UL 991

STANDARD FOR SAFETY

Tests for Safety-Related Controls Employing Solid-State Devices

UL Standard for Safety for Tests for Safety-Related Controls Employing Solid-State Devices, UL 991

Third Edition, Dated October 22, 2004

Summary of Topics

This revision of UL 991 dated December 27, 2024 includes the following changes in requirements:

– Clarification of requirements if no critical components are found in a failure mode and effects analysis: Figure 6.1, 6.3, and 23.4.

– Alternate test methods for the environmental stress tests: 11.1.1, 12.1, 13.1, 14.1.1, 15.1.1 – 15.1.4, 15.1.1A, 15.2.1A, 15.2.2A, 15.2.3A, 15.2.4A.

Text that has been changed in any manner or impacted by ULSE's electronic publishing system is marked with a vertical line in the margin.

The new and revised requirements are substantially in accordance with Proposal(s) on this subject dated February 16, 2024

No Text on This Page

UL 991

Standard for Tests for Safety-Related Controls Employing Solid-State Devices

First Edition – January, 1989
Second Edition – June, 1995

Third Edition

October 22, 2004

This UL Standard for Safety consists of the Third Edition including revisions through December 27, 2024.

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

The text included in paragraphs 11.2.1, 11.3.1, 11.4.1, 11.4.2, and 11.4.3 is based on material in Electromagnetic compatibility (EMC) – Part 4: Testing and measuring techniques – Section 11: Voltage dips, short interruptions and voltage variations immunity tests, IEC 61000-4-11, First edition copyright 1994-06. This material is used in this Standard with the consent of the IEC and the American National Standards Institute (ANSI). The IEC copyrighted material has been reproduced with permission from ANSI. ANSI should be contacted regarding the reproduction of any portion of the IEC material. Copies of the IEC Publication 61000-4-11 may be purchased from ANSI, 11 West 42nd Street, New York, New York, 10036, (212)642-4900.

No Text on This Page

CONTENTS

INTRODUCTION

INVESTIGATION

ENVIRONMENTAL STRESS TESTS

COMPUTATIONAL INVESTIGATION AND DEMONSTRATED METHOD

POWER CYCLING TESTS

FOLLOW-UP PROGRAM

RATING

MARKING

SUPPLEMENT SA – FOLLOW-UP PROGRAM

INTRODUCTION

INTRODUCTION

1 Scope

1.1 These requirements apply to controls that employ solid-state devices and are intended for specified safety-related protective functions.

1.2 These requirements address the potential risks unique to the electronic nature of a control. Equipment or components employing an electronic feature shall also comply with the basic construction and performance requirements contained in the applicable end-product or component standard. These requirements are intended to supplement applicable end-product or component standards and are not intended to serve as the sole basis for investigating the risks of fire, electric shock, or injury to persons associated with a control.

1.3 These requirements do not cover controls covered by end-product standards in which an electronic control investigation is specified.

1.4 Sections 9 – 22 contain standardized test methods for investigating the performance of an electronic control when subjected to particular environmental stresses. The suitability of each test to a given control shall be determined by the end-product standard(s). Determination shall include an assessment of:

a) Whether the control will be exposed to a particular environmental stress in its application, and

b) Whether the response of the control to a particular environmental stress is relevant to its intended safety-related protective function in its application.

2 Components

2.1 Except as noted in 2.2, a component of a product covered by this standard shall comply with the requirements for that component.

2.2 A component is not required to comply with a specific requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product covered by this standard, or

b) Is superseded by a requirement in this standard.

2.3 A component shall be used in accordance with its rating established for the intended conditions of use.

2.4 Specific components are incomplete in construction features or restricted in performance capabilities. Such components are intended for use only under limited conditions, such as certain temperatures not exceeding specified limits, and shall be used only under those specific conditions.

3 Units of Measurement

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

3.2 In addition to being stated in the inch/pound units that are customary in the USA, each of the requirements in this standard is also stated in units that make the requirement conveniently usable in countries employing the various metric systems (practical SI and customary).

4 Undated References

4.1 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.

5 Glossary

5.1 For the purpose of this standard, the following definitions apply.

5.2 CONTROL – For the purpose of this standard, a control shall be considered a complete control, a subassembly, a circuit, or an individual component.

5.3 CRITICAL CIRCUIT – A circuit that performs one or more safety related functions and has been identified as critical in accordance with General, Section 6, and Failure Mode and Effect Analysis, Section 7.

5.4 CRITICAL COMPONENT – A component that performs one or more safety-related functions and that has been identified as critical in accordance with General, Section 6, and Failure Mode and Effect Analysis, Section 7.

5.5 CRITICAL FAILURE – A failure of a component or circuit that results in a condition, such as the risk of fire, electric shock, or injury to persons, in the end product application.

5.6 CRITICAL FUNCTION – The failure of a specific action of a control that results in a condition, such as the risk of fire, electric shock, or injury to persons in the end product application.

5.7 DECADE – 3.32 octaves.

5.8 DISTINCTIVE AUDIBLE SIGNAL – A signal obtained from various devices such as bells, horns, sirens, and buzzers, or a variance in the nature of the signal such as a continuous signal obtained under one condition and a pulsing signal under another.

5.9 ELECTROMAGNETIC INTERFERENCE (EMI) – The impairment of a desired electromagnetic signal by an electromagnetic disturbance.

5.10 ELECTROMAGNETIC SUSCEPTIBILITY – The characteristic of electronic equipment that results in undesirable responses when subjected to an electromagnetic disturbance.

5.11 OCTAVE – A range of signals having a frequency ratio of 2:1.

5.12 SUPERVISION – The monitoring of a circuit so that a fault condition will result in a trouble indication or other acceptable action.

5.13 TEST ACCELERATION FACTOR – A number, that varies with the test temperature, chosen to conduct the Demonstrated Method, Section 25. It is used to calculate the required test unit-hours.

5.14 TEST UNIT-HOURS – The mathematical product of the number of samples under test and the time of the test.

5.15 TROUBLE INDICATION – A visible or audible signal intended to indicate a fault or trouble condition, such as an open or shorted condition of a component in the device or an open or ground in the connected wiring.

5.16 USAGE LEVEL – The range of hours per year that a control is expected to be subjected to electrical or thermal stress or a combination of electrical and thermal stresses.

INVESTIGATION

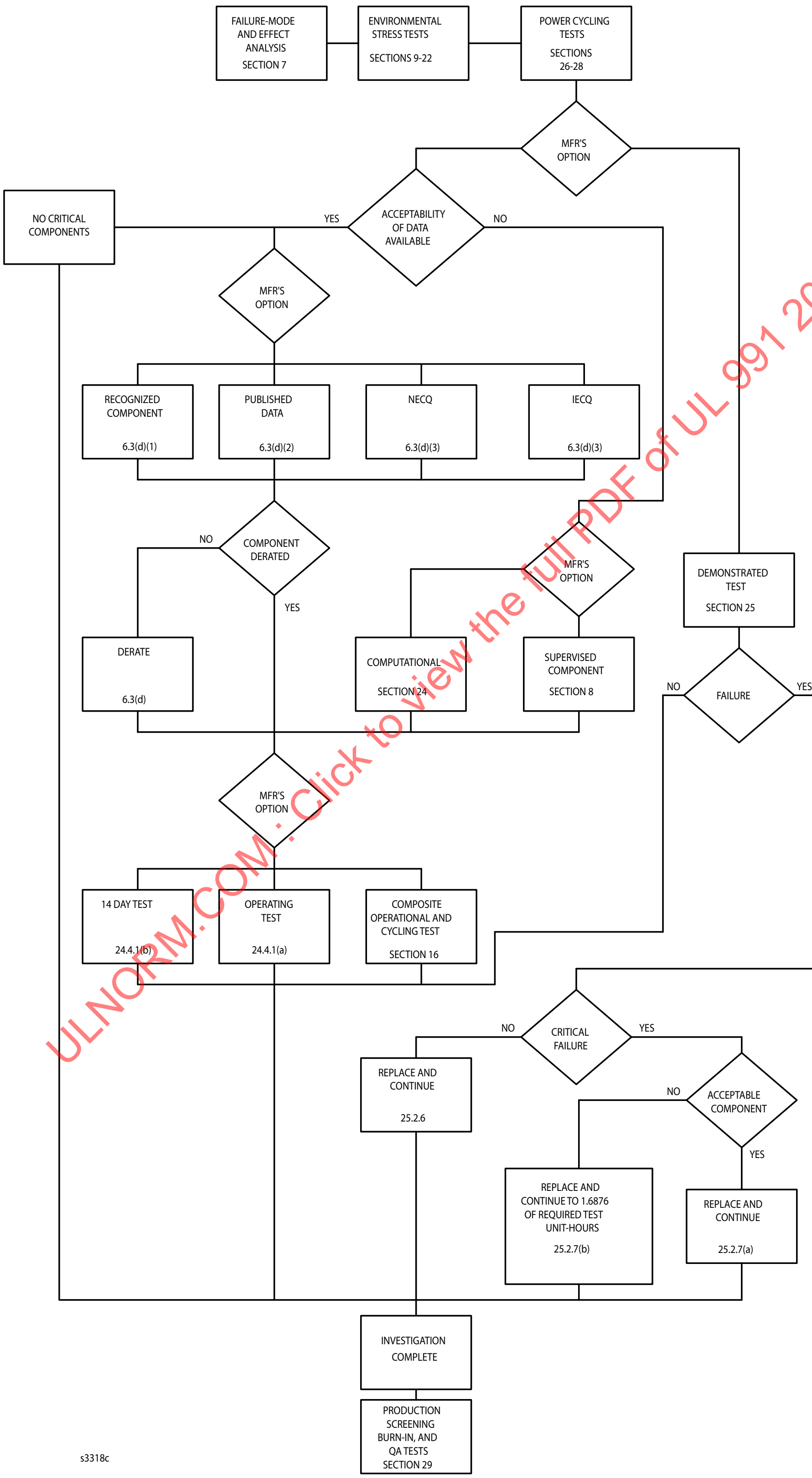
6 General

6.1 A description of the operation and safety features of the control with respect to the controlled element shall be provided by the manufacturer and shall be used as a guide in the examination and test of the device. For example, the operation of an electronic temperature limiting control might be in an inactive state in a certain temperature range but is intended to disconnect the load from the electrical supply at a higher predetermined temperature.

6.2 A control designed for a specified safety-related protective function shall be investigated in accordance with a four part program consisting of environmental stress tests, power cycling tests, investigation of critical components, and production-line tests. The investigation of controls shall be based on Figure 6.1.

Figure 6.1

Investigation flowchart



6.3 The investigation of critical components for controls containing critical devices or components shall include one of the following:

a) Demonstrated method, Section 25;

b) Computational investigation, Section 24;

c) Electrical supervision, Section 8; or

d) Derating in accordance with the Electronic Reliability Design Handbook, Military Handbook Number 338 and has a rating derived from a test program; and

1) The component is recognized under a program in which the manufacturer of the control conducts in-coming inspections, screening, quality assurance, and burn-in tests;

2) The test data is available on the component in widely accepted, documented publications and the component complies with screening test requirements; or

3) The component has received qualification approval under the International Electrotechnical Commission Quality Assessment System for Electronic Components (IECQ) or the National Electronic Components Quality Certification System (NECQC) program.

Exception: Investigation of critical components is not required if the Failure-Mode and Effects Analysis (FMEA) of Section 7 does not identify any critical components.

NOTE: Some end-product standards (e.g., UL 2271) do not permit any critical components.

6.4 A failure-mode and effect analysis (FMEA) in accordance with Failure-Mode and Effect Analysis (FMEA), Section 7 is required to identify critical components.

6.5 The failure of a solid-state device or an electronic component (such as due to an open or short circuit within a component) during operation of a control shall result in one or more of the following conditions:

a) No loss of declared protective function as a result of control shutdown or on the intended operation.

b) For attended products, activation of a trouble indication considered as acceptable in the end-product standard.

c) Shutdown in a manner that complies with the end-product application if the protective function has been negated.

6.6 If a failure results in a condition other than as specified in 6.5, the device or component shall be considered critical.

7 Failure-Mode and Effect Analysis (FMEA)

7.1 A fault analysis and failure mode chart of all components shall be prepared in accordance with Table 7.1. For this purpose, all active terminals of a multi-pin device shall be considered input, output, power supply, or ground.

Table 7.1
Circuit identification

Part name[a]	Mfgr[b]	Cat. No.[b]	Ratings[b]	Schematic reference[c]	Function[d]	Failure mode[e]	Failure effect[f]	Critical or non-critical[g]

[a] Each electronic component in the control to be investigated is to be included.

[b] This information is to be supplied for each critical component.

[c] Each component is to be identified as R1, C1, or an equivalent component identification.

[d] The function of each component is to be described.

[e] The effects of open and short faults are to be evaluated for each component. The following are alternatives to shorting all combinations of terminals on multiple pin components, such as integrated circuits.

1) Short each pair of adjacent pins.

2) Short each input pin to (referenced) ground.

3) Short each output pin to (referenced) ground.

4) Short each input pin to the power supply.

5) Short each output pin to the power supply.

A circuit analysis made to assess the performance of individual components under a fault condition rather than actually creating the fault to determine its effect also meets the intent of the requirements.

[f] The effect resulting from the failure on the control and also on the end use product is to be stated.

[g] The failure effect is to be identified as within the intent of General, Section 6.

8 Electrical Supervision

8.1 If permitted by the end-product standard, a circuit element may be electrically supervised so that a failure such as an open, short, or other fault involving a critical function will result in a trouble indication considered to be acceptable in the end-product standard.

8.2 A supervisory circuit is considered a critical circuit and shall comply with the applicable requirements. Supervision of a supervisory circuit is not required.

8.3 To determine if the element is acceptably supervised, the control is to be energized and operated in its intended manner, and various fault conditions are to be introduced. Each fault is to be applied separately, the response of the supervisory circuit noted, the fault removed, and the control restored to its normal operating condition prior to establishing the next fault. The introduction of the fault is to be done for each normal operating mode.

