

INTERNATIONAL STANDARD



**Electrical resistance trace heating systems for industrial and commercial applications –
Part 1: General and testing requirements**



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Electrical resistance trace heating systems for industrial and commercial applications – Part 1: General and testing requirements

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ELECTRICAL RESISTANCE TRACE HEATING SYSTEMS FOR INDUSTRIAL AND COMMERCIAL APPLICATIONS –

Part 1: General and testing requirements

FOREWORD

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IEC/IEEE 62395-1 has been prepared by IEC technical committee 27: Industrial electroheating and electromagnetic processing, in cooperation with Petroleum & Chemical Industry Committee of the IEEE Industrial Applications Society, under the IEC/IEEE Dual Logo Agreement between IEC and IEEE. It is an International Standard.

This document is published as an IEC/IEEE Dual Logo standard.

This first edition cancels and replaces the second edition published in 2013. This edition constitutes a technical revision.

This edition includes the following significant technical changes, apart from general revisions of IEC 62395-1 and harmonization with IEEE 515 [1]¹ and IEEE 515.1 [2], with respect to the previous edition:

- a) Added control and monitoring requirements for fire sprinkler systems and safety showers.
- b) Provided a supplemental ice bath method for verification of rated output.
- c) Provided constructional and type test requirements for glands used to terminate heating devices to an exposed enclosure.

The text of this International Standard is based on the following IEC documents:

Draft	Report on voting
27/1182A/FDIS	27/1186/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications/.

A list of all parts in the IEC 62395 series, published under the general title *Electrical resistance trace heating systems for industrial and commercial applications*, can be found on the IEC website.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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¹ Numbers in square brackets refer to the Bibliography.

INTRODUCTION

IEC/IEEE 62395-1 provides the essential requirements and testing appropriate to electrical resistance trace heating equipment used in industrial and commercial applications. While some of this work already exists in national or international standards, this document has collated much of this existing work and added considerably to it.

IEC/IEEE 62395-2 provides detailed recommendations for the system design, installation and maintenance of electric trace heating systems in industrial and commercial applications.

It is the objective of the IEC/IEEE 62395 series that, when in normal use, electrical trace heating systems operate safely under their defined conditions of use, by

- a) employing heaters of the appropriate construction and meeting the test criteria detailed in IEC/IEEE 62395-1. The construction includes a metallic sheath, braid, screen or equivalent electrically conductive covering;
- b) operating at safe temperatures when designed, installed, and maintained in accordance with IEC/IEEE 62395-2.
- c) having at least the minimum levels of overcurrent and earth-fault protection required in IEC/IEEE 62395-1 and IEC/IEEE 62395-2.

ELECTRICAL RESISTANCE TRACE HEATING SYSTEMS FOR INDUSTRIAL AND COMMERCIAL APPLICATIONS –

Part 1: General and testing requirements

1 Scope

This part of IEC/IEEE 62395 specifies requirements for electrical resistance trace heating systems and includes general test requirements.

This document pertains to trace heating systems that can comprise either factory-fabricated or field-assembled (work-site) units, and which can be series and parallel trace heaters or surface heaters (heater pads and heater panels) that have been assembled and/or terminated in accordance with the manufacturer's instructions.

This document also includes requirements for termination assemblies and control methods used with trace heating systems.

This document provides the essential requirements and testing appropriate to electrical resistance trace heating equipment used in industrial and commercial applications. The products complying with this document are intended to be installed by persons who are suitably trained in the techniques required and that only trained personnel carry out especially critical work, such as the installation of connections and terminations. Installations are intended to be carried out under the supervision of a qualified person who has undergone supplementary training in electric trace heating systems.

This document does not include or provide for any applications in potentially explosive atmospheres.

This document does not cover induction, impedance or skin effect heating.

Trace heating systems are grouped into different types of applications and the different conditions found during and after installation necessitate different requirements for testing. Trace heating systems are usually for a specific type of installation or application. The product type grouping, applications and product attributes are indicated in Table 1.

