conductor in the same winding. [Used in a mechanical application only, and does not serve as electrical insulation.]
Lead Wire	–	X	The insulated wire attached to the end of a winding to connect the device to a circuit. [It is identified as part of the system when its insulation enters the confines of the winding or outer wrap. When used to form a magnetic winding, it is identified as a filament winding.]
Litz wire (Transformer Term)	X	X	A bundle of magnet wire bound together by a strand of magnet wire or another material (dacron, fiberglass, aramid fiber, or similar materials). The magnet wire portion of a Litz wire is considered an EIM component. The non-wire portion wrapped or extruded around the bundle and/or core material is considered a NIM component. [Typically used in high frequency transformers.]
Magnet/Winding Wire	X	–	An insulated conductor used in wound coils to provide a magnetic field.
Non-enameled Magnet/Winding Wire	X	–	Magnet/Winding Wires that are insulated with materials that are not applied via solvent removal and the curing of polymeric resins.
Outer Wrap	X	X	The material that is placed over the final layer of winding. [It is an EIM when there is not a 1/32-in (0.8-mm) minimum air gap separating it from grounded or dead metal.]
Phase Insulation (Motor Term)	–	X	An EIM placed between adjacent windings of a multi-phase rotating device where coils are in direct contact with coils are different voltages and/or dead metal parts.
Potting Compound	–	X	A NIM which is placed in a permanent housing or enclosure where the housing or enclosure (potting shell) remains as part of the construction of the component. The potting compound functions for purposes such as holding components in place, providing a means for heat dissipation, or other NIM functions. If the potting compound was not part of the product the component could still function properly.
Potting Shell	–	X	The enclosure that holds the potting compound and insulation system.
Securement Tape	–	X	Tapes used in mechanical applications only, and have not been evaluated as electrical insulation within the system. Also known as "anchor tape".
Shaft Tube or Shaft Hugger (Motor Term)	X	X	The insulating tube between the shaft and windings. [It is an EIM when it relied upon to provide the insulation between the conductors and shaft. It is a NIM when provided with either required EIM insulation or a 1/32-in (0.8-mm) minimum air space, between conductors and the shaft.]

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Table 4.1 Continued

Type	EIM	NIM	Definition/[Comments]
Sleeving and Tubing	–	X	Materials that typically are used to cover electrical connections.
Slot Liner (Motor Term)	X	–	The material used in the channels of a rotor or stator that is relied upon to insulate the winding from grounded or dead metal parts.
Spacers, Wedges and Topsticks	–	X	Materials that are used in a mechanical capacity within the device.
Tie Cord	–	X	Strings, cords or cable ties that are used for mechanical securement.
Touch-Up or Overcoat Varnish	–	X	A material typically applied over the insulating varnish for aesthetic purposes.
Turn Insulation	X	–	Any material relied upon to electrically isolate adjacent conductors. [For example: magnet/winding wire insulation, sheet materials and filament windings' insulation.]
Varnish and Impregnating Resin	X	X	A liquid insulator which coats or impregnates the coil and is then cured. [It is an EIM component when a varnish was present in the original full thermal aging where it may have contributed to the overall performance of the system.]
Window Insulation (Transformer Term)	X	X	A material used to supplement an air gap between a winding and grounded or dead metal. [It is identified as EIM when the air gap separating the insulation from the grounded or dead metal is less than 1/32 in (0.8 mm).] Also known as "core window insulation".
Note: X means this type of material complies with the EIM and/or NIM designation.			

PERFORMANCE CRITERIA

5 Insulation Systems

5.1 General

5.1.1 Insulation systems shall be subjected to a full thermal aging program, in conjunction with a qualified reference insulation system. Test protocol and sample requirements are specified in Section 6, Electrical Insulation Systems – Full Thermal Aging.

5.1.2 An insulation system shall be investigated to determine whether the components within an insulation system are compatible and to establish a temperature class for the system.

5.1.3 Insulating materials having different assigned temperature classes are able to be combined to form an insulation system having a temperature class that is higher or lower than that of any of the individual components.

5.1.4 The compatibility of an insulating material with other materials in the same insulation system shall be investigated to determine whether thermal aging of such components makes the system susceptible to unacceptable deterioration that inhibits intended performance in normal service at the assigned temperature class of the system.

