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Tests for Safety-Related Controls Employing Solid-State Devices



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public safety
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Underwriters Laboratories Inc.®

Standard



Underwriters Laboratories Inc.®

A not-for-profit organization dedicated to public safety
and committed to quality service

June 23, 1995

Standard for

Tests for Safety-Related Controls Employing Solid-State Devices

UL 991, Second Edition

Accompanying this transmittal notice is a copy of the Second edition of UL 991.

THIS EDITION OF THE STANDARD IS NOW IN EFFECT.

Revised and/or additional pages may be issued from time to time.

JUNE 23, 1995

1

UL 991

Standard for

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

First Edition – January, 1989

Second Edition

June 23, 1995

An effective date included as a note immediately following certain requirements is one established by Underwriters Laboratories Inc.

Revisions of this standard will be made by issuing revised or additional pages bearing their date of issue. A UL Standard is current only if it incorporates the most recently adopted revisions, all of which are itemized on the transmittal notice that accompanies the latest published set of revision pages.

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FOREWORD

A. This Standard contains a description of the basic test method(s) for evaluating products covered by Underwriters Laboratories Inc. (UL) under its Follow-Up Service for this category within the limitations given below and in the Scope section of this Standard. This test method(s) is based upon sound engineering principles, research, records of tests and field experience, and an appreciation of the problems of manufacture, installation, and use derived from consultation with and information obtained from manufacturers, users, inspection authorities, and others having specialized experience. It is subject to revision as further experience and investigation may show is necessary or desirable.

B. The consistent and uniform production of the product so that it will perform in the manner indicated by the coverage is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which performs in a specified manner will not necessarily be judged to be eligible for coverage if, when examined and tested, it is found to have other features which impair the significance associated with such performance.

D. UL, in performing its functions in accordance with its objectives, does not assume or undertake to discharge any responsibility of the manufacturer or any other party. The opinions and findings of UL represent its professional judgment given with due consideration to the necessary limitations of practical operation and state of the art at the time the Standard is processed. UL shall not be responsible to anyone for the use of or reliance upon this Standard by anyone. UL shall not incur any obligation or liability for damages, including consequential damages, arising out of or in connection with the use, interpretation of, or reliance upon this Standard.

E. Many tests required by the Standards of UL are inherently hazardous and adequate safeguards for personnel and property shall be employed in conducting such tests.

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.

1.5 End-product standard requirements may supersede recommended severity levels for those tests where optional severity levels are provided.

1.6 A product that contains features, characteristics, components, materials, or systems new or different from those covered by the requirements in this standard, and that involves a risk of fire, electric shock, or injury to persons shall be evaluated using the appropriate additional component and end-product requirements as determined necessary to maintain the acceptable level of safety as originally anticipated by the intent of this standard. A product whose features, characteristics, components, materials, or systems conflict with specific requirements or provisions of this standard cannot be judged to comply with this standard. Where considered appropriate, revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this standard.

1.6 effective June 23, 1995

2 Components

2.1 A component of a product covered by this standard shall comply with the requirements for that component.

Exception: A component need not comply with a specific requirement that:

- a) *Involves a feature or characteristic not needed in the application of the component in the product covered by this standard, or*
- b) *Is superseded by a requirement in this standard.*

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

2.3 Specific components are recognized as being 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 for which they have been recognized.

3 Units of Measurement

3.1 If a value for measurement is followed by a value in other units in parentheses, the second value may be only approximate. The first stated value is the requirement.

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 in 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 **DECADE** – 3.32 octaves.

5.4 **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.

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

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

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

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

5.9 **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.

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

5.11 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.

5.12 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.