8.4 Each introduction of a fault is to result in a distinctive audible signal or other action designated as acceptable in the end-product standard.

8.5 A manual means for silencing the audible signal may be provided only if a visible trouble indicator remains activated or is simultaneously activated when the signal is silenced. Automatic silencing of the audible signal is not permitted.

8.6 When the fault is cleared, the alarm is to either give an audible signal when left in the silenced position or automatically become enabled to respond to new faults.

8.7 Disconnecting and then reconnecting the power supply to the control shall not disable a trouble indicator if a fault condition still exists.

ENVIRONMENTAL STRESS TESTS

9 General

9.1 Production samples shall perform acceptably when subjected to the applicable tests specified in Table 9.1.

Exception: Prototype samples may be tested if they are entirely representative of future production.

Table 9.1
Environmental stress tests

Tests	Section
Overvoltage and undervoltage	10
Power supply interruption	11
Transient overvoltage	12
Ramp voltage	13
Electromagnetic susceptibility	14
Electrostatic discharge	15
Composite operational and cycling test	16
Test for effects of shipping and storage	17
Thermal cycling	18
Humidity	19
Dust	20
Vibration	21
Jarring	22

9.2 The tests specified in Table 9.1 are intended to determine the ability of an electronic control to perform its intended protective function after exposure to a series of environmental stresses. Compliance is determined by having the control perform its intended function both before and after such exposures.

9.3 Unless otherwise specified, the various tests are to be performed at rated frequency and at the voltage specified in Table 9.2 with the control installed as intended in the end-product.

Table 9.2
Tests voltages

Voltage rating of control, V[a,b]	Test potential, V
110 – 120	120
220 – 240	240
254 – 277	277
440 – 480	480
550 – 600	600

Table 9.2 Continued on Next Page

Table 9.2 Continued

Voltage rating of control, V[a,b]	Test potential, V
[a] When a single voltage rating of a control does not fall within any of the indicated voltage ranges, the control is to be tested at its rated voltage. When a range of voltages is specified and one or more of the values fall within one of the indicated voltage ranges, the control is to be tested at the test potential specified for the indicated range or the highest value of the rating, whichever is greater. When a range of voltages is specified and none of the values fall within any of the indicated voltage ranges, the control is to be tested at the highest value in the specified range. For a control with a dual rating, the control is to be tested based on both ratings unless it is determined that testing based on one rating represents testing based on the other rating. [b] When the control operation changes due to varying the input voltage within the rated range, a test is to be performed at both the high and low values of the rated voltage range. For a control with a single voltage rating, when its operation changes as a result of testing at the test potential specified in Table 9.2, a test is to be performed at the voltage rating of the control.	

9.4 During the environmental stress and demonstrated tests, a control shall operate at least once in each of its functions unless otherwise specified, and the effects on the control function are to be monitored by lights, specified rated loads, or other acceptable means that indicate intended operation.

9.5 A temperature is constant when three successive readings, measured by thermocouples and taken at intervals of 10 percent of the previously elapsed duration of the test, and not less than 5 min intervals, indicate no change.

10 Overvoltage and Undervoltage Tests

10.1 A control shall operate as intended during continuous application of:

a) 110 percent of the test potential specified in Table 9.2, and

b) The undervoltage as specified in 10.2,

until temperatures have become constant or for 7 h, whichever occurs first. When an operating voltage range is specified, the overvoltage is to be either 110 percent of the test voltage specified in Table 9.2 or the upper limit of the specified range, whichever is higher.

Exception: A control that complies with the Composite Operational and Cycling Test, Section 16, is not required to be subjected to this test.

10.2 A control is then to be energized from a source of supply in accordance with Table 9.2 until constant temperatures are attained. The voltage is then to be reduced to 85 percent of the original test voltage or 85 percent of the lower limit of the range.

Exception: A control that complies with the Composite Operational and Cycling Test, Section 16, is not required to be subjected to this test.

11 Power Supply Voltage Dips and Short Interruption Test

11.1 General

11.1.1 The protective function of a control shall not be adversely affected or the control shall shut down without loss of protective function after being subjected to the tests described in one of the following:

a) 11.2 – 11.4, or

b) The Voltage Dips and Short Interruptions Test in IEC 61000-4-11. Unless otherwise specified in the end-product standard, Class 3 shall be used.

The control shall be mounted, connected, and operating as intended in the application. Before each successive set of tests, the control shall be operated as intended with no loss of protective function.

11.2 Test voltage levels

11.2.1 The test voltage levels and durations for the tests in 11.3 – 11.4 are given in Table 11.1. A test voltage level of 0 percent of the rated voltage (V_R) corresponds to a total supply voltage interruption. In practice, a test voltage level from 0 percent V_R to 20 percent V_R is evaluated as a total interruption.

Table 11.1
Test values for voltage dips and interruptions

Test	ΔV	Duration, s
Voltage Dips	30 percent	0.5
	60 percent	0.5
Voltage Interruptions[a]	100 percent	1 cycle of supply wave form
		0.5
		60.0

[a] In the event intermediate durations of voltage interruption affect either the inherent safety of the control or the output of a safety control, end-use standards shall indicate voltage interruptions at other points in the interval such as 1 cycle and 1, 5, 10, 25, 50, and 60 s.

11.3 Test Conditions

11.3.1 The test shall be conducted in the following climatic conditions:

a) Temperature: 15°C (59°F) – 35°C (95°F)

b) Relative Humidity: 25 percent – 75 percent

c) Barometric Pressure: 86 kPa – 106 kPa (25.4 in of Hg – 31.3 in of Hg)

Exception: Other climatic conditions are able to be specified in the end-use standard.

11.4 Test procedure

11.4.1 The test shall be conducted with the control connected to the test generator with the shortest possible length of the power supply cable or wiring required for the application of the control.

11.4.2 The control shall be tested for each combination of test voltage and duration specified in Table 11.1 with intervals not less than 10 seconds between each test and the resulting event, such as the operation or function of a control. Each representative mode of operation shall be tested. This test is able to be performed on one or more samples, as required.

11.4.3 Interruptions in power supply voltage shall occur at zero crossings of the power supply voltage, and at additional angles determined to be critical, preferably specified from 45, 90, 135, 180, 225, 270, and 315 degrees on each phase.

12 Transient Overvoltage Test

12.1 The protective function of a control shall not be adversely affected or the control shall shut down without loss of protective function after being subjected to the tests described in one of the following:

a) 12.2 – 12.8, or

b) IEC 61000-4-5 and IEC 61000-4-12. Unless otherwise specified in the end-product standard, Test Level 3 shall be used.

12.2 The control is to be connected to a transient generator, capable of producing the impulse waveshapes shown in Figure 12.1 and Figure 12.2. Typical transient generator circuits are shown in Figure 12.3 and Figure 12.4; other test circuits that produce the required waveshape may also be used.

Figure 12.1

100 kHz ring wave

(open circuit voltage)

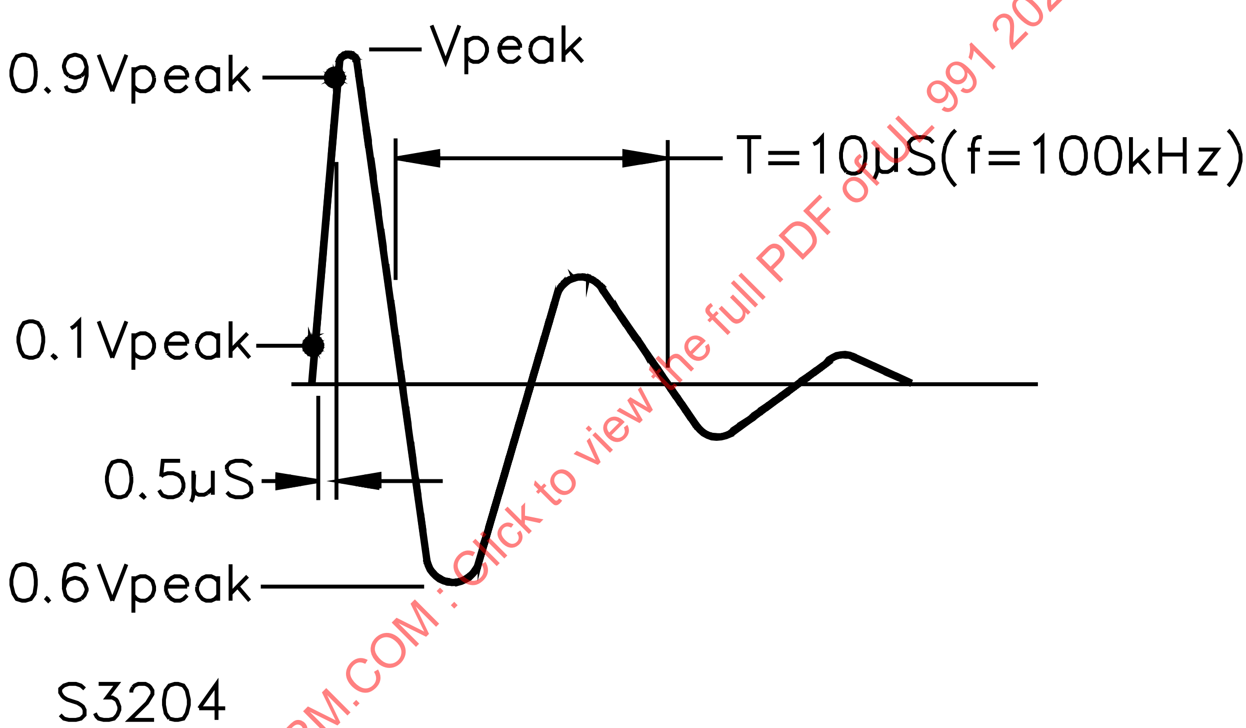
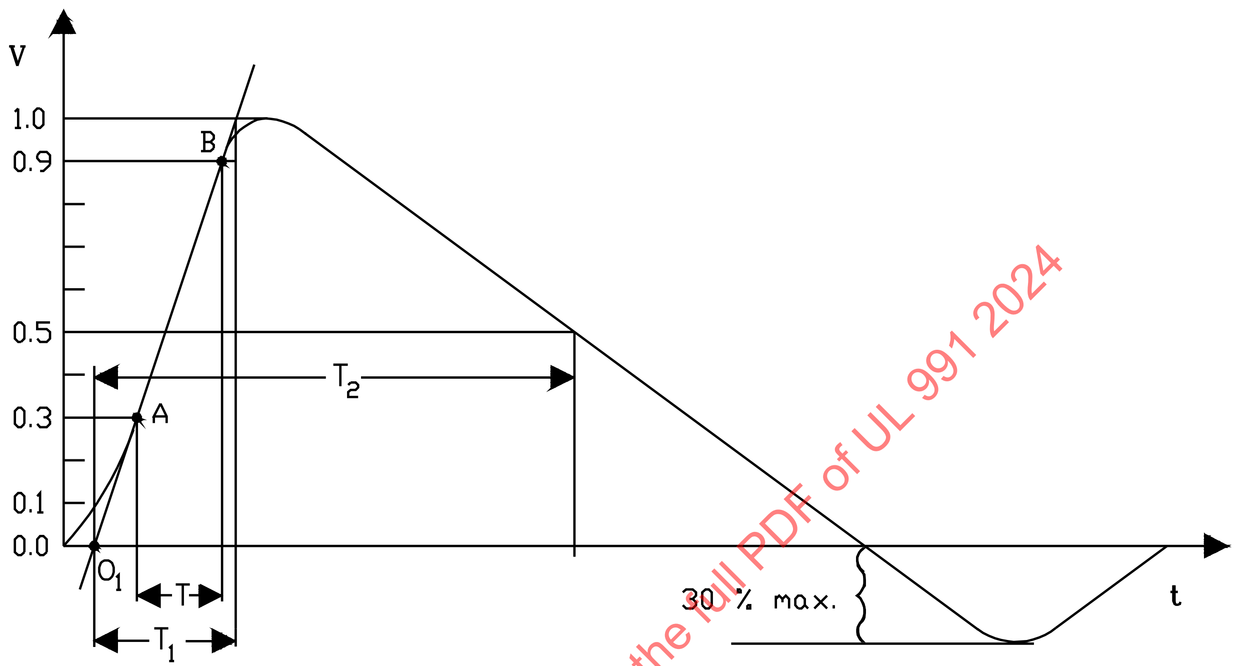


Figure 12.2

Impulse waves

(Open-circuited generator voltage wave (1.2/50 µs))



SM1 1 71 A

NOTES

1 Front time: T_1 = 1.67 × T = 1.2 µs ±30 percent

2 Time to half value: T_2 = 50 µs ±20 percent

3 Line AB is the virtual rise time line formed with points A and B

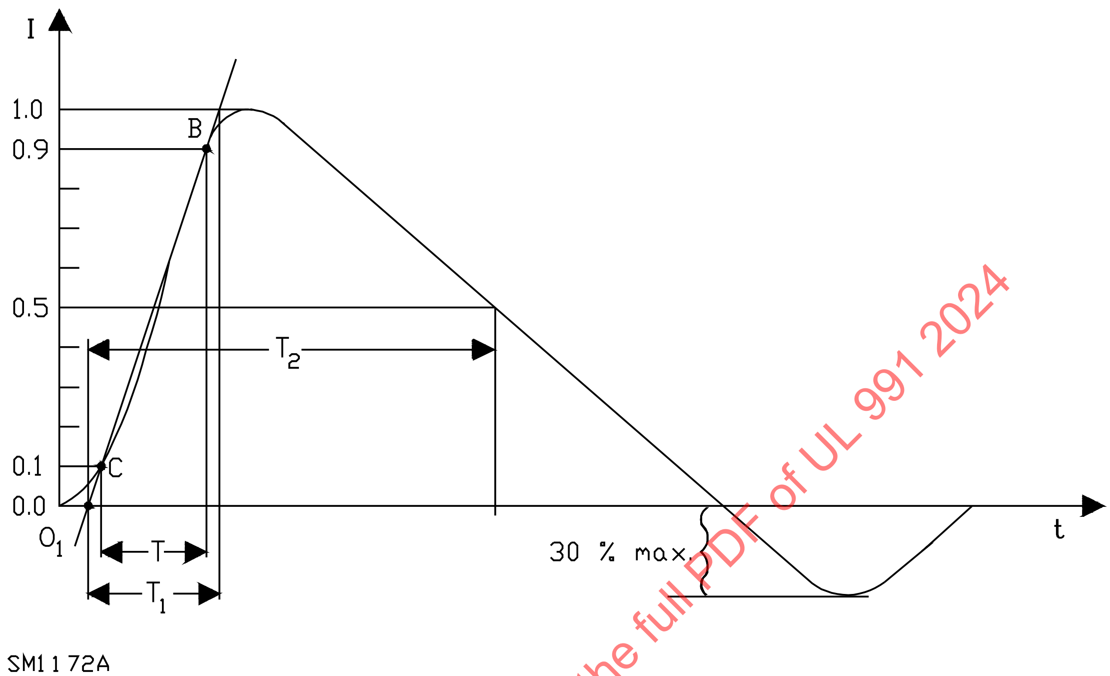
4 A is the point on line AB at 30 percent of the peak value