NOTE Trace heating systems intended for use in explosive atmospheres are the subject of IEC/IEEE 60079-30-1 [3] and IEC/IEEE 60079-30-2 [4].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60519-1, *Safety in installations for electroheating and electromagnetic processing – Part 1: General requirements*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60695-11-3:2012, *Fire hazard testing – Part 11-3: Test flames – 500 W flames – Apparatus and confirmational test methods*

IEC/IEEE 62395-2:2024, *Electrical resistance trace heating systems for industrial and commercial applications – Part 2: Application guide for system design, installation and maintenance*

ISO 7240-2:2017, *Fire detection and alarm systems – Part 2: Fire detection control and indicating equipment*

ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems – Control and Indicating Equipment*

ASTM D 5025-20, *Standard Specification for Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials*

ASTM G155-21, *Standard practice for operating xenon arc light apparatus for exposure of non-metallic materials*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO, IEC and IEEE maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEEE Standards Dictionary Online: available at <http://dictionary.ieee.org>

NOTE 1 General definitions are given in the International Electrotechnical Vocabulary, IEC 60050 (all parts) [5]. Terms relating to industrial electroheat are defined in IEC 60050-841 [6].

NOTE 2 The terms defined in this Clause 3 are used both in IEC/IEEE 62395-1 and IEC/IEEE 62395-2.

3.1

ambient temperature

temperature surrounding the object under consideration

Note 1 to entry: Where trace heaters or surface heaters are enclosed in thermal insulation, the ambient temperature is the temperature exterior to such thermal insulation.

3.1.1

maximum ambient temperature

highest specified ambient temperature

3.1.2

minimum ambient temperature

lowest specified ambient temperature

Note 1 to entry: Heat-loss calculations in IEC 62395-2 are based on the minimum ambient temperature.

3.2

branch circuit

portion of the wiring installation between the overcurrent device protecting the circuit and the trace heater(s) or surface heater(s)

3.3

cold lead

electrically insulated conductor or conductors used to connect a trace heater or surface heater to the branch circuit and designed so that it does not produce significant heat

**3.4
connection**

termination or splice used to attach trace heaters or surface heaters to power wiring or to connect sections of these devices

**3.5
dead-leg**

segment of process piping segregated from the normal flow pattern for the purpose of providing a heat loss reference

**3.6
design loading**

minimum power that meets the design requirements, in the specified adverse conditions (minimum ambient and maximum wind velocity), after voltage and resistance tolerances and appropriate safety factors have been considered

[SOURCE: IEC/IEEE 60079-30-1:2015, 3.6]

**3.7
electrically conductive covering**

metallic braid, metallic sheath, or alternative covering with sufficient conductivity so that, when bonded to ground, it will allow a ground fault protective device to operate under a fault condition

**3.8
end termination**

termination, which can be heat producing, applied to a trace heater at the end opposite to that where the power is supplied

**3.9
factory-fabricated unit**

trace heater unit or set or surface heater unit or set, including the necessary terminations and connections, assembled by the manufacturer

**3.10
field-assembled unit**

trace heaters or surface heaters supplied unterminated with terminating components to be assembled at the work site

**3.11
heat loss**

energy flow from a workpiece, pipe, vessel or equipment to its surroundings

**3.12
heat sink**

part that conducts and dissipates heat away from a workpiece

Note 1 to entry: Typical heat sinks are pipe shoes, pipe supports and items of large mass such as valve actuators or pump bodies.

**3.13
heat transfer aids**

thermally conductive materials, such as metallic foils or heat transfer compounds used to increase the heat-transfer efficiency from trace heaters or surface heaters to the workpiece

**3.14
heater pad**

surface heater, comprising series or parallel connected elements having sufficient flexibility to conform to the shape of the surface to be heated

3.15

heater panel

non-flexible surface heater, comprising series or parallel connected elements fabricated to conform to the general shape of the surface to be heated

3.16

heating device

trace heater or surface heater

3.17

heating device set

heating device assembled with the associated parts necessary to connect it to a source of electrical supply