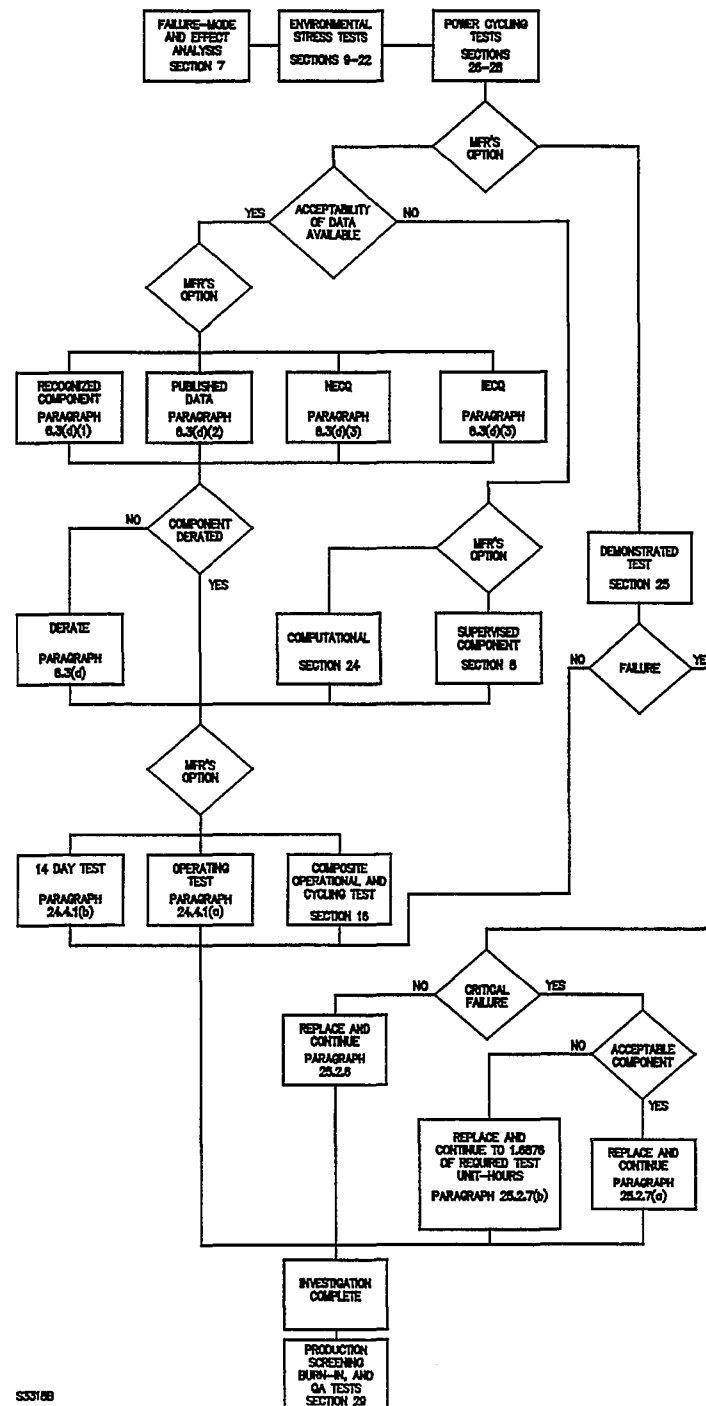
INVESTIGATION

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.

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 | Mfg ^b | Cat. No. ^b | Ratings ^b | Schematic reference ^c | Function ^d | Failure mode ^e | Failure effect ^f | Critical or non-critical ^g |
|---|------------------|-----------------------|----------------------|----------------------------------|-----------------------|---------------------------|-----------------------------|---------------------------------------|
| <p>^a Each electronic component in the control to be investigated is to be included.</p> <p>^b This information is to be provided for each component.</p> <p>^c Each component is to be identified as R1, C1, and the like.</p> <p>^d The function of each component is to be described.</p> <p>^e Open and short faults are to be considered for each component. The following alternative to shorting all combinations of terminals on multiple pin components, such as integrated circuits, may be utilized:</p> <ol style="list-style-type: none"> 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. <p>A circuit analysis may be made to assess the performance of individual components under a fault condition rather than actually creating the fault to determine its effect.</p> <p>^f The system effect caused by the failure is to be stated.</p> <p>^g The failure effect is to be identified as within the intent of General, Section 6. Those components or circuits the failure of which causes a condition considered to be unacceptable in the end-product application are considered critical. If the fault in a component or circuit results in a shutdown considered to be acceptable in the end-product application or in no appreciable effect on performance, the component or circuit is considered noncritical.</p> | | | | | | | | |

7.2 The FMEA is to be conducted as described in the Procedure for Preparing/Performing a Failure Mode, Effects and Criticality Analysis, Military Specification Number 1629.