5 B is the point on line AB at 90 percent of the peak value

6 0_1 is the virtual origin point

Figure 12.2 (Cont'd)

Impulse waves
(Short-circuited generator current wave (8/20 μs))



NOTES

1 Front time: T_1 = 1.25 × T = 8 μs ±20 percent

2 Time to half value: T_2 = 20 μs ±20 percent

3 Line CB is the virtual rise time line formed with points C and B

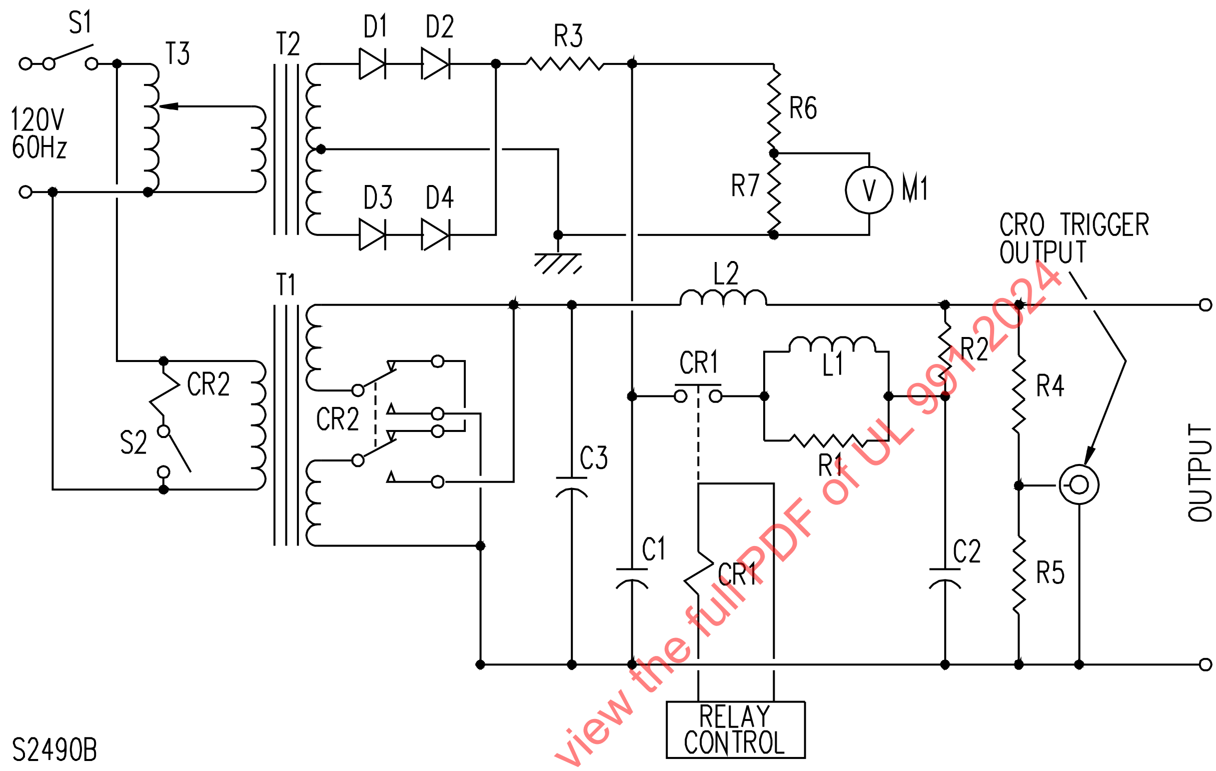
4 C is the point on line BC at 10 percent of the peak value

5 B is the point on line BC at 90 percent of the peak value

6 0_1 is the virtual origin point

Figure 12.3

Surge generator circuit
(Ring Wave)



C1 – Capacitor, 0.025 µf, 10 kV

C2 – Capacitor, 0.006 µf, 10 kV

C3 – Capacitor, 10 µf, 400 V

CR1 – Relay, coil 24 V, dc. Contacts, 3-pole, single throw, each contact rated 25 A, 600 V, ac maximum: All three poles wired in series

CR2 – Relay, coil 120 V, ac. Contacts DPDT. Provides either 120 V or 240 V test circuit.

D1 – D4 – Diodes, 25 kV PIV each

L1 – Inductor, 15 µH [33 turns, 22 AWG wire, wound on 0.835 in (21.2 mm) diameter PVC tubing]

L2 – Inductor, 70 µH [45 turns, 14 AWG wire, wound on 2.375 in (60.33 mm) diameter PVC tubing]

M1 – Meter, 0 – 20 V, dc

R1 – Resistor, 22 Ω, 1 W, composition

R2 – Resistor, 12 Ω, 1 W, composition

R3 – Resistor, 1.3 MΩ (12 in series, 110 kΩ each, 1/2 W)

R4 – Resistor, 47 kΩ (10 in series, 4.7 kΩ each, 1/2 W)

R5 – Resistor, 470 Ω, 1/2 W

R6 – Resistor, 200 MΩ, 2 W, 10 kV

R7 – Resistor, 0.2 MΩ (2 in series, 100 kΩ each, 2 W, carbon)

S1 – Switch, SPST

S2 – Switch, SPST, key-operated, 120 V, ac, 1 A

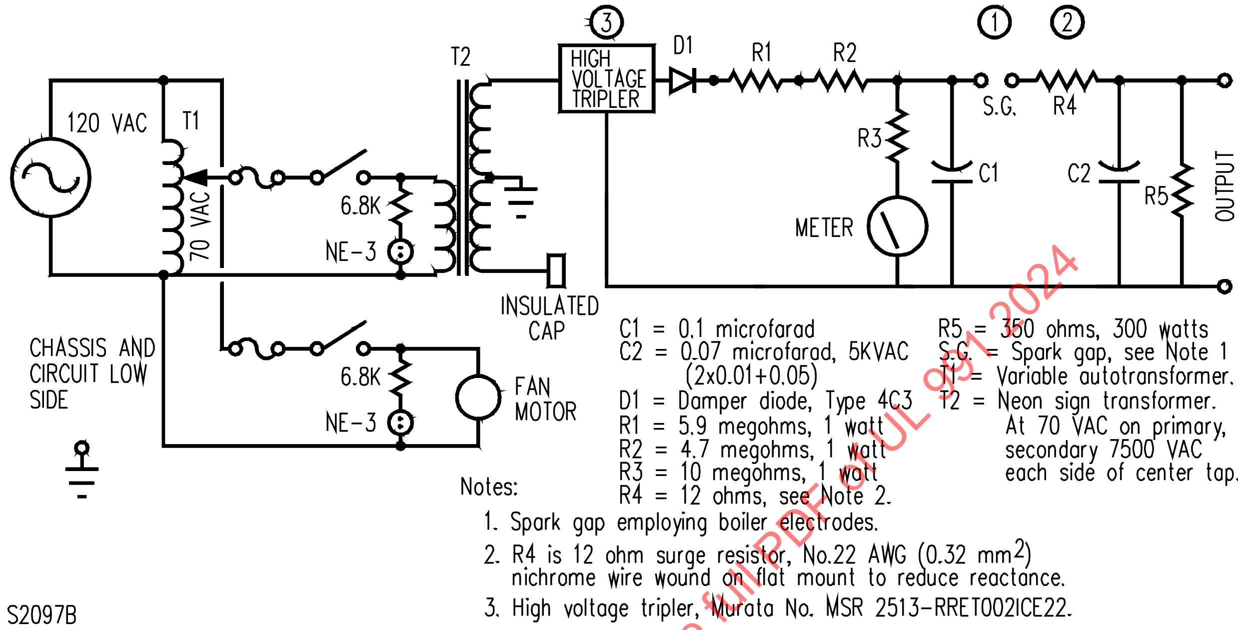
T1 – Transformer, 2 kVA, 120 V primary, 1:1 (120 V or 240 V output)

T2 – Transformer, 90 VA, 120/15,000 V

T3 – Variable autotransformer, 2.5 A

Figure 12.4

Surge generator circuit (Impulse Wave)



12.3 The control is to be connected to a supply circuit of the voltage specified in Table 9.2. A transient generator, which is isolated from the power supply circuit by an acceptable impedance (filter), shall be connected to the control so as to apply impulses in each of the following modes:

a) Each line separately to ground,

b) All lines simultaneously to ground, and

c) Line to line.

12.4 The impulse is to be introduced in both positive and negative polarities and at specified angles of the power supply wave.

12.5 Positive polarity impulses are to be introduced at 45-, 90-, and 270-degree angles of the power supply wave and negative polarity impulses at 90-, 225-, and 270-degree angles. The impulse polarity and angle of application are to be proportioned evenly among the required total number of impulses. See Table 12.1.

Table 12.1
Impulse distribution

Impulse type[a]	No. of impulses	Impulse, polarity	Angle of supply wavedegrees
1.2 × 50 µs	2	Positive	45
1.2 × 50 µs	2	Positive	90
1.2 × 50 µs	2	Positive	270
1.2 × 50 µs	2	Negative	90
1.2 × 50 µs	2	Negative	225
1.2 × 50 µs	2	Negative	270
0.5 µs × 100 kHz	20	Positive	45
0.5 µs × 100 kHz	20	Positive	90
0.5 µs × 100 kHz	20	Positive	270
0.5 µs × 100 kHz	20	Negative	90
0.5 µs × 100 kHz	20	Negative	225
0.5 µs × 100 kHz	20	Negative	270

[a] The 0.8 × 20 µs current waveform shown in Part B of Figure 12.2 is characteristic of low-impedance loads in contrast to the 1.2 × 50 µs voltage waveform in Part A of Figure 12.2 which is characteristic of high-impedance loads. See 12.8 for the peak open circuit voltage and maximum short-circuit current for the respective waveforms.

12.6 A single sample shall be subjected to all required impulses in each connection mode when testing with the ring wave impulse shown in Figure 12.1. At the manufacturer's option, multiple samples may be used to complete the testing with the impulse wave shown in Figure 12.2.

12.7 Each connection mode shall be subjected to the type and number of impulses of the polarity and at the supply wave angle shown in Table 12.1. The interval between impulses is not to be less than 10 s. Each impulse is to be at a polarity opposite that of the previous impulse.

12.8 The peak open-circuit voltage of the impulse wave shall be 6 kV. The short-circuit current of the 100 kHz ring waveshape shown in Figure 12.1 and the impulse wave shown in Figure 12.2 shall be 500 A and 3 kA respectively.

Exception: If overvoltages are controlled by means of limiting devices, such as transient voltage suppressors, known installed impedances and clearances, or other means acceptable in the end-product standard, the peak voltage of the impulse wave is to be determined by the rated voltage and installation category of the control. See the International Electrotechnical Commission (IEC) publication, Insulation Coordination for Equipment Within Low-Voltage Systems; Part 1: Principles, Requirements and Tests, IEC 60664-1, for specific details of impulse voltages (Table I) and installation categories. See also Table 12.2 of this standard.

Table 12.2
Preferred series of values of impulse voltages for rated voltages based on controlled overvoltages

Voltages phase-to-earth derived from rated system including V rms and dc	Preferred series of impulse voltages in peak volts for installation category[a]		
	I	II	III
50	330	500	800
100	500	800	1500

Table 12.2 Continued on Next Page

Table 12.2 Continued

Voltages phase-to-earth derived from rated system including V rms and dc	Preferred series of impulse voltages in peak volts for installation category[a]		
	I	II	III
150	800	1500	2500
300	1500	2500	4000
600	2500	4000	6000

[a] Refer to the Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment, IEC 60664 for information on installation categories.

13 Voltage Variation Test

13.1 General

13.1.1 The protective function of the control shall not be adversely affected or the control shall shut down without loss of protective function after being subjected to the tests described in one of the following:

a) 13.2.1 – 13.2.2, or

b) The Voltage Variations test in IEC 61000-4-11.

13.2 Test duration and procedure

13.2.1 The duration of the voltage changes and the time for which the reduced voltages are to be maintained are given in Table 13.1 and illustrated in Figure 13.1. The rate of change of voltage is to be constant; however, the voltage is able to be stepped. The steps shall be positioned at zero crossing, and shall be not larger than 10 percent of V_R. Steps under 1 percent of V_R are evaluated as constant rate of change of voltage.

