

**Compendium "Certification of  
electrical insulation systems acc. to UL 1446"**



## IMPRINT

### COMPENDIUM "CERTIFICATION OF ELECTRICAL INSULATION SYSTEMS ACC. TO UL STANDARD 1446

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## 1 Introduction

In the course of globalisation and world-wide trade the certification of German electrical industry products gains importance. Only safe products, i.e. such products which are tested and certified by approved testing and certifying institutes, find their way to the world market customers.

One of the most common quality symbols is the American UL mark. Often it is a must for products to be sold to the North-American market. The mark is owned by Underwriters Laboratories Inc. (UL), established in 1894, headquarters in Northbrook (Illinois). Functions of UL are similar to VDE or TÜV.

UL is one of the leading organisations in the US when it comes to electrical safety. Various product standards cover the entire range of electrical and electronic products and applications.

Comparing the safety philosophies of VDE and UL, there is a wide difference: Whereas the VDE tests focus on single components, UL tests include the complete system.



## 2 Reliability of electrical equipment

The condition of electrical equipment is crucial for safe operation. Great reliability, good efficiency, low failure probability, minor maintenance costs are the decisive factors for selecting suitable equipment. And one of the most crucial parameters is the aging behaviour caused by system load.

There are various kinds of aging:

- electrical (creepage current, partial discharge, interfacial processes)
- chemical (chemical incompatibility, e.g. softener outgassing, degradation)
- thermal (diffusion or thermo-mechanical alternating load, substance degradation)
- mechanical (vibration and shock impact, sub-surface migration, abrasion)
- environmental (UV radiation, exposure, salt fog)

There are intrinsic and extrinsic aging mechanisms. A temporary decline of conditions is called degradation, whereas a permanent decline is called deterioration.

All these loads cause aging and impairment of insulating materials determining the operational safety. If the worst comes to the worst operation would even become dangerous (fire hazard, electric shock).

Electrical aging is due to physical processes, like creepage or partial discharge, or interfacial processes. The aging function, i.e. the interconnection of life span and load follows an (empirically determined) inverse law of life span

$$L_{el} \sim E^{-nt},$$

E stands for electrical load and, n is the life span exponent, and t stands for time.

Whereas thermal aging is caused rather by chemical and/ or physical processes, like curing, polymerisation, diffusion or even thermo-mechanic load. In this case the mathematic dependency follows exponential law, resembling the so-called Arrhenius equation, which is a measure of reaction kinetics in chemical processes in dependency with temperature:

$$L_{th} \sim A \cdot e^{-m/T},$$

m stands for life-span long-term exponent and T for the absolute temperature.

Rule of thumb is that an increase of the operational temperature by 10°C halves the life-span.

### 3 Construction/ components of electrical insulation systems

Operational reliability and long-life cycles are closely connected with the applied insulation technology of coilware. Operational temperatures may lead to chemical reactions with aging effects associated with material weakening and therefore dangerous operational situations (e.g. fire, danger of contact to current-carrying parts).

Winding goods are made up of a variety of components. Reels made of winding wire (enamelled copper wires, covered wires etc.) and the permeable core (electrical sheets, ferrite core, etc.) are indispensable for operation. Mostly the winding materials are built on a coil form with insulating layers.

The winding itself has to be protected against contact to current-carrying parts and ignition at operational temperatures. Other components are insulation materials, impregnants, connection cables, insulating sleeveings, and sometimes potting compounds.

Based on UL 1446 (Standard for Safety for Systems of Insulation Materials – General) UL certified systems require the interaction of all components and electrical insulation materials (EIM) in an electrical insulation system (EIS).

### 4 UL approval of electrical insulation systems

There are two categories of electrical insulation systems: The first category is called "Systems Electrical Insulation (OBJY2)" and comprises an UL approved EIS for a specific motor or transformer. The second category "System Components, Electrical Insulation (OBJS2)" is intended for external use and is listed in the iQ Electrical Insulation System database and provided to customers of big producers.

Each EIS to be certified is made of many different electrical insulation materials (EIM), divided into major and minor components. Differentiation of major and minor components is based on the assumption that major components are of particular importance, i.e. the insulating barrier between conductor and ground, whereas minor components serve non-electrical purposes, i.e. related to physical (mechanical) resistance or absorption of thermal and mechanical load. German language use often refers to the term "primary insulation", replacing the term "major components". "Minor components" is replaced by the term "secondary insulation" correspondingly.

Summary of the most important major and minor components:

Type	Purpose	Components
Major	Components of significant importance regarding safety.	Insulated magnet wire coil form insulating material varnish (impregnant)* resin (impregnant)*
Minor	Components without significant importance regarding safety.	connection wires sleevings layer insulation tapes potting compounds

\* Varnishes and resins (impregnants): The material is rated „major component“ when included in the original full thermal aging test or affecting the overall performance of the system (see U -1446, chart 4.2 page 10), if not those materials are rated “minor component” and need to be added by sealed tube test (CCT).