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 conducted at rated frequency and at the voltage specified in Table 9.2 with the control installed as intended in the end-product. If the control operation changes due to varying the input voltage within the rated range, a test is also to be conducted at both the high and low values of the rated voltage range. For a control with a single voltage rating, if its operation changes as a result of testing at the test potential specified in Table 9.2, a test is also to be conducted at the voltage rating of the control.

Table 9.2
Tests voltages

| Voltage rating of control, volts ^a | Test potential, volts |
|---|-----------------------|
| 110 – 120 | 120 |
| 220 – 240 | 240 |
| 254 – 277 | 277 |
| 440 – 480 | 480 |
| 550 – 600 | 600 |

NOTE – See also 9.3.

^a If 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. If 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. If a range of voltages is specified and none of the values fall within any of the indicated voltage ranges, the control shall 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 can be shown that testing based on one rating would represent testing based on the other rating.

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 considered to be constant when three successive readings, measured by thermocouples and taken at intervals of 10 percent of the previously elapsed duration of the test, but not less than 5 minute intervals, indicate no significant change.

10 Overvoltage and Undervoltage Tests

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

- a) 110 percent of the normal supply test potential specified in Table 9.2, and
- b) The reduced voltage specified in 10.2,

until temperatures have become constant or for 7 hours, whichever occurs first. If 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.

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 investigated by the Composite Operational and Cycling Test, Section 16, need not be subjected to these tests.

11 Power Supply Interruption Test

11.1 While connected to a supply circuit of the voltage specified in Table 9.2, a control is to be set in an operating mode and subjected to interruption of the power supply. Before each successive interruption, the control is to be operating as intended. The interruption time is to be periodically increased in accordance with the increments specified in Table 11.1 until the operation of the control ceases. Initiation of the interruptions is to be random with respect to the phase angle of the power supply wave. The control shall operate as intended after each interruption or shall cease functioning with no loss of protective function.

Table 11.1
Power supply interruption sequence

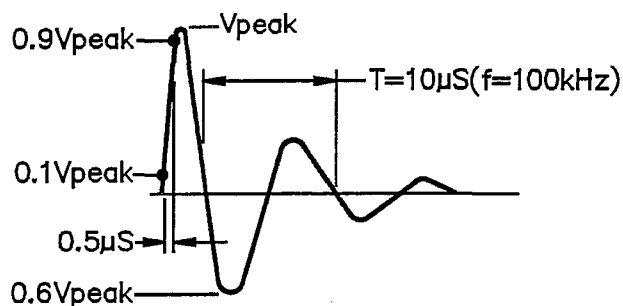
| Interruption time milliseconds | Interruption increments, milliseconds |
|-----------------------------------|--|
| 1 – 10 | 1 |
| 15 – 100 | 5 |
| 125 – above | 25 |

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 this section.

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

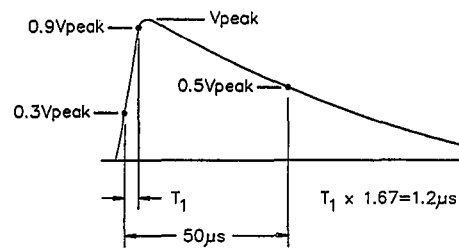
Figure 12.1
100 kilohertz ring wave
(open circuit voltage)