3.18

integral component

component such as a heat shrink termination, a cold lead connection, a moulded end seal or a splice, which conforms to the general shape of the trace heater or surface heater and is exposed to the same environment as the trace heater or surface heater, which can be factory-fabricated or field-assembled, and which is not intended to be re-used in the event of a repair or modification

3.19

low risk of mechanical damage

installations and applications where only lower levels of impact and deformation are expected to occur

3.20

maximum continuous exposure temperature (trace heater de-energized)

highest allowable continuous temperature to which the trace heating system can be exposed as declared by the manufacturer

3.21

maximum intermittent exposure temperature

highest allowable intermittent temperature to which a trace heater can be exposed, as declared by the manufacturer

3.22

maximum maintain temperature

specified maximum workpiece or process temperature the trace heater can maintain as declared by the manufacture

3.23

maximum continuous operating temperature

specified maximum workpiece temperature, the trace heater, can operate continuously when energized as declared by the manufacturer

3.24

maintain temperature

specified temperature of a workpiece or process that the trace heaters shall be able to maintain

3.25

maximum sheath temperature

maximum temperature of the outermost continuous covering of the trace heater or surface heater

3.26

maximum withstand temperature

maximum continuous exposure temperature or the maximum intermittent exposure temperature (energized or de-energized) whichever is higher, as declared by the manufacturer

3.27

minimum installation temperature

minimum temperature at which the trace heating system can be handled and installed

3.28

MI trace heater

mineral insulated metal sheathed trace heater typically containing one or more heating conductors

3.29

operating voltage

actual voltage applied to the trace heater or surface heater when in service

3.30

outdoor exposure

exposure to outdoor conditions of ultraviolet light and moisture

3.31

overjacket

continuous layer of material applied over the trace heater or surface heater to provide mechanical or environmental protection

3.32

parallel trace heater

heating elements that are electrically connected in parallel, either continuously or in zones, so that the power output per lineal length is maintained, irrespective of any change in length for the continuous type or for any number of discrete zones

3.33

rated output

total power or the power per unit length or power per unit surface area of the trace heater or surface heater at rated voltage, temperature, and length or area

3.34

rated voltage

voltage assigned by the manufacturer to which operating and performance characteristics of trace heaters or surface heaters are referred

3.35

routine test

test that is carried out by the manufacturer of the trace heater or surface heater on all trace heaters or surface heaters during or after the production process

3.36

series trace heater

heating elements electrically connected in series with a single current path and with a specific resistance at a given temperature for a given length

3.37

sheath

uniform and continuous metallic or non-metallic covering enclosing components of the trace heater or surface heater to provide protection against influence from the surroundings (e.g., corrosion, moisture, abrasion, etc.)

Note 1 to entry: See overjacket (3.31).

3.38

sheath temperature

temperature of the outermost continuous covering (braid, sheath, or overjacket) that can be exposed to the surrounding environment

3.39

stabilized design

design method where the temperature of the trace heater or surface heater will, by design and use, stabilize below the limiting temperature, under the most unfavourable conditions, without the need for a protective system to limit the temperature

3.40

start-up current

current of a trace heater or surface heater following energization

3.41

surface heater

heater pad or heater panel

3.42

surface heater unit

surface heater suitably terminated in conformity with the manufacturer's instructions

3.43

system documentation

information provided by the trace heater manufacturer to allow satisfactory understanding, installation and safe use of the trace heating system

3.44

tee

electrical connection of trace heaters, in series or in parallel, to accommodate a branch or a branch circuit

3.45

temperature controller

device or combination of devices incorporating a means of sensing temperature and of controlling the energy supplied to the trace heater or surface heater

3.46

temperature sensor

device designed to respond to temperature providing an electrical signal or mechanical operation

3.47

thermal insulation

material having air- or gas-filled pockets, voids, or heat reflecting surfaces that, when properly applied, retards the transfer of heat

3.48

trace heater

device of linear geometry designed for the purpose of producing heat on the principle of electrical resistance

3.49

trace heater unit

trace heater suitably terminated in conformity with the manufacturer's instructions

3.50

trace heating

utilization of trace heaters or surface heaters as well as support components, designed for the purpose of producing heat through heating elements electrically connected in series or in parallel, used to maintain or raise temperatures of piping, tanks and other surfaces