#### 4.1 Full Thermal Aging Test (FTA)

A so-called full thermal aging test (FTA) is precondition when filing for approval of an UL recognized insulation system, for adoption of previously evaluated systems the so-called sealed tube test (CCT) will possibly suffice.

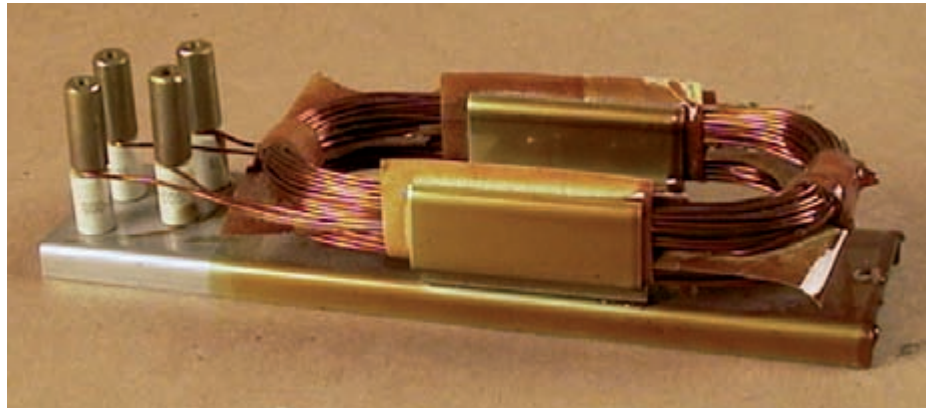
Test rigs, called motorettes (reduced motor model) or transformettes (reduced transformer model) are required for UL approval of an EIS according to UL 1446.

Temperature class ratings are crucial:

Temperature class [°C]	Numeric designation	System Class Designation	
		IEC 60085	UL 1446 / max. hotspot °C / °F
< 90	70	70	(none)
> 90 - 105	90	Y	(none)
> 105 - 120	105	A	(none)
> 120 - 130	120	E	120 (E) 120 / 248
> 130 - 155	130	B	130 (B) 130 / 255
> 155 - 180	155	F	155 (F) 155 / 311
> 180 - 200	180	H	180 (H) 180 / 356
> 200 - 220	200	200	200 (N) 200 / 392
> 220 - 250	220	220	220 (R) 220 / 428
> 250	250	250	240 (S) 240 / 454 over 240 (C) 240 / >464

Insulating systems exceeding 105 °C long-term operation require tests of all major components according to the standards of UL 1446 at least at three different temperatures (minor components can, yet do not have to be included in the test and can be verified subsequently by shortened test, e.g. the sealed tube test).

This long-term thermal aging test aims at evaluating the thermal durability of insulation systems. During this test major components in representative assemblies (motor, transformer, or standardized models, e.g. "motorettes" or "transformerettes") are exposed to a determined sequence of heat and cold aging, atmospheric change tests, humidity, if applicable mechanical vibrations, and finally to electric tests (earth insulation, phase to phase, layer insulation).



Pic 1: motorette

Dielectric tests aim to determine the interconnection of dielectric strength of major components to aging under thermal load.

The test is valid when the dielectric strength of the insulating material after each test cycle (see thermal load test in the chart below) still is 600 V (phase-phase and phase-earth) or 120 V (winding-winding).

The test has to be performed at least at 3 different temperatures to provide reliable figures.

The following chart roughly shows the test procedure:

Test cycle	Performance
Motorette/ transformerette construction	Various test rigs
Temperature test	Highest temperature: 3 day cycle next lower temperature: 7 day cycle next lower temperature: 14 day cycle lowest temperature: 28 day cycle
Cold shock	temperature -20 °C
Mechanical load	Vibration 60 Hz (1 h for motorettes, 3 minutes for transformerettes)
Humidity test	92 % to 100 % relative humidity at room temperature for 48 h
End of Life Test (at the end of each cycle)	600 V phase - phase phase - earth 120 V winding - winding until insulation yields



10 test specimens are required for each aging temperature. Three aging temperatures are required, of which the shortest duration must be at least 100 hours of aging time, and the longest duration test must be at least 5000 hours of aging time. Due to uncertainties of when specimens will reach end-of-life, four temperatures are often conducted as described in the previous table. Motorettes and transformerettes are built by the testing laboratory personnel (UL or independent testing laboratory). Aging temperatures chosen are based on the expected system thermal rating. For example, for a 130(B) system, the aging temperatures chosen typically range from 145°C to 175°C, but often higher temperatures (up to 190°C can also be used).

The typical procedure of insulation system tests of new EIS is as follows:

- 1.) Complete aging test
- 2.) Complementing minor components by sealed tube test
- 3.) Use of EIS in end use

Evaluation of a new EIS takes one year at least.

#### 4.2 Sealed Tube Test (CCT)

It is possible to replace time-consuming complete aging tests by shortened tests to complete previously evaluated EIS with favoured minor parts.

It has to be explicitly emphasized that it is not permitted to exchange or complement any „major part“ of a previously evaluated EIS.