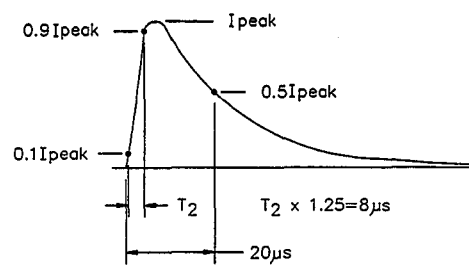
S3204

Figure 12.2
Unidirectional waveshapes

(A) OPEN-CIRCUIT VOLTAGE WAVEFORM

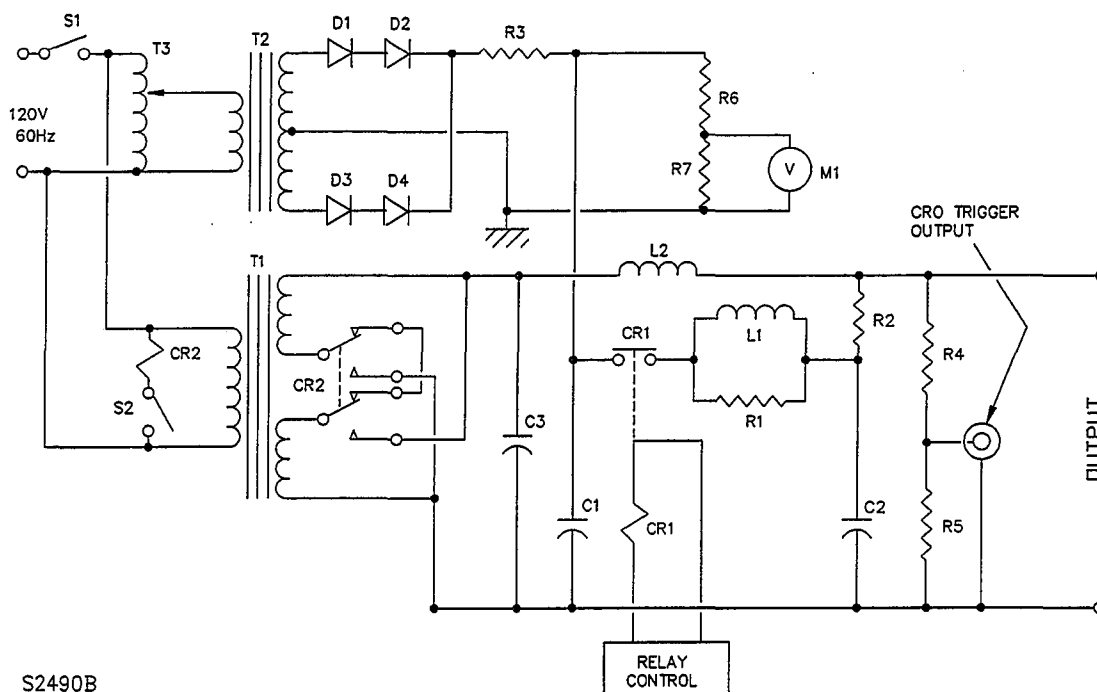


(B) LOW IMPEDANCE DISCHARGE
CURRENT WAVEFORM



S3205

Figure 12.3
Surge generator circuit



Ring Wave

- C1 - Capacitor, 0.025 μ F, 10 kV
- C2 - Capacitor, 0.006 μ F, 10 kV
- C3 - Capacitor, 10 μ F, 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 μ H [33 turns, No. 22 AWG wire, wound on 0.835 inch (21.2 mm) diameter PVC tubing]
- L2 - Inductor, 70 μ H [45 turns, No. 14 AWG wire, wound on 2.375 inch (60.33 mm) diameter PVC tubing]

M1 - Meter, 0 - 20 V, DC

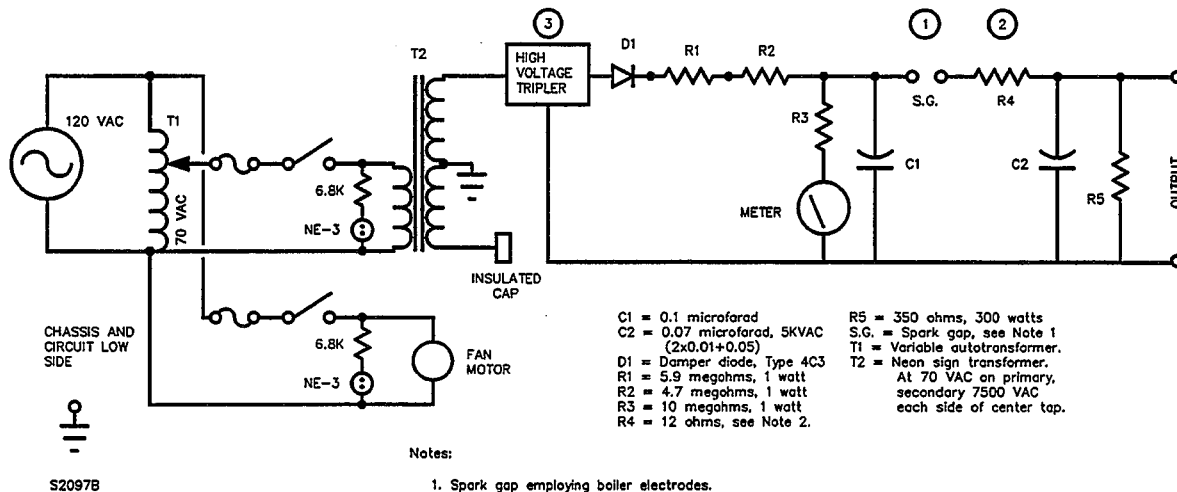
- R1 - Resistor, 22 Ohms, 1 W, composition
- R2 - Resistor, 12 Ohms, 1 W, composition
- R3 - Resistor, 1.3 Megohms (12 in series, 110k Ohms each, 1/2 W)
- R4 - Resistor, 47k Ohms (10 in series, 4.7k Ohms each, 1/2 W)
- R5 - Resistor, 470 Ohms, 1/2 W
- R6 - Resistor, 200 Megohms, 2 W, 10 kV
- R7 - Resistor, 0.2 Megohms (2 in series, 100k Ohms 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