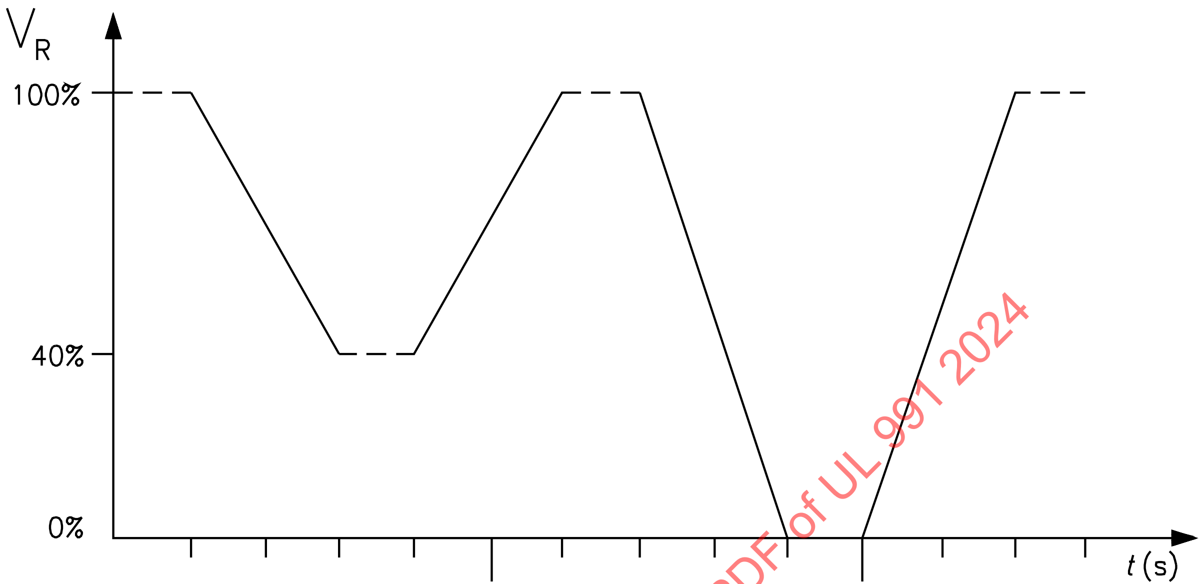
Table 13.1
Timing of short-term supply voltage variations

Voltage test level	Time for decreasing voltage	Time at reduced voltage	Time for increasing voltage
40 percent V_R	2 s ±20 percent	1 s ±20 percent	2 s ±20 percent
0 percent V_R	2 s ±20 percent	1 s ±20 percent	2 s ±20 percent
	x	x	x

NOTE – x represents an open set of durations and is able to be given in the end-use product standard.

Figure 13.1

Voltage Variation Test



NOTE – The voltage gradually decreases.

S4127A

13.2.2 The control is subjected to each of the specified voltage test cycles three times with 10-s intervals between each test cycle for the most representative modes of operation. Additional voltage test levels are able to be specified in the end-use standard.

14 Electromagnetic Susceptibility Tests

14.1 General

14.1.1 The control shall perform its intended function, or shut down without loss of protective function, when subjected to the tests described in one of the following:

a) 14.2 – 14.10, or

b) IEC 61000-4-4, IEC 61000-4-6, and IEC 61000-4-3. Unless otherwise specified in the end-product standard, the following shall be used:

1) For IEC 61000-4-4 and IEC 61000-4-6, Test Level 3.

2) For IEC 61000-4-3, Test Level 3 from 80 MHz to 1 GHz, and Test Level 2 from 1.4 GHz to 6.0 GHz.

14.2 Electrical fast transient/burst test

14.2.1 The following circuits of a control shall be subjected to the electrical fast transient/burst test as described in 14.2.2 – 14.6.1:

a) The low voltage input/output communication or signal circuits,

b) The power supply circuit at line and neutral, and

c) The equipment ground.

14.2.2 The control is to be mounted as intended and interwired as appropriate for the circuit being investigated. While the control is operating, the output of the electrical fast transient/burst generator shall be applied, one by one, to the wiring under test. See 14.5.1 and 14.6.1.

14.2.3 The connections to the circuit being investigated are to be made in accordance with Figure 14.1 and Figure 14.2, and the test sequence is to be in accordance with the following:

a) Connect all circuits as appropriate to their function.

b) Energize the control.

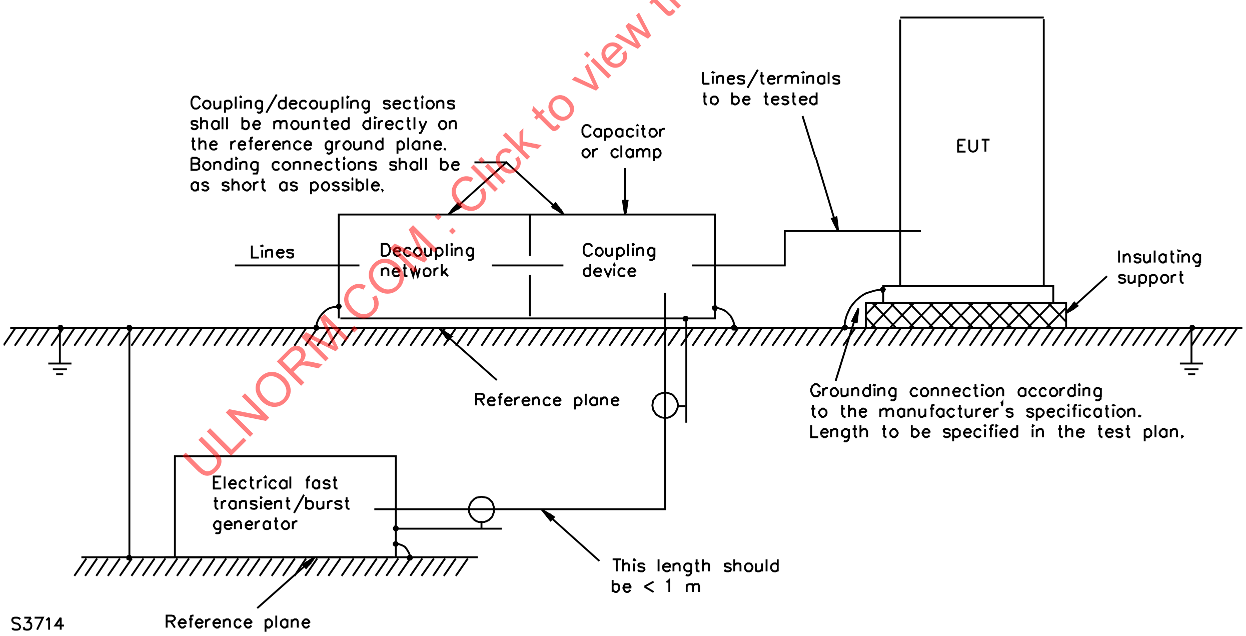
c) Energize the electrical fast transient/burst generator.

d) Exercise all functions of the control.

e) Repeat procedure for each circuit being investigated.

Figure 14.1

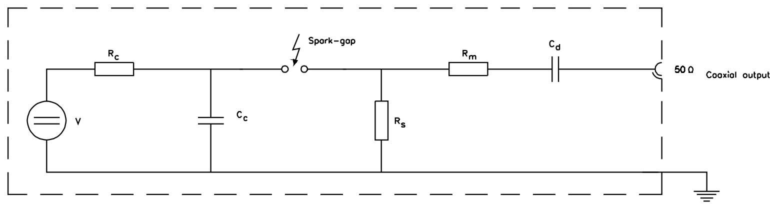
Test connections



NOTE – EUT is equipment under test, which may be a control by itself.

Figure 14.2

Electrical fast transient/burst generator – simplified circuit diagram



NOTES

1 V is the high-voltage source

2 R_c is the charging resistor

3 C_c is the energy storage capacitor

4 R_s is the pulse duration shaping resistor

5 R_m is the impedance matching resistor

6 C_d is the d-c blocking capacitor

CAUTION – THE VOLTAGES AND POWER AVAILABLE MAY BE DANGEROUS TO HUMAN LIFE. THE EQUIPMENT MUST BE HANDLED WITH CARE.

14.3 Electrical fast transient/burst generator

14.3.1 The electrical fast transient/burst generator shall have the following characteristics when calibrated with a 50-Ω load:

a) For a single pulse refer to Figure 14.3; and

b) A repetition rate of the impulses and peak values of the output voltage as specified in Table 14.1. The repetition period depends on the test peak output voltage level specified in Table 14.1. See Figure 14.4 for examples of the repetition period of individual pulses within a burst and a burst period between successive bursts.

Table 14.1
Impulses generated by the electrical fast transient/burst generator with a 50-Ω load

Repetition rate, kHz ±20 percent	Peak output voltage, kV
5	0.125
5	0.25
5	0.5
5	1.0
2.5	2.0

Figure 14.3

Generator single pulse waveform with 50-Ω load

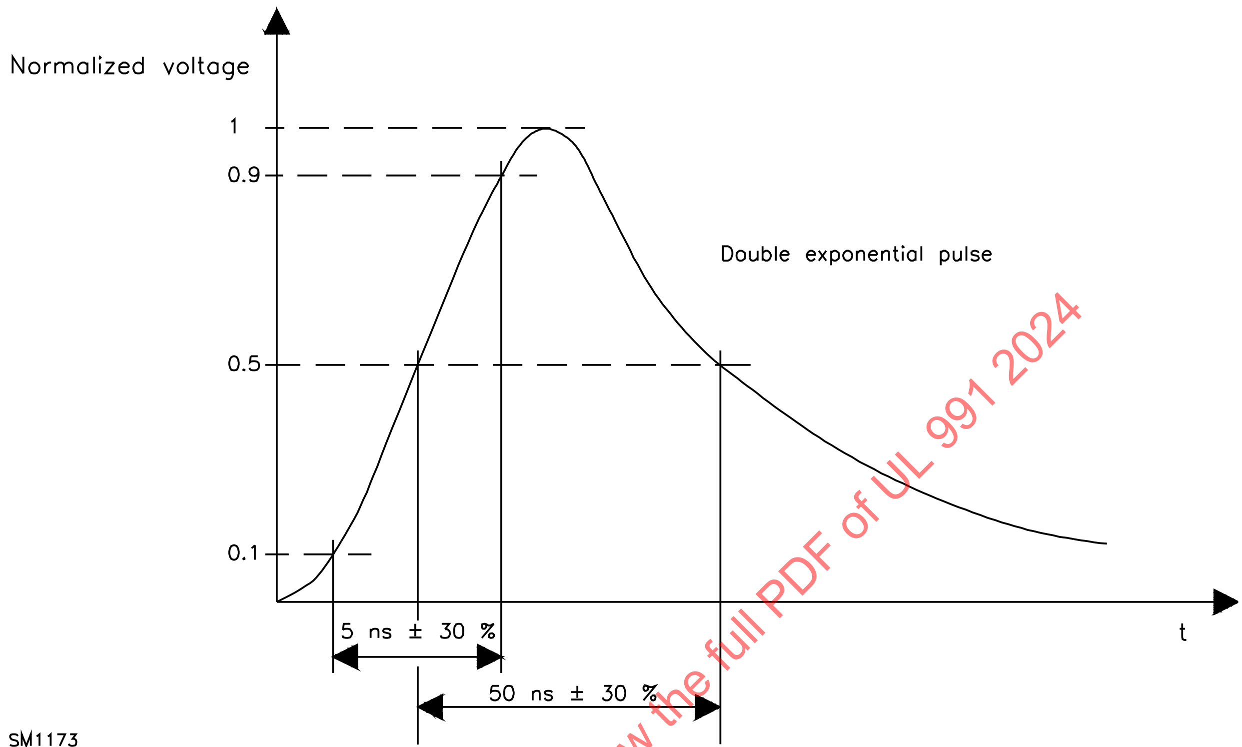
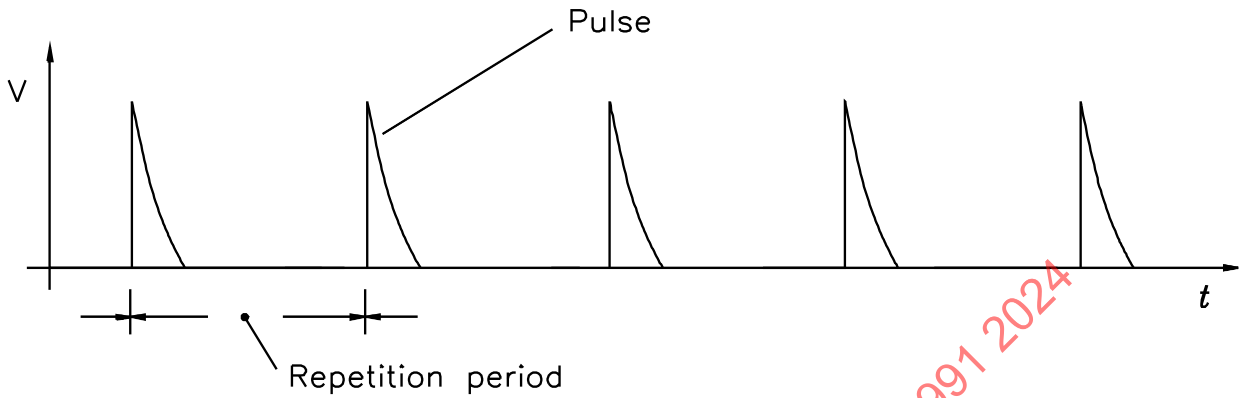


Figure 14.4

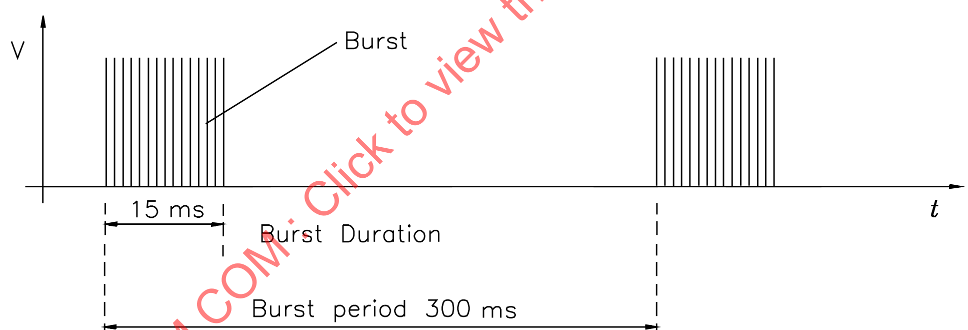
General graph of an electrical fast transient/burst

(Single pulses within a burst)



S3716

(Burst duration and burst period)