Except for:

- Insulating varnishes which are rated in the applicable thermal class by means of FTA tests.
- Composite materials, e.g. NMN (Nomex®-Mylar®-Nomex®) or DMD (Dacron®-Mylar®-Dacron®), provided that one of the composite material components is at least as thick as the part of the EIS.
- Enamelled magnet wires can be complemented/ exchanged according to the terms stated in appendix A of UL 1446



Pic 2: Glass plunger (sealed tube) and heat cabinet

The sealed tube test verifies the chemical compatibility of major insulating materials in regard of outgassings of complemented minor components (e.g. adhesive tapes, potting compounds, cords) by means of standardized processes.

Main focus of attention is the dielectric strength of varnish insulated wires which is evaluated after 14 days of aging together with all other components<sup>1</sup> in a sealed off test case (sealed tube, quasi a closed quartz glass bulb). Aging is at the temperature of the requested EIS class plus 25°C.

For reference purposes another specimen (sealed tube) passes the same procedure, however, only containing the components of the original EIS.

The modified EIS will be approved if the dielectric strength of the winding wires is at least 50 % of the winding wires in the reference tube.

The modified EIS can be used immediately after performance of the sealed tube tests. UL typically allows 8 weeks to perform the aging, testing of materials, and to provide the paperwork documenting this type of system testing.

Preparatory work:

Provided that there is an OBJS2 system (that means an already existing and previously evaluated EIS) which could be modified to suit own needs, contact to the "owner" of the OBJS2 system has to be established who needs to issue a so-called "Release Letter" and pass it on to UL. The release letter permits the required modification and at the same time discloses all components of the original EIS. This information allows the applicant to assemble the test materials for the CCT.

It is up to the applicant to provide all materials needed for the sealed tube test.

Final evaluation is documented in a file which is published by UL. For this purpose UL developed a database collecting the results of tested and released EIS ([www.ul.com/iq](http://www.ul.com/iq)).

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<sup>1)</sup> The sealed tube contains small samples of the insulation materials, approx. 25x25 mm<sup>2</sup>, and cured potting compounds as well as varnish coated twisted pairs (twisted enamelled wires, one set with min. 5 pieces per wire type) and other components.

### 4.3 Adoption of previously evaluated EIS

The easiest and most cost-effective method for a manufacturer of electrical equipment to have their own EIS system designation is to adopt a previously evaluated EIS without any modifications<sup>2</sup>. Since it is not necessary to use all components of such an EIS the user could select an EIS containing all components needed.

Adoption of a previously evaluated EIS is possible in two ways:

- The electronic copy takes over all data of the previously evaluated EIS into the own EIS.
- The new EIS is included in the follow-Up service (quality control) of the customer.

The owner of the original EIS needs to provide a release letter to approve use of his system.

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<sup>2</sup>) *The following modifications are possible in the course of EIS adoption:*

*Exceptions are only possible in case the substituting products are identical with the products contained in the EIS. Modification always requires co-ordination with UL.*

*The analogy of two products is valuated by comparing IR spectrums. In case of high analogy products can be replaced without any further tests.*

*Thanks to the experience at UL it is possible to categorise electrical adhesive tapes in so-called matrices. The idea is that many adhesive tapes of one manufacturer only differ in thickness, colour, or transparency. The chemical composition is identic so there should not be any different influences on the wires in the course of the sealed tube test. Therefore the number of submitted adhesive tapes can be reduced in co-ordination with UL.*

## 5 Notes

UL verifies the chemical compatibility of materials used at given long term operational temperatures. It is possible to submit materials without UL ratings or which have UL temperature ratings of a lower thermal class than the desired system temperature class. Care should be taken when doing this, as any low temperature component which has chemical issues (such as the chemical incompatibility or outgassing described earlier) could negatively impact the performance in the system test and cause the overall system rating to be lower than desired. Often the personnel at the testing laboratories have knowledge about which materials to avoid for which temperature class evaluation.

UL 1446 requires no additional material evaluations for materials having direct contact to voltage carrying parts. This is part of the end-product tests and depends on construction, thermal classification, distances, and other parameters determined by the end-product standard. Additional parameters which might be needed at a later stage are e.g. HWI (hot wire ignition), CTI (comparative tracking index), HAI (high arc ignition) etc. and should be taken into consideration when testing materials.

IEC 61857 and IEC 61858 (all parts) provide near equivalent test procedures to those outlined in UL 1446. Thermal classifications for the systems based on these test procedures are outlined in IEC 60085.

## 6 Abbreviations

CCT: Components Compatibility Test (Sealed Tube Test)

EIM: Electrical Insulating Material

EIS: Electrical Insulation System

UL: Underwriters Laboratories, Inc.

FTA: Full Thermal Aging Test

Accreditation: NRTL (USA), SCC (Canada)

Marks: UL marks for USA, C-UL marks for Canada, combined cULus-Marks (USA and Canada)

NRTL: Nationally Recognized Testing Laboratories

SCC: Standards Council of Canada (accredited testing and certification institutes) (CO and TO)

CO: Certification Organisation

TO: Testing Organisation

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