Unidirectional 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 wave, degrees |
|---------------------------|-----------------|-------------------|-------------------------------|
| 1.2 x 50 μ s | 2 | Positive | 45 |
| 1.2 x 50 μ s | 2 | Positive | 90 |
| 1.2 x 50 μ s | 2 | Positive | 270 |
| 1.2 x 50 μ s | 2 | Negative | 90 |
| 1.2 x 50 μ s | 2 | Negative | 225 |
| 1.2 x 50 μ s | 2 | Negative | 270 |
| 0.5 μ s x 100 kHz | 20 | Positive | 45 |
| 0.5 μ s x 100 kHz | 20 | Positive | 90 |
| 0.5 μ s x 100 kHz | 20 | Positive | 270 |
| 0.5 μ s x 100 kHz | 20 | Negative | 90 |
| 0.5 μ s x 100 kHz | 20 | Negative | 225 |
| 0.5 μ s x 100 kHz | 20 | Negative | 270 |

^a The 0.8 x 20 μ s current waveform shown in Part B of Figure 12.2 is characteristic of low-impedance loads in contrast to the 1.2 x 50 μ s 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 unidirectional 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 seconds. 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 kilovolts. The short-circuit current of the 100 kHz ring waveshape shown in Figure 12.1 and the unidirectional waveshape shown in Figure 12.2 shall be 500 amperes and 3 kiloamperes 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 664-1, 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 |
| 150 | 800 | 1500 | 2500 |
| 300 | 1500 | 2500 | 4000 |
| 600 | 2500 | 4000 | 6000 |

^a Refer to the International Electrotechnical Commission (IEC) Publication 664, Insulation Coordination Within Low-Voltage Systems Including Clearances and Creepage Distances for Equipment for information on installation categories.

13 Ramp Voltage Tests

13.1 Voltage rise test

13.1.1 A control is to be subjected to a power increase by continuously raising the voltage from 20 percent of rated voltage to 100 percent at a rate of 40 percent of rated voltage per second. This test is to be repeated ten times. At the 100 percent value, the control shall perform its intended function.

13.2 Voltage fall test

13.2.1 A control is to be subjected to a power decrease by continuously lowering the voltage from 100 percent of rated voltage to 20 percent at a rate of 40 percent of rated voltage per second. At the 20 percent value, the control shall no longer operate. This test is to be repeated ten times. At the conclusion of the test, the control shall be returned to 100 percent of rated voltage and shall perform its intended function.

14 Electromagnetic Susceptibility Tests

14.1 General

14.1.1 A control shall perform its intended function when subjected to extraneous transients generated by the equipment described in 14.4.1 – 14.6.1, or shut down without loss of protective function.

14.2 Input and output fast transient test

14.2.1 The input, output, and supply circuit of a control shall be subjected to the fast transient (electrical noise) test as described in 14.2.2 – 14.6.1.

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 noise generator, fed through a coupling cabling assembly, shall be applied, one by one, to the wiring under test. See 14.5.1 and 14.6.1.

14.3 Noise injected on control wiring

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

- a) Connect all other circuits as appropriate to their function.
- b) Energize the control.
- c) Energize the fast transient (noise) generator.
- d) Exercise all functions of the control.
- e) Repeat procedure for each circuit being investigated.