3.51

type test

conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.52

weather barrier

material that, when installed on the outer surface of thermal insulation, protects the thermal insulation from water or other liquids, from physical damage caused by ice pellets, wind or mechanical abuse and from deterioration caused by solar radiation or atmospheric contamination

3.53

workpiece

object to which a trace heater or surface heater is applied

4 General requirements

4.1 General

Electrical resistance trace heating systems within the scope of this document shall be designed and constructed so as to help ensure electrical, thermal and mechanical durability and reliable performance such that, in normal use, they pose no danger to the user or the surroundings.

Trace heaters which are identified for use only in areas with a low risk of mechanical damage are subjected to a reduced load in the impact tests in 5.2.4 and 5.2.5 and a reduced force in the deformation test in 5.2.6 and shall be clearly marked as specified in Clause 7.

Trace heaters and surface heaters can be supplied with additional mechanical protection to meet the requirements of this document if they are supplied as an integral assembly (prefabricated) and shall be marked as required by Clause 7, item g).

Trace heating equipment intended for use in contact with potable water shall be constructed of materials that meet relevant toxicity requirements.

Trace heaters and surface heaters temperature ratings that are required to conduct the type test in this document, shall be stated and controlled by the trace heater manufacturer in their documentation and published in their literature. The trace heater manufacturer shall provide documentation of the specification of non-metallic materials on which the mechanical strength and the electrical insulation depend (between the heater and other conductive parts) which shall include identification of the material type.

4.2 Electrically conductive covering

Trace heaters and surface heaters shall be provided with an evenly distributed electrically conductive covering which shall cover at least 70 % of the surface. Surface heating units shall be constructed such that the electrically conductive covering shall be opposite the surface to be heated.

4.3 Electrical circuit protection requirements for branch circuits

The minimum requirements for trace heating systems are:

- a) a means of isolating all live conductors from the supply;
- b) over-current protection provided for each branch circuit;
- c) a means of protecting against earth-faults by disconnecting all live conductors.

The trace heater or surface heater branch circuit electrical protection shall be capable of interrupting earth faults, as well as short-circuit faults. An earth-fault protective device or a controller with earth-fault interruption capability shall be used. The preferred trip level is nominal 30 mA or 30 mA above any inherent capacitive leakage characteristic of the heater as specified by the trace heater or surface heater supplier. These devices are intended for use in conjunction with circuit overcurrent protection. Where conditions of maintenance and supervision help ensure that only qualified persons will service the installed systems and continued circuit operation is necessary for the safe operation of the equipment or processes, earth-fault detection without interruption is acceptable if alarmed in a manner assuring an acknowledged response.

4.4 Temperature requirements

4.4.1 General

A trace heating system shall be designed so that under all conditions that can reasonably be foreseen, the surface temperature of the trace heater or surface heater does not exceed its maximum withstand temperature or any maximum system temperature ratings. This shall be achieved by a stabilized design or controlled design. In the design process of a system, the temperatures that occur have to be considered. All components, for example terminals or glands used with the trace heaters, have to resist the adjacent temperatures.

4.4.2 Stabilized design

Stabilized design applications, in which the maximum surface temperature of the trace heater or surface heater is determined without thermostatic control, shall employ either the systems approach specified in 5.2.13.2 or the product approach specified in 5.2.13.3.

4.4.3 Controlled design

The surface temperature obtained through controlled design is based on energy limitation by temperature controllers or high temperature limiters. There are no additional requirements for temperature controllers and high temperature limiters beyond those of the general industrial standards.

NOTE Typical general industrial requirements for temperature controllers and high temperature limiters can be found in the following documents. It is not a requirement of this document that conformity to those standards be verified.

- a) IEC 61010-1, *Electrical Equipment for Measurement, Control, and Laboratory Use – Part 1: General requirements* [7];
- b) IEC 60730-2-9, *Automatic electrical controls – Part 2-9: Particular requirements for temperature sensing control* [8];
- c) UL 508, *Industrial Controls* [9];
- d) CSA C22.2 No. 14, *Industrial control equipment* [10];
- e) CSA C22.2 No. 24, *Temperature Indicating and Regulating Equipment* [11].