S3717

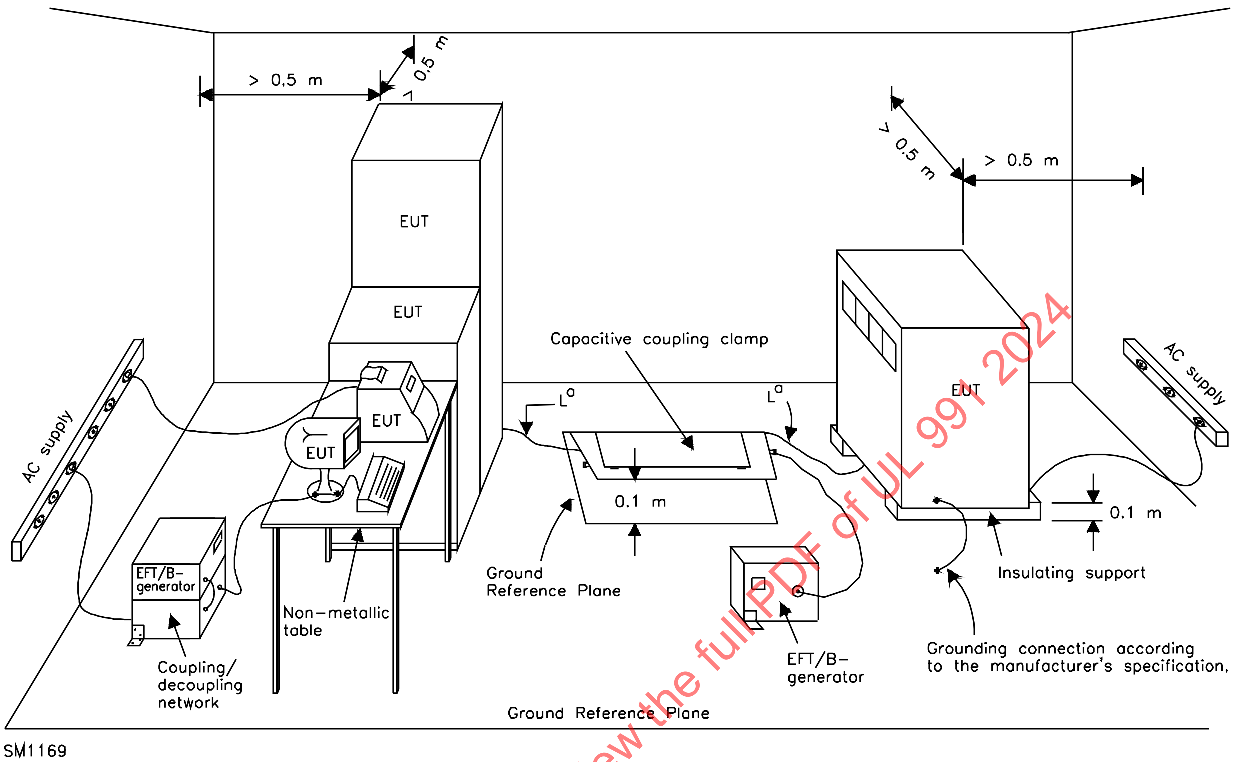
14.3.2 The electrical fast transient/burst test voltage is to be applied:

a) To the power supply and equipment grounding circuits of the control under test by direct coupling of the test voltage through a coupling/decoupling network. See Figure 14.5 for general test set-up;

b) To the low voltage input/output/signal, data, and control circuits of the control under test through a capacitive coupling clamp such that the test voltage is applied in a nonsymmetrical condition. See Figure 14.5 for general test set-up and Figure 14.6 for an example of a coupling clamp.

Figure 14.5

General test set-up



NOTES

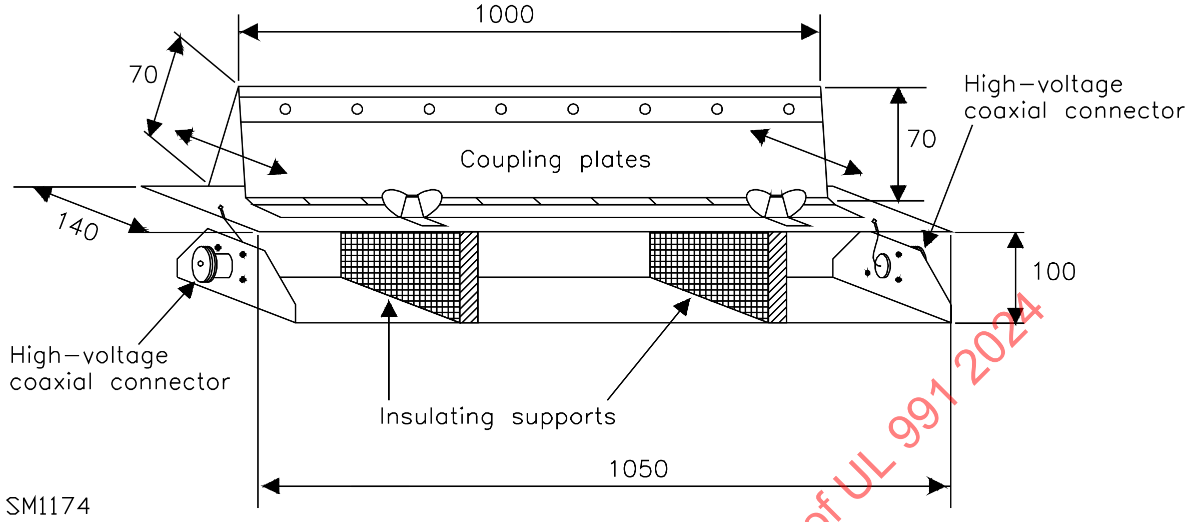
1 EUT is the equipment under test which may be a control by itself;

2 EFT/B is electrical fast transient/burst;

[a] L is the length of cord between the clamp and the EUT and should not be more than 3.3 feet (1 m).

Figure 14.6

Capacitive coupling clamp



NOTES

1 Dimensions in mm

2 The distance of the coupling section to all other conductive constructions except to the cable under test and the ground reference plane is to be greater than 1.8 ft (0.5 m).

14.4 Test levels

14.4.1 Test levels specified in Table 14.2 are to be determined in accordance with the intended conditions of use as described in (a) – (d):

a) Test level 1 for areas such as computer rooms and clean rooms in which:

1) Transients in the switched control circuits are suppressed;

2) Supply, control, and signal circuits that are intended to be subjected to other conditions of use are physically separated; and

3) The power supply leads are shielded and grounded at both ends to the equipment grounding means, and the power supply is protected by filtering.

b) Test level 2 for areas such as a control room or a terminal room in industrial type environments in which:

1) Control circuits are switched by relays (no contactors), and transients are partially suppressed;

2) Circuits are separated from all other circuits intended for use in more severe conditions; and

3) Unshielded power supply leads are physically separated from control and signal circuits.

c) Test level 3 for other areas within industrial environments in which:

1) There is no suppression of transients and no requirements for separation of circuits subjected to different conditions of use;

2) Equipment grounding is provided by a metal wiring system, or by equipment grounding conductors.

d) Test level 4 for outdoor use areas, such as high voltage substations, and industrial environments where no specific installation practice has been used.

Table 14.2
Test levels

Level[a]	Open circuit output test voltage			
	Power supply circuit		Input/output signal, data, and control circuits	
	kV	kHz	kV	kHz
1	0.5	5	0.25	5
2	1	5	0.5	5
3	2	5	1	5
4	4	2.5	2	5
b	b	b	b	b

[a] See 14.4.1.

[b] A level other than levels 1 – 4 as defined in the end-use product standard.

14.5 Test procedure

14.5.1 The test voltage is to be applied to the circuit (see 14.3.2) under test at the test level prescribed.

14.5.2 For power supply circuits, the test voltage is to be applied for 2 min in both positive and negative polarity for each of the following points with respect to the ground reference plane:

a) Line,

b) Neutral,

c) Line and neutral,

d) Equipment ground,

e) Neutral and equipment ground,

f) Line and equipment ground, and

g) Line, neutral, and equipment ground.

14.5.3 For low voltage input/output control and signal circuits, the points of application are to be determined for each control tested and the test level voltage is to be applied for 2 min in both the positive and negative polarity of the test voltage between the point of application and the ground reference plane.

14.6 Test conditions

14.6.1 All connections from the generator to the control and from the control to the ground reference plane are to be with connecting cables not more than 39 inches (1 m) in length. The insulation of the connecting cables is to have a dielectric strength to withstand the maximum test voltage.

14.6.2 The electrical fast transient/burst test generator is to be placed on a ground reference plane consisting of a 3.3 by 3.3 ft (1 m by 1 m) sheet of conductive metal 1/16 in (0.065 mm) thick. The equipment grounding means of a control is to be connected to the ground reference plane.

14.7 Signal circuit fast transient test

14.7.1 Signal circuits external to the control that are not surrounded by a conductive shield that is securely grounded at one end or otherwise segregated from sources of fast transients are to be tested as specified in 14.7.2 and 14.7.3. The equipment connected to these circuits shall operate as intended, or have no loss of declared protective function after being subjected to transient voltage pulses as described in 14.7.2.

Exception: A circuit or cable that interconnects equipment intended to be located within the same room need not be subjected to this test.

14.7.2 For this test, each circuit is to be subjected to four different transient waveforms having peak voltage levels in the range of 100 to 2400 V, as delivered into a 200 Ω load. A transient waveform at 2400 V is to have a pulse rise time of 100 V per μs, a pulse duration of approximately 80 μs, and an energy level of approximately 1.2 J. Other applied transients are to have peak voltages representative of the entire range of 100 to 2400 V but not equal to the clamping voltage of any transient suppressing device in the circuit, with pulse durations from 80 to 1110 μs, and energy levels not less than 0.03 J or greater than 1.2 J. The transient pulses are to be coupled directly onto the circuit conductors of the equipment under test.

14.7.3 The equipment is to be subjected to transient pulses induced at the rate of six pulses per minute as follows:

a) Sixteen pulses (two at each transient voltage level specified in 14.7.2) between each circuit lead or terminal and earth ground, consisting of eight pulses of one polarity, and eight of the opposite polarity, and

b) Sixteen pulses (two at each transient voltage level specified in 14.7.2) between any two circuit leads or terminals consisting of eight pulses of one polarity and eight pulses of the opposite polarity.

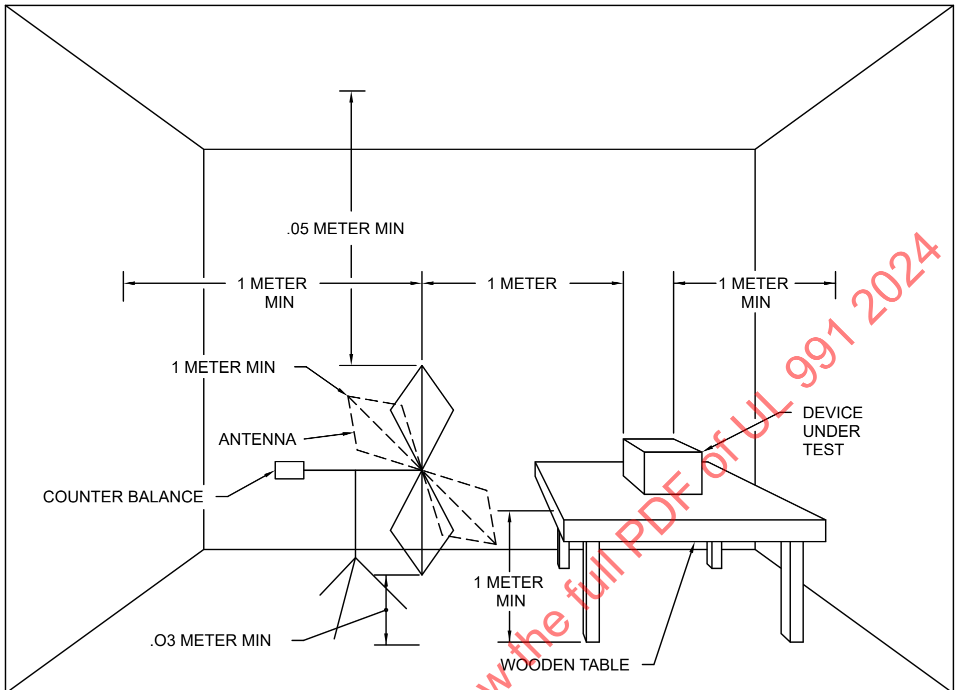
14.7.4 If transient suppressing devices are provided in the circuit, an additional two pulses of each polarity at the clamping voltage of the device shall be applied between the circuit and earth ground and, if applicable, between circuits.

14.8 Radiated EMI test

14.8.1 The control under test and the signal source of EMI generator are to be located in a shielded test area as indicated in Figure 14.7. The electrical connections to the test sample are to be made in accordance with the manufacturer's installation instructions. All covers and access panels of the control are to be in place unless otherwise stated. If the control is intended to be mounted in a panel, rack, or cabinet, it is to be tested in this configuration. If the wiring to and from the equipment is unspecified, a 3.3-ft or 1-m length of unshielded twisted pair of wires is to be used for the connections, installed in a manner that results in the greatest interference transmitted to the control.

Figure 14.7

Test setup for radiated EMI susceptibility (biconical antenna)



S3319

14.8.2 The test frequency range is to be from 25 MHz to 1 GHz. The signal generator is to provide amplitude modulation. The sweep rate is to be 0.005 octave per second (1.5×10^{-3} decade per second) or slower. When the frequency is below 50 MHz, the test is to be run with an amplitude modulation of 90 percent with a 1000 Hz sine wave unless the control is investigated in accordance with 14.9.1.

14.8.3 The antenna types may be as shown in Table 14.3, other antenna types may be used if the required signal strength can be achieved. When using an antenna which generates a polarized signal such as a biconical or log periodic antenna, the test is to be conducted twice, once at horizontal polarization and once at vertical polarization.

Table 14.3
Transmission characteristics

Frequency range	Typical antenna types
25 MHz – 200 MHz	Biconical
200 MHz – 1 GHz	Log conical or log periodic

14.8.4 The signal generator is to be operated to sweep through the required frequency band, or to dwell at a minimum of three frequencies per octave, while monitoring the intended operation (protective function) of the control. Table 14.4 specifies test levels for low and moderate exposures. Unless otherwise indicated in the end-product standard, a field strength of 3 V/m is to be used. The sweep frequency procedure is to be repeated with each of the accessible sides of a control exposed to the signal source.