5.1.5 The compatibility of an EIS with one or more separate EIS in proximity to it shall be investigated when the insulation systems are in direct contact with each other. For example, a transformer primary coil that is wound directly over and in contact with the transformer secondary coil.

5.1.6 Constructional features, such as mechanical and electrical properties of lead-wire insulation, including thickness and type, thickness and dielectric strength of a component, electrical spacings, and operating temperatures, shall be evaluated in the end-use product.

5.2 EIS components

5.2.1 EIS components include magnet/winding wire, ground insulation, encapsulant, phase insulation, varnish/impregnating resins, wedges, tapes, lead wire, tie cord, sleeving, and all similar parts.

5.2.2 For the purpose of documenting materials and facilitating component substitutions, information concerning insulation system components shall be obtained prior to testing. The information shall include:

- a) Manufacturers' name and catalog numbers or the equivalent;
- b) Thicknesses of EIM components (where appropriate), including the thickness of each layer of a laminate; temperature classes, when appropriate; the temperature class and style or type designation of each type of lead wire; and
- c) Other appropriate information.

5.2.3 Bobbins intended for use as ground or interwinding insulation that are molded from polymeric materials shall comply with the Standard for Polymeric Materials – Fabricated Parts, UL 746D.

5.2.4 When utilized in a full thermal aging program, sheet materials used as turn insulation in bare-conductor configurations shall be evaluated in the same manner as magnet wire.

5.2.5 A coating resin intended for use as integral ground insulation shall comply with the requirements specified in Section 6, Electrical Insulation Systems – Full Thermal Aging.

5.2.6 A lead wire having a temperature rating that is more than 5°C (9°F) lower than the temperature rating of the insulation system in which it is connected shall be compatible and shall be separated from the windings by a barrier or envelope of a material compatible with the system. The temperature rating of the lead wire shall not be less than that specified in Table 5.1.

Exception: Lead wire that has been evaluated for use in the insulation system by means of at least a one temperature thermal aging program is not required to comply with this requirement. See SA7.1.1(d) and SA7.2.1(e).

Table 5.1
Lead wire temperature ratings

Insulation system class	Minimum lead-wire temperature rating	
	°C	(°F)
120(E)	90	(194)
130(B)	90	(194)
155(F)	125	(257)
180(H)	150	(302)
200(N)	180	(356)
220(R)	200	(392)
240(S)	220	(428)

5.2.7 The use of metal foil or an adhesive backed metal foil tape used as shielding in an insulation system requires a suitable ground or interwinding insulation between the metal foil and all windings.

5.2.8 The use of metal foil or an adhesive backed metal foil tape used to make a winding in an insulation system requires a suitable turn insulation between consecutive turns.

PERFORMANCE TESTS

6 Electrical Insulation Systems – Full Thermal Aging

6.1 General

6.1.1 Representative samples of the candidate insulation system and a qualified reference insulation system shall be subjected to a full thermal aging, consisting of a minimum of three temperatures. At each of the aging temperatures, samples shall be subjected to a cycling program, undergo diagnostic testing, and the data from all temperatures shall be analyzed to determine a thermal class rating by comparison to the reference system.

6.1.2 Additional components not present in the thermally aged samples shall be added by methods outlined in Supplement SA.

6.2 Samples

6.2.1 Test samples of either an operating part or a representative construction shall include all EIM components, and any additional NIM components, assembled to represent the intended end-use insulation system. Test samples of an open-type (non-encapsulated) system are not representative of an encapsulated system. Materials acting in a ground, interwinding, or encapsulating capacity shall be tested in the minimum thickness. When subsequent thickness reduction is required, see SA6.3.

6.2.2 Test samples representative of an encapsulated system shall be subjected to a thermal aging program per Section 6, Electrical Insulation Systems – Full Thermal Aging.

6.2.3 The winding configuration of the intended end-use insulation system is to be represented in the test samples. Tests on a random wound construction are determined to be representative of other winding configurations such as layer wound or precision wound, and not the opposite. Lead wires are to be additionally protected beyond where they emerge from the windings, so that contact with sample frames does not occur. The protection is to be an inert material, such as unimpregnated glass-fiber tubing, that is not able to interact with the insulation system.