4.4.4 Controls and monitoring for fire sprinkler systems and safety showers

4.4.4.1 General

Temperature controllers and high temperature limiters for fire sprinkler systems and safety showers shall comply with 4.4.4.2 and 4.4.4.3.

Testing requirements for trace heaters and control systems for use with fire sprinkler systems are given in 5.6.

4.4.4.2 Control systems requirements

Temperature controllers and high temperature limiters for fire sprinkler systems and safety showers shall comply with the relevant parts of standards such as:

- a) Additional design requirements as specified in ISO 7240-2, *Fire Detection and Alarm Systems – Control and Indicating Equipment*;
- b) ANSI/UL 864, *Standard for Control Units and Accessories for Fire Alarm Systems – Control and Indicating Equipment*, which includes additional design requirements for software control and indicating equipment

4.4.4.3 Monitoring requirements

For safety showers, alarms are required to provide indication when ground fault circuit protection interrupts the circuit.

For fire sprinkler lines, the following are required:

Provisions for annunciating a local audible and visual alarm and providing a supervisory signal to a fire alarm system shall be provided for the following conditions depending upon the system design:

- a) earth/Ground fault;
- b) low sprinkler system temperature;
- c) high sprinkler system temperature;
- d) temperature sensor failure;
- e) primary controller failure;
- f) loss of continuity;
- g) loss on incoming supply voltage;
- h) any engagement of a secondary high temperature limiter, if provided.

5 Testing

5.1 Type tests – General

All trace heaters and surface heaters shall meet the requirements of the type tests given in 5.2. Trace heaters and surface heaters intended for applications described in Table 1 shall also meet the requirements specified in Table 2. The test samples needed for the type tests are summarized in Annex A.

Samples of trace heaters selected for testing shall be at least 3 m in length, unless otherwise specified.

Integral components shall be subjected to the same type test as the trace heater or surface heater unless otherwise noted.

System components, other than those identified as integral, shall be evaluated in accordance with standards relevant to their construction and use.

Tests shall be conducted at a room temperature between 10 °C and 40 °C unless otherwise specified.

Separate samples shall be used for each test unless otherwise specified. These shall be prepared in accordance with the manufacturer's recommendations.

Table 1 – Trace heater and surface heater types and related attributes

Trace heater type	Intended installations	Examples of installations	Required attributes
A	Insulated surfaces (including pipe)	Hot water lines Freeze protection Grease lines Fuel oil lines Pre-insulated pipe Below grade trace heating Sprinkler systems	Dielectric, thermal, mechanical, moisture exclusion, and performance characteristics verification Sprinkler system verification (if specified for use)
B	Outdoor exposed areas	Roof deicing Gutter and downspouts deicing Catch basins and drains Rail heating systems	Dielectric, thermal, mechanical, moisture exclusion, and performance characteristics verification Increased moisture resistance UV and condensation resistance Resistance to cutting Abrasion resistance Tension test Rail system tests (if specified for use)
C	Installations with embedded trace heating	Embedded snow melting Embedded frost heave protection Embedded floor warming Embedded energy storage systems Embedded door frames	Dielectric, thermal, mechanical, moisture exclusion, and performance characteristics verification Resistance to cutting Deformation test
D	Installations with trace heater inside conduit or piping	Embedded snow melting Embedded frost heave protection Embedded floor warming Embedded energy storage systems Embedded door frames Internal trace heating for freeze protection of potable water lines Enclosed drains and culverts	Dielectric, thermal, mechanical, moisture exclusion, and performance characteristics verification Increased moisture resistance (pressurized or non-pressurized) Pull-strength evaluation

Table 2 – Applicable tests for trace heaters, surface heaters, and integral components, by trace heater and surface heater type