Table 14.4
Transmission levels

EMI level	Field strength, V/m
Low	3
Moderate	10
As stated in end-product standard	Other

14.9 Digital equipment modulation interference test

14.9.1 A digital type control using a square wave oscillator clock circuit (other than for time display) is to be exposed to electromagnetic radiation of the frequency range shown in Table 14.3 that is 90 percent amplitude (pulse or square wave) modulated at approximate frequency of, but no less than, 10 kHz. The modulation frequency is not to be phase locked with the digital clock frequency.

14.10 Keying interference test

14.10.1 A control is to be subjected to signal sources that are switched between 0 and 100 percent of the carrier wave amplitude as stated in 14.8.2. The switched signal is to have an on and off duration of at least 1 second each and rise and fall times of no greater than 50 μs. At least three keying cycles per frequency octave are to be conducted.

15 Electrostatic Discharge Test

15.1 General

15.1.1 *Deleted*

15.1.1A The control shall perform its intended function, or shut down without loss of protective function, when subjected to the tests described in one of the following:

a) 15.2 – 15.6, or

b) IEC 61000-4-2 and IEC 61000-4-8. Unless otherwise specified in the end-product standard, Test Level 3 shall be used.

15.1.2 *Deleted*

15.1.3 *Deleted*

15.1.4 *Deleted*

15.2 Test methods

15.2.1 For the contact discharge test method, the electrostatic discharge probe is to be in contact with the test point and then the test voltage is to be applied. The electrostatic discharge probe is to penetrate any dry, non-insulating coatings, such as paint.

15.2.1A After being subjected to electrostatic discharges described in this section, a control shall be energized for 72 h at normal ambient conditions during which time it shall perform as intended or shut down with no loss of protective function. Prior to the electrostatic discharge exposures, the control is to be conditioned for at least 24 h, and the test is to be conducted, in an ambient temperature of 23 ±3°C or 73

±5°F, at a relative humidity of 20 ±5 percent, and a barometric pressure of not less than 700 mm Hg (94 kPa) or an environment of equivalent water vapor content.

Exception: The control may be tested at a relative humidity of 25 – 50 percent if the tests are completed within 3/4 h after removal from the conditioning chamber.

15.2.2 For the air discharge test method, the charged electrostatic discharge probe is to be brought to the preselected test point until a discharge through air occurs.

15.2.2A Each control selected for energization as specified in 15.1.1A shall have been subjected to at least one sequence of discharges from lowest to highest value.

15.2.3 With reference to the Discharge test in 15.4.1 – 15.4.4, the contact discharge test method is the preferred method. The air discharge test method is to be used if contact with the test point cannot be made for the contact discharge test method.

15.2.3A A control is to be mounted in its intended mounting position and connected to a source of supply in accordance with Table 9.2. A ground reference plane of conductive metal at least 39 in (1 m) square and 1/16 in (0.065 mm) thick is to be provided on the floor of the test room and connected to earth ground. For a control intended to be installed on an electrically conductive plate or mounting bracket, the plate or bracket is to be connected to earth ground.

15.2.4 The voltage range over which the test is to be conducted is to be 4 – 20 kV maximum for the air discharge test method and 2 – 8 kV maximum for the contact discharge test method unless a voltage other than these maximums is specified in the end-product standard.

15.2.4A The voltage range over which the test is to be conducted is to be 4 – 20 kV unless a maximum voltage other than 20 kV is specified in the end-product standard.

15.3 Electrostatic discharge probe

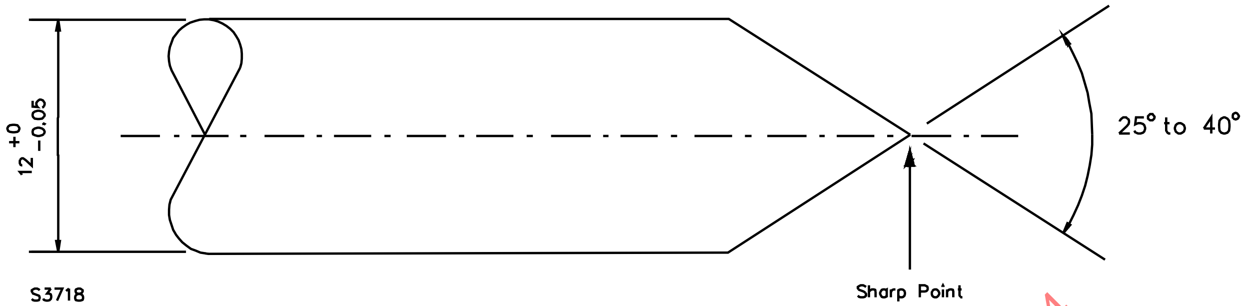
15.3.1 The relevant characteristics of the electrostatic discharge probe for the air discharge test method and the contact discharge test method are specified in Table 15.1.

Table 15.1
Electric discharge probe characteristics

Characteristics	Test method	
	Air discharge	Contact discharge
Energy storage capacitor	100 pf ±10 percent	150 pf ±10 percent
Discharge resistor	1500 Ω ±5 percent	330 Ω ±5 percent
Output voltage	4 – 20 kV	2 – 8 kV
Discharge tip	8 ±0.05 mm diameter	Sharp point (See Figure 15.1)

Figure 15.1

Probe for contact discharge test method



NOTE – Dimensions are in mm

15.4 Discharge test

15.4.1 The discharge test is to be conducted in increasing 2-kV increments. As applicable, the test points are to include:

a) The control ground terminal,

b) The exterior surface near each hole, slot, seam, or opening,

c) Each control terminal, and

d) Any area that can be contacted during installation or use.

15.4.2 The control is to be tested in each of the following configurations:

a) Mounted and wired, as in typical installation, in both the energized and de-energized mode.

b) Unpowered and unconnected on a nonconductive surface.

15.4.3 A total of ten discharges are to be applied to each test point on the exposed surface of the control. Five discharges are to be made at each polarity. The polarity is to be alternated for each successive discharge. The interval between successive single discharges is to be at least 5 s. For a control intended to be serviced by the user, ten additional discharges are to be applied as described to internal parts that would normally be contacted by the user. If an overvoltage protective device in a sample is damaged by the discharge at any voltage but the lowest, that sample is to be subjected to ten additional discharges of each polarity at 4 kV.

15.4.4 Any single test specimen shall be at least subjected to discharges over the entire specified voltage range and at both polarities. However, no single specimen need be subjected to more than 200 cumulative discharges.

15.5 Electric field test

15.5.1 The control is to be tested in a collapsing electrical field created by static discharge. The control is to be placed on a nonconductive surface in the normal operating position. A metal plate electrode, equal to or larger than the control surface, is to be positioned about 2 in from one of the surfaces of the control according to Figure 15.2 and is to be insulated from ground. The test probe is to be:

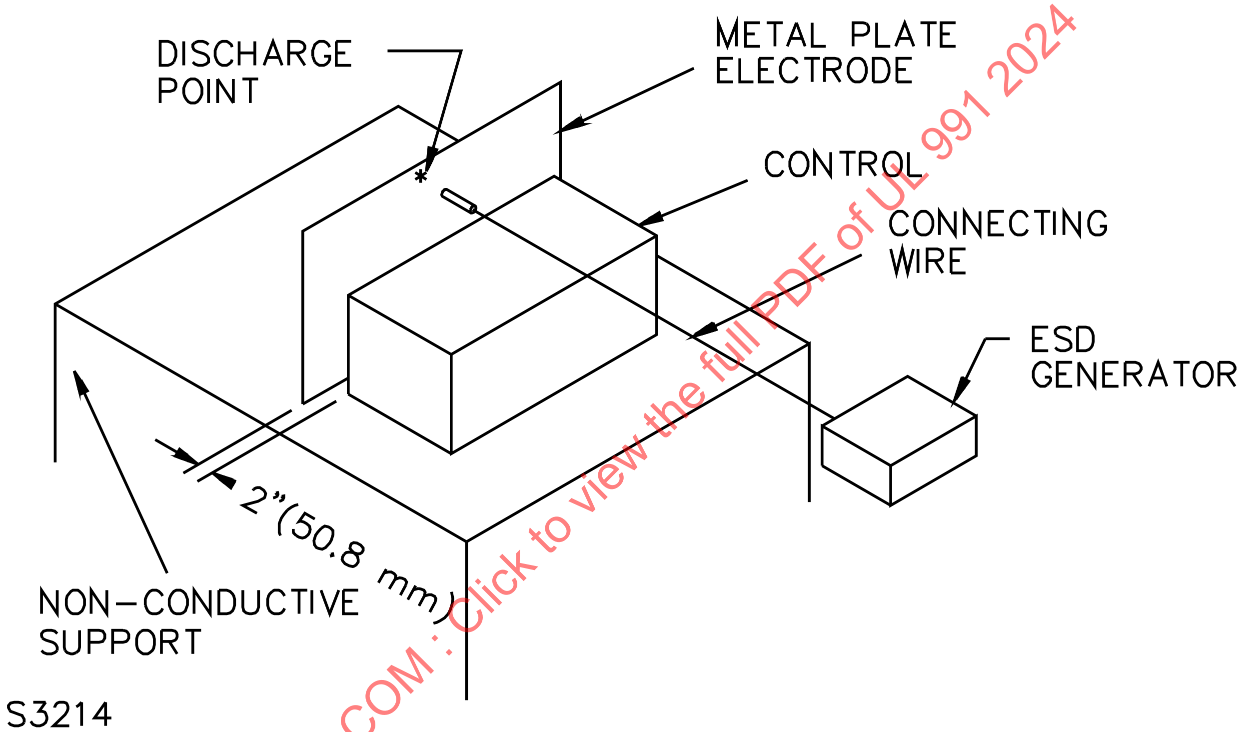
a) Attached to the electrostatic discharge generator by 4 ft of 18 AWG or 1.02 mm diameter insulated wire suitable for the voltages involved, and

b) Charged to 20 kV.

The electrical field collapse is produced by approaching the plate with the test probe until an air discharge occurs. The connecting wire is to be routed alongside and 1/8 in or 3 mm from the surface of the control. The test is to be conducted at both polarities for each side of the control, except for the mounting surface.

Figure 15.2

Electric field test method

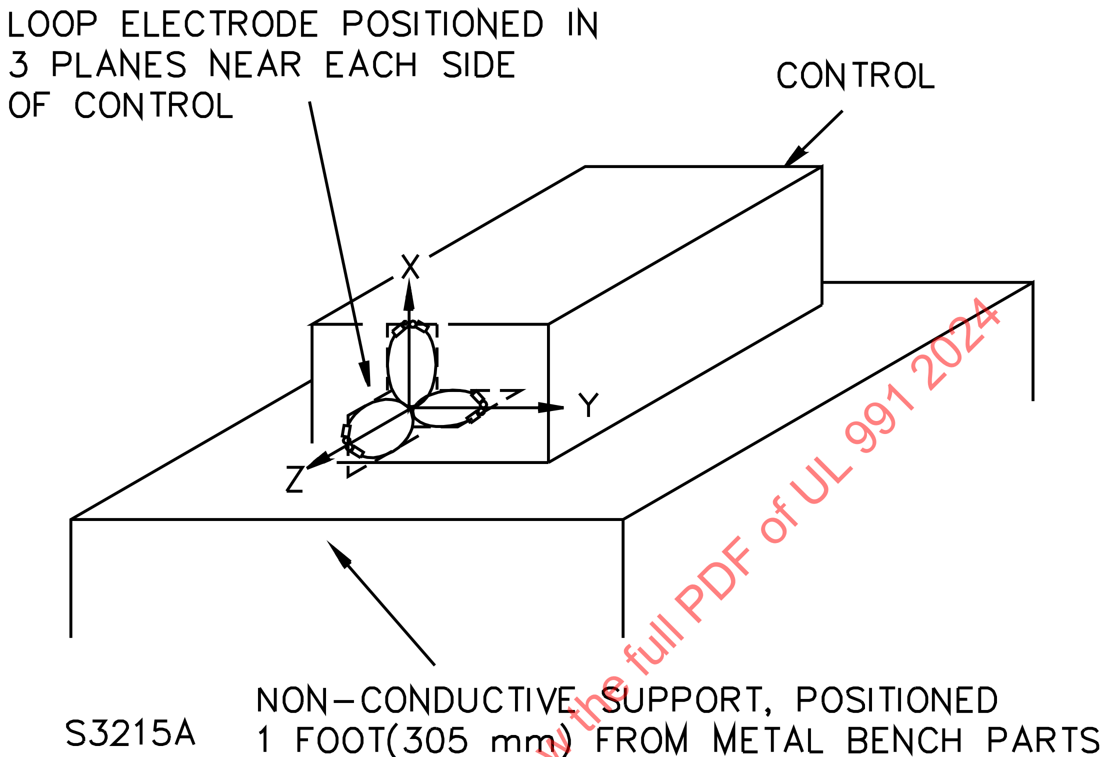


15.6 Magnetic field test

15.6.1 The control is to be tested in a magnetic field created by static discharge. The test probe is to be charged to 20 kV. The magnetic field is produced by forming an approximately 12-in or 300-mm diameter loop of the wire connecting the probe and the electrostatic discharge generator. The probe is to be discharged through the loop within 2 in or 51 mm of each side of the control. This test is to be repeated in both polarities in at least three planes perpendicular to each other near each surface in accordance with Figure 15.3. Controls that fit within the loop are to be tested within the loop; for such controls, six discharges are sufficient and the 2-in limit does not apply.

Figure 15.3

Magnetic field test method



16 Composite Operational and Thermal Cycling Test

16.1 A control shall operate as intended following exposure to variations in temperature and voltage.

16.2 The control shall be energized at 110 percent of the rated voltage specified in Table 9.2 except that for 30 min during each 24 h period the test voltage is to be reduced to 85 percent of the original voltage. The change in voltage should not be synchronized with the change of temperature. Each 24 h period shall also include at least one period of 30 s during which the supply voltage is switched off.