Required test procedure	Subclause	Trace heater and surface heater type			
		Type A	Type B	Type C	Type D
Dielectric test	5.2.1	X	X	X	X
Electrical insulation resistance test	5.2.2	X	X	X	X
Flammability test	5.2.3	X	X	X	X
Room temperature impact test	5.2.4	X	X	X	X
Minimum temperature impact test	5.2.5	X	X	X	X
Deformation test	5.2.6	X	X	X	X
Cold bend test	5.2.7	X	X	X	X
Water resistance test	5.2.8	X	X	X	X
Integral components resistance to water test	5.2.9	X	X	X	X
Verification of rated output	5.2.10	X	X	X	X
Thermal stability of electrical insulating material	5.2.11	X	X	X	X
Thermal performance test	5.2.12	X	X	X	X
Maximum sheath temperature	5.2.13	X	X	X	X
Verification of start-up current	5.2.14	X	X	X	X
Verification of the electrical resistance of the electrically conductive covering	5.2.15	X	X	X	X
Test for heating device / heating device set glands - General	5.2.16	X	X	X	X
Connection integrity (integral components)	5.2.17	X	X	X	X
Verification of rated output – for outdoor exposed systems	5.3.1		X		
Determination of maximum sheath temperature – for outdoor exposed systems	5.3.2		X		
Increased moisture resistance test	5.3.3		X		
UV and condensation test	5.3.4		X		
Resistance to cutting test	5.3.5		X		
Abrasion test	5.3.6		X		
Tension test	5.3.7		X		
Rail system voltage spike test (if specified for rail heating)	5.3.8		X		
Rail system over-voltage test (if specified for rail heating)	5.3.9		X		
Verification of rated output – for embedded systems	5.4.1			X	
Determination of maximum sheath temperature – for embedded systems	5.4.2			X	
Resistance to cutting test	5.4.3			X	
Flammability test (exemption, if applicable)	5.4.4			X	
Verification of rated output – for systems internal to conduit and piping	5.5.1				X
Determination of maximum sheath temperature – for systems internal to conduit and piping	5.5.2				X

Required test procedure	Subclause	Trace heater and surface heater type			
		Type A	Type B	Type C	Type D
Increased moisture resistance test (for pressurized and non-pressurized systems)	5.5.3				X
Pull-strength test	5.5.4				X
Normal and abnormal operation test – for sprinkler systems (if applicable)	5.6.1	X			
Normal operation test – for sprinkler systems (if applicable)	5.6.2	X			
Abnormal operation test – for sprinkler systems (if applicable)	5.6.3	X			
Abnormal operation test without controller (if applicable)	5.6.4	X			

5.2 Type tests – All applications

5.2.1 Dielectric test

The dielectric test shall be performed on trace heaters or surface heaters in accordance with Table 3.

Table 3 – Test voltages for the dielectric test

Rated voltage U	Test voltage VAC. (RMS.)
< 30 VAC(RMS.)	500
< 60 VDC	500
≥ 30 VAC (RMS.)	$2U + 1\,000^1$
≥ 60 VDC	$\sqrt{2}U + 1\,000^1$
¹ For MI trace heaters, the required test voltage shall be reduced to $2U + 500$ for products rated at or over 30 VAC., or to $\sqrt{2}U + 500$ for products rated at or over 60 VDC.	

For single conductor series trace heaters or surface heaters the voltage shall be applied between the conductor and the metallic sheath, braid, screen or equivalent electrically conductive covering.

For multi-conductor series trace heaters or surface heaters the voltage shall be applied between the conductors connected together and the metallic sheath, braid, screen or equivalent electrically conductive covering, and also between each conductor in turn with the remaining conductor(s) connected together.

For parallel trace heaters or surface heaters the voltage shall be applied between the conductors connected together and the metallic sheath, braid, screen or equivalent electrically conductive covering.

Alternatively, the dielectric test can be conducted by submerging the trace heaters or surface heaters in tap water at room temperature (resistivity typically 500 $\Omega \cdot m$). The test voltage shall be applied between the heating conductors and the water.

The rate of rise shall be neither less than 100 V/s nor more than 200 V/s and maintained for 1 min at the specified test voltage without dielectric breakdown. The test voltage waveform shall be essentially sinusoidal, with a frequency of 45 Hz to 65 Hz.