16.3 The ambient temperature and/or the mounting surface temperature are to be varied between maximum and minimum, as specified in the end-product standard, to cause the temperature of the components of the electronic circuit to be cycled between their resulting extremes. The rate of ambient and/or mounting surface temperature change is to be approximately 1°C/min and the extremes of temperature are to be maintained for approximately 1 h.

16.4 During the test, the control shall be cycled through its operational modes at the fastest rate possible up to a maximum of six cycle per minute, subject to the need to cycle components between their temperature extremes. If an operational mode, such as speed control, can be set by the user, the test period shall be divided into three periods, one period being at maximum, one period at minimum and one at an intermediate setting.

16.5 The test shall be conducted for:

a) Fourteen days, or

b) A period of time as specified by the end-product standard.

17 Test for Effects of Shipping and Storage

17.1 A control shall operate as intended following exposure to high and low temperatures representative of shipping and storage likely to be encountered by the end product.

17.2 A control is to be subjected, first to a temperature of 70 ±3°C (158 ±5°F) for a period of 24 h, cooled to a room temperature of 23 ±3°C (73 ±5°F) for not less than 1 h, and then exposed to a temperature of minus 30 ±3°C (minus 22 ±5°F) for not less than 3 h and finally warmed up to room temperature for a minimum of 3 h. The rate of change between constant temperature conditions is not to exceed 1°C (1.8°F) per minute.

18 Thermal Cycling Test

18.1 After 10 cycles of temperature variation between 0 and 49°C or 32 and 120°F while unenergized, a control shall perform its intended function. A control intended for outdoor use shall perform its intended function at both temperature extremes and at room temperature.

18.2 The transfer time from one extreme to the other is to be a maximum of 5 min, and there is to be a period of not less than 10 min at each temperature level after the mass of the test sample has reached the specified temperature. Each cycle is to start at one test condition, change to the other extreme, and return to the original test condition. After 10 cycles, the control is to be stabilized at the normal test ambient temperature before operation.

Exception: A control investigated by the Composite Operational and Cycling Test, Section 16, need not be subjected to this test.

19 Humidity Test

19.1 A control shall perform its intended function after exposure to one of the humidity exposure classes as indicated in Table 19.1 and specified in the end-product standard.

Exception: If the control is expected to be exposed to condensation in the end-product application, the humidity test exposure shall be in accordance with Basic Environmental Testing Procedures Part 2: Tests – Test Db and Guidance: Damp Heat, Cyclic (12 + 12-Hour Cycle), IEC 60068-2-30 with the following parameters:

a) Severity level:

1) Upper temperature: 40 ±2°C or 104 ±4°F

2) Number of cycles: 6

b) Stabilizing temperature: 20 ±5°C or 68 ±9°F

c) Test cycle: Variant 2

d) State of specimen during conditioning: Unenergized

e) Intermediate measurements: none required

f) Recovery conditions: 2 h at standard laboratory atmosphere (15 – 35°C or 59 – 95°F, 45 – 75 percent Relative Humidity)

g) Check tests: Immediately upon completion of the recovery period, the control is to be energized and checked to determine that it operates as intended.

Table 19.1
Humidity classes

Class[a]	H1	H2	H3	H4	H5	H6
Temperature	30 ±2°C or 86 ±4°F	30 ±2°C or 86 ±4°F	40 ±2°C or 104 ±4°F	40 ±2°C or 104 ±4°F	40 ±2°C or 104 ±4°F	As stated in end-product
Minimum R.H. ±5 percent	20	20	20	20	–	
Maximum R.H. ±5 percent	90	90	95	95	95	
Duration	6 cycles	12 cycles	6 cycles	12 cycles	333 h	

[a] Typical examples of Class applications for controls are as follows:

Class H1 – Controls used in equipment intended for occupational spaces.

Class H2 – Controls used in equipment intended for laundry rooms, basements, etc.

Class H3 – Controls intended for household heating appliances.

Class H4 – Controls intended for appliances used in bathrooms and areas exposed to high humidity.

Class H5 – Controls intended for spa equipment and commercial heating and cooking equipment.

19.2 The test cycle sequence is to consist of alternating periods of minimum and maximum relative humidity (RH) until the indicated number of cycles or hours is attained. A cycle consists of 8 h exposure to each of the specified humidity levels. The time required to reach the level is not to exceed 1 h.

19.3 During the test, the control is to be shielded from any dripping condensate and is not to be energized. Distilled water or the equivalent is to be used to obtain the RH.

19.4 During the last 2 h of exposure at maximum RH, the control is to be energized and checked to determine that it operates as intended.

20 Dust Test

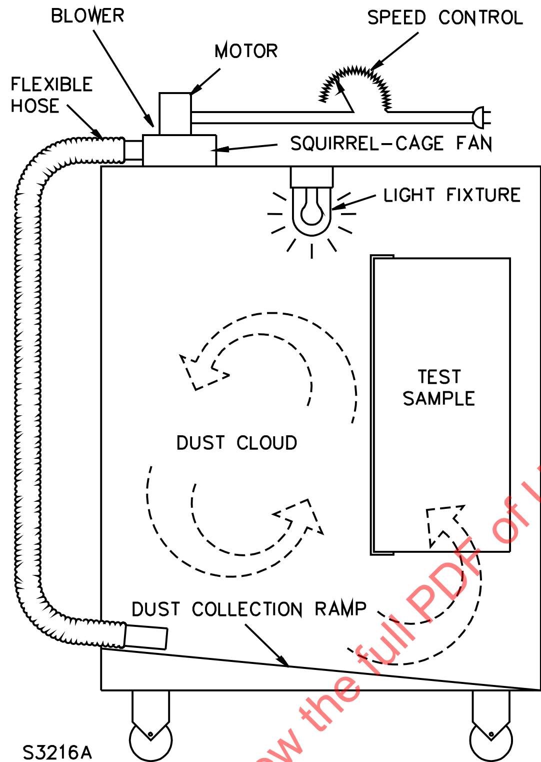
20.1 A control that incorporates an optical element, the obscuring of which would result in a loss of protective function, shall perform its intended function after exposure to an accumulation of dust.

Exception: A control mounted in a dust-tight enclosure need not be tested.

20.2 A sample in its intended mounting position is to be placed, de-energized, in a dust-tight chamber as described in Figure 20.1 having an internal volume of at least 6 ft^3 or 0.17 m^3, and dimensions not less than 150 percent of the dimensions of the product under test. Additional samples of a control intended for mounting in more than one position are to be tested in each position.

Figure 20.1

Dust test apparatus



20.3 Approximately 1.5 oz of cement per cubic foot or 1.5 kg of cement per cubic meter of test chamber, maintained in an ambient 20 – 50 percent relative humidity at room temperature, is to be circulated for 5 min by means of blower/suction units so as to completely envelop the sample in the chamber. The air flow at the outlet of the blower is to be maintained at a velocity of approximately 50 ft/min or 15 m/min. Type 1 general-purpose cement is to be used as it has a controlled particle size distribution. The analysis of a typical sample is indicated in Table 20.1.

Table 20.1
Particle size of cement

Mesh	Particle size		Content percent
	in	mm	
Coarser than 200	Larger than 0.0029	Larger than 0.074	3
200	0.0029	0.074	8
325	0.0017	0.043	7
400	0.0015 or smaller	0.038 or smaller	82

21 Vibration Test

21.1 General

21.1.1 A control shall operate as intended after a vibration test.

21.2 Mounting

21.2.1 A control is to be secured to a vibration generator by its intended mounting means either directly or by means of a fixture. The fixture is to:

a) Be as free as possible of any resonances over the test frequency range, and

b) Enable the control to be vibrated in each of three perpendicular planes.

The control is to be energized during this test. A control with a vibration isolator is to be tested with it in place. If this is not practical, the control may be tested without the isolator at a different amplitude of vibration.

21.2.2 A cable or other hardware that is required to be connected to the control for proper operation is to be used with the control during this test.

21.3 Vibration characteristics

21.3.1 The vibration level is to be 5 g unless otherwise specified by the end-product standard. Other preferred levels are shown in Table 21.1. The frequency range shall be 10 to 150 Hz.

Table 21.1
Vibration classes

Class	Maximum displacement amplitude		Maximum acceleration level, g
	mm	in	
A	0.075	0.003	1
B	0.15	0.006	2
C	0.35	0.014	5
D	0.75	0.03	10

21.3.2 The applied motion is to be sinusoidal and result in the fixing points of the control moving in phase and in straight parallel lines. The motion is to attain the specified maximum displacement amplitude as frequency is increased from 10 Hz until a crossover point at 60 Hz is reached which is where the specified maximum acceleration is attained. The maximum acceleration level is to then be maintained as frequency is increased to the upper limit of the range. The maximum acceleration or displacement amplitude levels are then to be maintained as frequency is reduced through the crossover point to 10 Hz. See Figure 21.1.

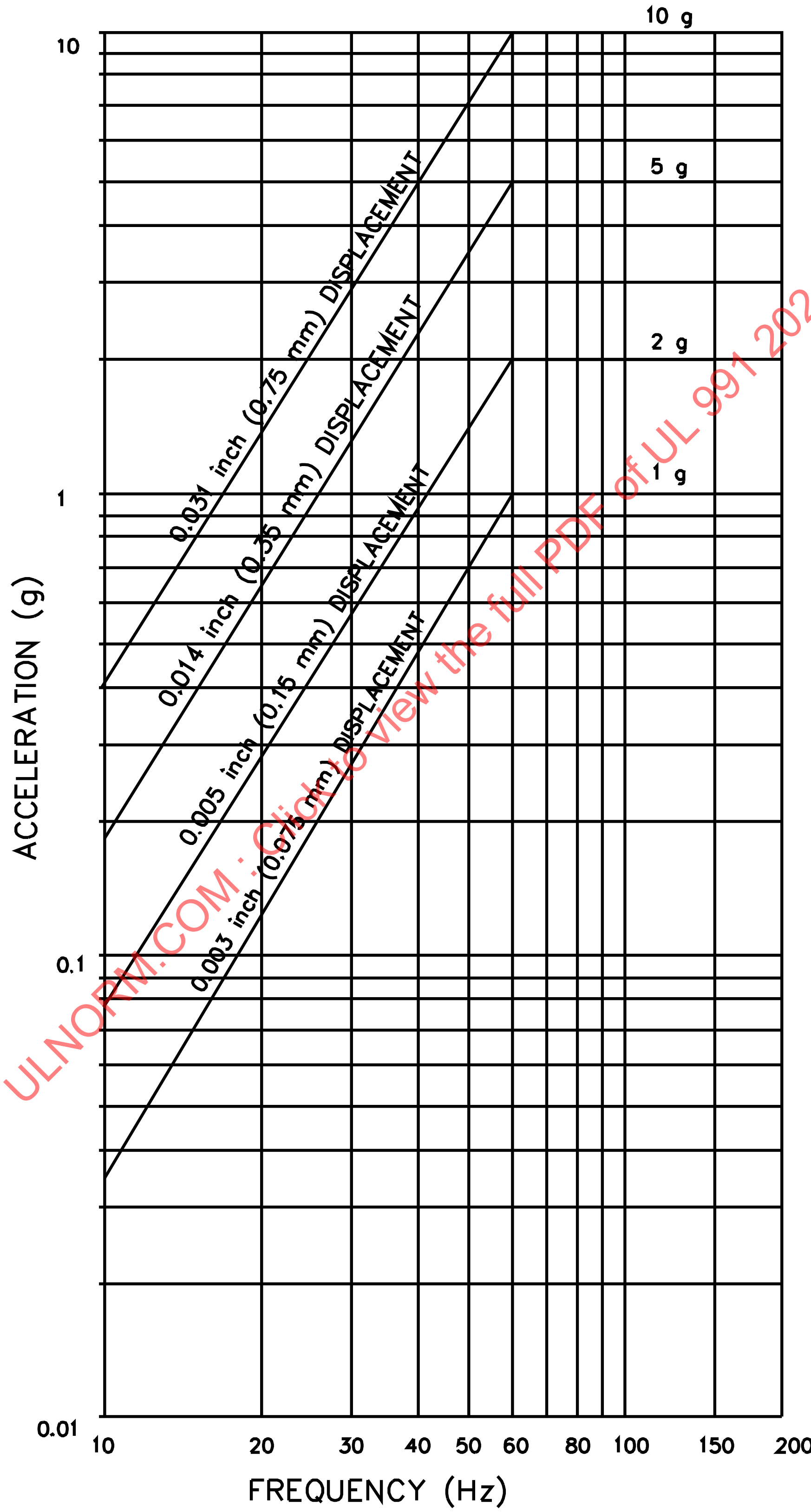
21.3.3 The frequency is to be varied by continuously sweeping over the specified range at a rate of one octave per minute ±10 percent. The tolerance for the frequency is to be ±1 percent up to 50 Hz and ±2 percent above 50 Hz. The vibration amplitude tolerance in the observed direction is to be ±15 percent.

21.3.4 Any vibration resonances are to be noted and the control is to be vibrated at those resonant frequencies for 10 min. If no resonant frequency is obtained, the control is to be tested for ten sweep cycles. A sweep cycle is a traverse of the specified frequency range from minimum to maximum and back to minimum frequency.

21.3.5 For these tests, amplitude is defined as the maximum displacement of sinusoidal motion from a position of rest or one-half of the total table displacement. Resonance is defined as a magnification of the applied vibration occurring on a part or assembly.

Figure 21.1

Vibration amplitude/acceleration



S3317

22 Jarring Test

22.1 A control shall withstand jarring resulting from the impact described in 22.2 without dislodgement of any parts and without impairing its intended operation.

Exception: Dislodgement of parts is permitted if:

a) The dislodged part does not affect the intended operation of the unit,

b) There are no uninsulated live parts exposed, and

c) The condition is visually obvious.

22.2 The control is to be mounted in a position of intended use to the center of a 6- by 4-ft or 1.8- by 1.2-m, nominal 3/4-in or 20-mm thick plywood board that is secured in place at four corners. A single 3-ft-lb or 4.1-J impact is to be applied to the center of the reverse side of this board by means of a 1.18 lb or 0.54 kg, 2 in or 51 mm diameter steel sphere either:

a) Swung through a pendulum arc from a height of 2.54 ft or 775 mm, or

b) Dropped from height of 2.54 ft to apply 3 ft-lb of energy depending upon the mounting of the equipment.

COMPUTATIONAL INVESTIGATION AND DEMONSTRATED METHOD

23 General

23.1 An electronic device shall be constructed so that the level of performance specified for the device in the end-use application is maintained. Compliance is to be determined using the procedures specified in Computational Investigation, Section 24, or Demonstrated Method, Section 25. Failure of any single noncritical component shall not increase the thermal or electrical stresses of any critical component beyond the thermal or electrical stress levels used to calculate the failure rate of the critical component.

Exception: The failure of the noncritical component resulting in a trouble indication complying with the requirements for the end-use application meets the intent of the requirement.

23.2 In cases where cycling is the predominant operating mode of a control, consideration is to be given to the number of operational cycles and hours.

23.3 The Computational Investigation may be used to assess a control when an acceptable failure rate has been established in the end-product standard. The Demonstrated Test is used when such a failure rate is not defined.

23.4 An investigation of critical components to either the Computational Investigation (Section 24) or the Demonstrated Method (Section 25) is not required if the Failure Mode and Effects Analysis (FMEA) of Section 7 does not identify any critical components.

NOTE: Some end-product standards (e.g., UL 2271) do not permit any critical components.

24 Computational Investigation

24.1 General

24.1.1 The Computational Investigation is the Parts Stress Method which is based on a technique described in Military Standardization Handbook Number 217 followed by the operational test in 24.4.1. In this method, the equipment failure rate is determined by appropriately combining the failure rates of all critical components.

24.1.2 A control shall have a predicted failure rate (λp) equal to or less than the value stated in the end-product standard when calculated by the method described in this section.

24.2 Preliminary procedure

24.2.1 Components may fail in either open- or short-circuit modes or may show excessive parameter drift. By analysis of the circuit or by test, the effect of each failure mode of each component is to be determined.

24.2.2 All critical components are to be considered and the failure mode probability multiplier (π_{fm}) for each is to be determined by dividing the number of failure modes that are critical (with respect to increased risk of fire, electric shock, or injury to persons) by the total number of failure modes of that component. If the critical failure modes for a multipin device are more than five, a π_{fm} factor of one is to be used. The failure mode multiplier will be used in conjunction with other multiplying factors to determine each component's failure rate that, in turn, will be used in subsequent computations to determine the overall equipment failure rate.

24.3 Parts stress method

24.3.1 This method is as follows:

a) All critical components are to be itemized in the first column of the Parts Stress Method worksheet, Figure 24.1.

b) Applicable equations are to be selected from the Parts Stress Analysis Prediction method of Military Handbook Number 217.

c) For each component the base failure rate (λ_b) at operating stress and ambient temperature is to be recorded into the appropriate column of the worksheet.

d) All applicable multiplying factors (π factors) including the failure mode multiplier (π_{fm}) are to be entered into the worksheet, using an environmental factor, π_E, corresponding to G_F, unless another environmental factor is specified in the end-product standard.

e) Each component's failure rate, λ_p, is to be calculated using the applicable Military Handbook Number 217 equation which is then multiplied by π_{fm}.

f) All the individual part failure rates are to be appropriately mathematically combined to obtain the composite equipment failure rate.

Figure 24.1

Parts stress method worksheet

DEVICE	EQUATION	λ_b	π_{fm}	π_Q	π_E	π_A	π_{S2}	π_C	π_R	π_V	π_{TAPS}	π_{SR}	π_{CV}	π_F	π_N	π_{CYC}	π_L	π_P	λ_{CYC}	λ_P

λ_P = Failure rate for Component – Failures/10^6 hours
(Sum of numbers for that Component)

Overall System Failure Rate Failures/10^6 hours

S3316

24.3.2 The individual component failure rates may be obtained from any of the following sources:

a) The tables in Reliability Prediction of Electronic Equipment, Military Handbook Number 217F, if the components comply with all the requirements of the appropriate military specification, including all acceptance and conformance tests and documentation.

b) Same as in (a) multiplied by the "commercial grade" quality factor, based on an evaluation of the manufacturer's production tests. See Marking, Section 31.

c) Other widely accepted publications, such as the Rome Air Defense Command (RADC) series which accumulate historical failure data. Care needs to be exercised when this type of data is employed to ensure that the conditions of the component's use for which the historical data have been compiled approximate the intended use of the component in question. Adjustments to the failure rate data may be necessary to account for use differences.

d) A failure rate demonstration that consists of determining failure rates by tests performed. If this method is used to obtain component failure rates, it is required that quality assurance, screening, and burn-in program be implemented.

e) Manufacturer supplied data is acceptable if a review determines compliance with the same requirements, test conditions, and the like, as in (c). This also requires quality assurance, screening and burn-in programs.

24.4 Operational test

24.4.1 When operated under the conditions of normal use, a control shall perform its intended operation for:

a) A period of time and temperature as specified by the end-product standard or,

b) Fourteen days in an ambient air temperatures of 60°C or 140°F, or 10°C or 18°F greater than the operating temperature, whichever is higher.

Exception: A control investigated by the Composite Operational and Cycling Test, Section 16, or the Demonstrated Method, Section 25, need not comply with this test.

25 Demonstrated Method

25.1 General

25.1.1 A control shall perform its intended function after being subjected to the tests in this section. See 9.4.

25.1.2 Table 25.1 lists multiplying factors that, when multiplied by the test acceleration factor of Table 25.2, give the required number of test unit-hours. Any combination of sample units and test hours, the multiple of which equals the required test unit-hours, may be used. Minimum requirements for sample units and test hours may be established in the end-product standard. Identification of critical components is required.

Table 25.1
Multipliers for test acceleration factors

Intended use of control	Usage level h/yr[a,b]	Multiplier
Nonindustrial	1 – 100	57.63
	101 – 1000	576.30
	1001 – Continuous	5763.00
Industrial	1 – 100	86.98
	101 – 1000	869.80
	1001 – Continuous	8698.00

[a] As determined by the end-product standard.

[b] Of electrical or thermal stress, or combination thereof.

Table 25.2
Test acceleration factor equations

Use ambient	Equation
Any	Equation 1
40°C	Equation 2
25°C	Equation 3

Equation 1:

$$TAF = In^{-1}\left[\left(\frac{1}{T_t} - \frac{1}{T_a}\right)7543.23 + 4.6052\right]$$

Equation 2:

$$TAF = In^{-1}\left(\frac{7543.23}{T_t} - 19.4830\right)$$

Equation 3:

$$TAF = In^{-1}\left(\frac{7543.23}{T_t} - 20.6949\right)$$

in which:

kelvin = degrees Celsius + 273.15

T_t = Desired test temperature expressed in kelvin.

T_a = Control use ambient temperature expressed in kelvin.

TAF = Test acceleration factor.

25.1.3 The following procedure is to be used for selecting the required number of test unit-hours:

a) Table 25.1 determines the multiplier for the control according to intended use and usage level.

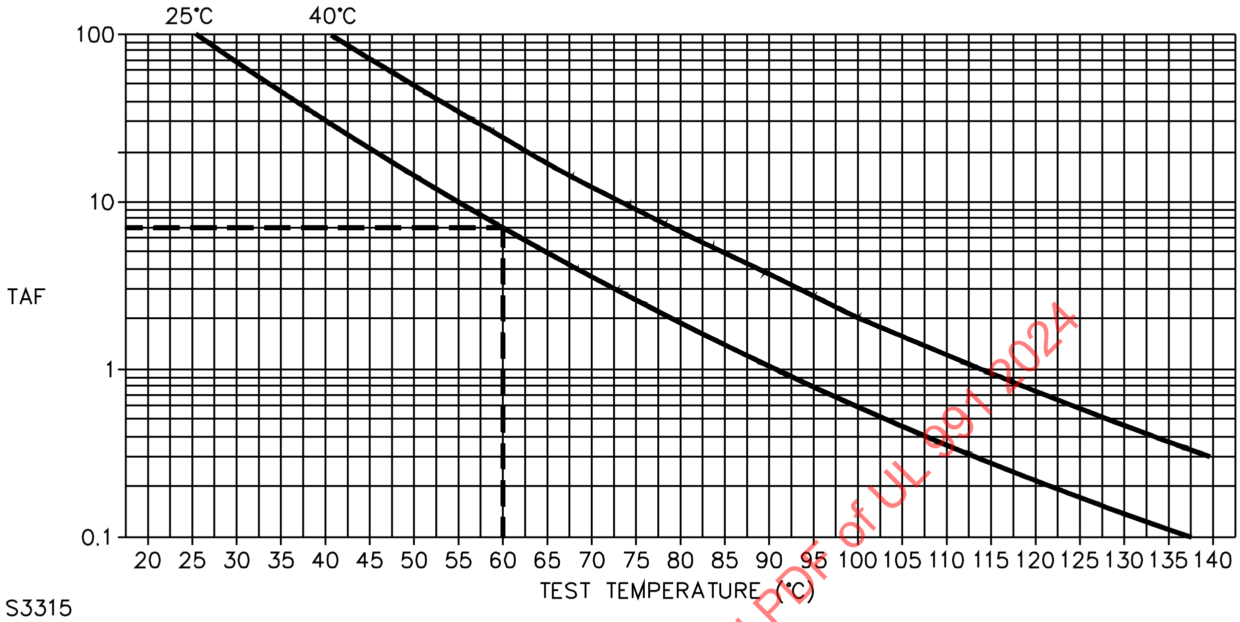
b) Figure 25.1 may be used to estimate the test acceleration factor for controls intended for use in either a 25°C or 77°F, or 40°C or 104°F ambient. This is done by projecting the chosen test temperature vertically until it intersects the appropriate ambient line. The ordinate value of this intersection point is the test acceleration factor.

c) The applicable equation in Table 25.2 shall be used to determine the test acceleration factor.

d) The required test unit-hours is the mathematical product of the multiplier and the test acceleration factor.

Figure 25.1

Determination of test acceleration factor



25.2 Test method

25.2.1 The controls are to be connected to the test voltage specified in Table 9.2 and then placed in a circulating air oven maintained at the chosen temperature, if necessary to provide an elevated ambient, until the required number of test unit-hours has been reached. The circulating air in the oven shall not serve to reduce the temperature of the control during the test.

25.2.2 A control that continuously cycles as part of its application is to be cycled during the test period. A control that is normally in a standby condition and is called upon to cycle at a predetermined condition is to be tested in the standby condition and periodically cycled during and at the conclusion of the test period.

25.2.3 The controlled functions are to be monitored and cycled as specified in the end-product standard. Lights, actual loads, or other acceptable loads which will represent the normal and intended operation may be specified.

25.2.4 The test is to be continued until the required number of test unit-hours is accumulated. Component replacement may be permitted as specified in 25.2.6 and 25.2.7.

25.2.5 At the conclusion of the test, the controls are to be subjected to 50 cycles of intended operation at the intended operating ambient.

25.2.6 A noncritical electronic component that malfunctions during the test shall be replaced and the test continued.

25.2.7 A critical electronic component that malfunctions during the test is to be considered unacceptable unless:

a) An electronic component that has been found acceptable in accordance with 6.3(d)(1), (2), or (3) may be replaced with one of the same manufacture and type and the test continued; or

b) The critical component may be replaced with one of the same type and manufacture and the test continued without further malfunction of any critical component until the test unit-hours equal 1.6876 times the initial value as determined in accordance with 25.1.3.

POWER CYCLING TESTS

26 General

26.1 A control shall perform acceptably when subjected to the tests in these sections, and there shall be no electrical or mechanical malfunction. The tests are to be conducted at 50 ±20 percent "on" time or at the inherent "on" time of the equipment duty cycle.

27 Overload Test

27.1 A control is to be mounted as in use and operated for 50 cycles of its intended operation at a rate of not more than 6 cycles per minute while connected to a circuit of 120 percent of the test voltage specified in Table 9.2. Each cycle is to consist of starting with the control energized in the standby condition, operating the control in the intended manner, and restoring the control to the standby condition.

27.2 A control intended specifically for use with a prevailing ambient temperature higher than 25°C or 77°F is to be tested at that temperature.

28 Endurance Test

28.1 Following the overload test, the same control is to operate for the number of cycles specified in the end-product standard at a rate of not more than 6 cycles per minute while connected to a supply circuit as specified in Table 9.2 and with related devices or equivalent loads connected to the output circuits.

FOLLOW-UP PROGRAM

29 General

29.1 To verify continued compliance with these requirements, a Follow-Up Program shall be implemented in accordance with Follow-Up Program, Supplement SA.

RATING

30 General

30.1 A device shall be rated in volts, and, as appropriate for the intended use, also in horsepower, amperes, amperes resistive (or resistance only or noninductive), volt-amperes or watts, or any combination thereof. The rating of a device shall include the current in amperes if the wattage rating is not a close indication of the volt-ampere input. The rating shall indicate whether the device is for direct or alternating current and, for an alternating-current device, the number of phases and, if necessary, the frequency, except that a single-pole or other device obviously intended only for single-phase use need not include the phase rating.

MARKING

31 General

31.1 A device shall be legibly and permanently marked with:

a) The manufacturer's name, tradename, or trademark or other descriptive marking by which the organization responsible for the device may be identified;

b) A distinctive catalog number or the equivalent; and

c) The electrical rating.

Exception No. 1: A device intended only for factory installation in end-use equipment need not be marked with a rating.

Exception No. 2: A device intended only for installation as part of other equipment need not be marked with a rating if a different catalog designation is employed for each different rating.

31.2 A distinct catalog number or suffix for each design or function shall be marked on the device.

31.3 If a manufacturer produces or assembles solid-state devices at more than one factory, each finished item of equipment shall have a distinctive marking, which may be in code, by which it may be identified as the product of a particular factory.