Figure 14.1
Noise test connection

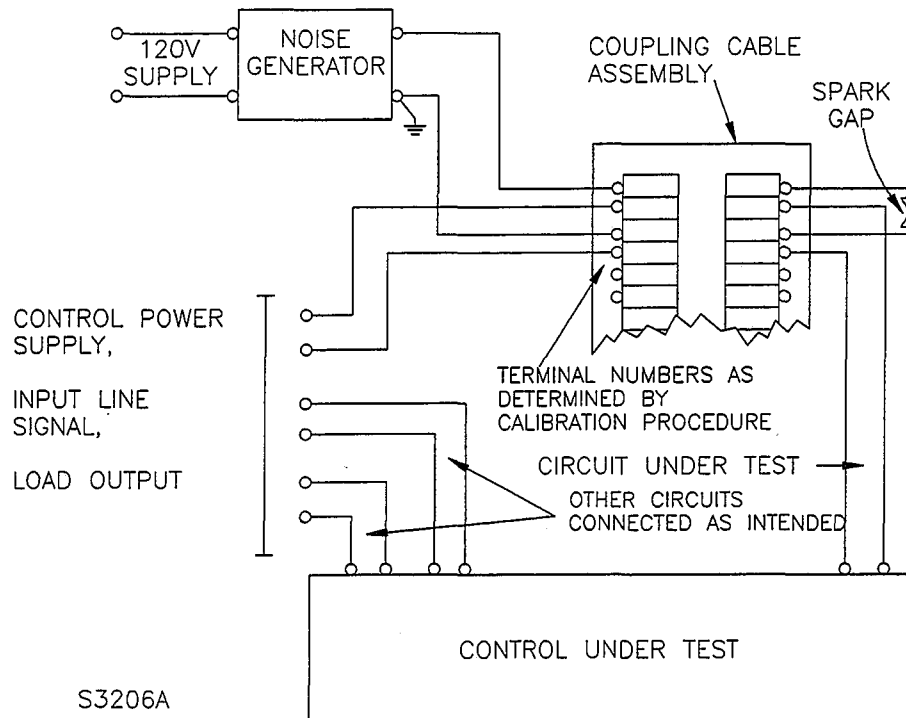
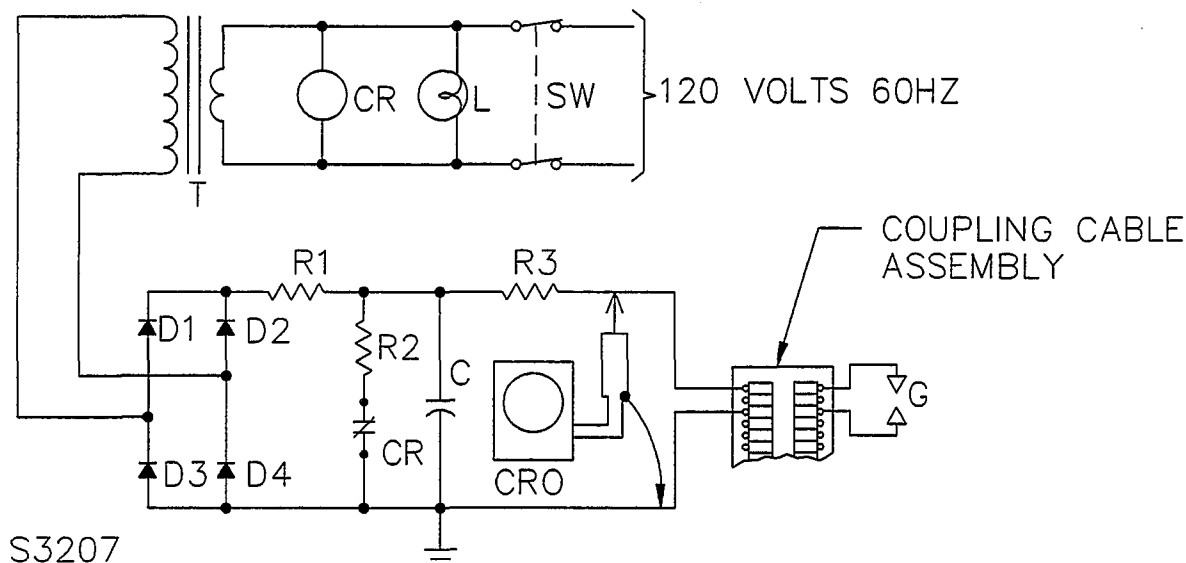


Figure 14.2
Fast transient (noise) generator



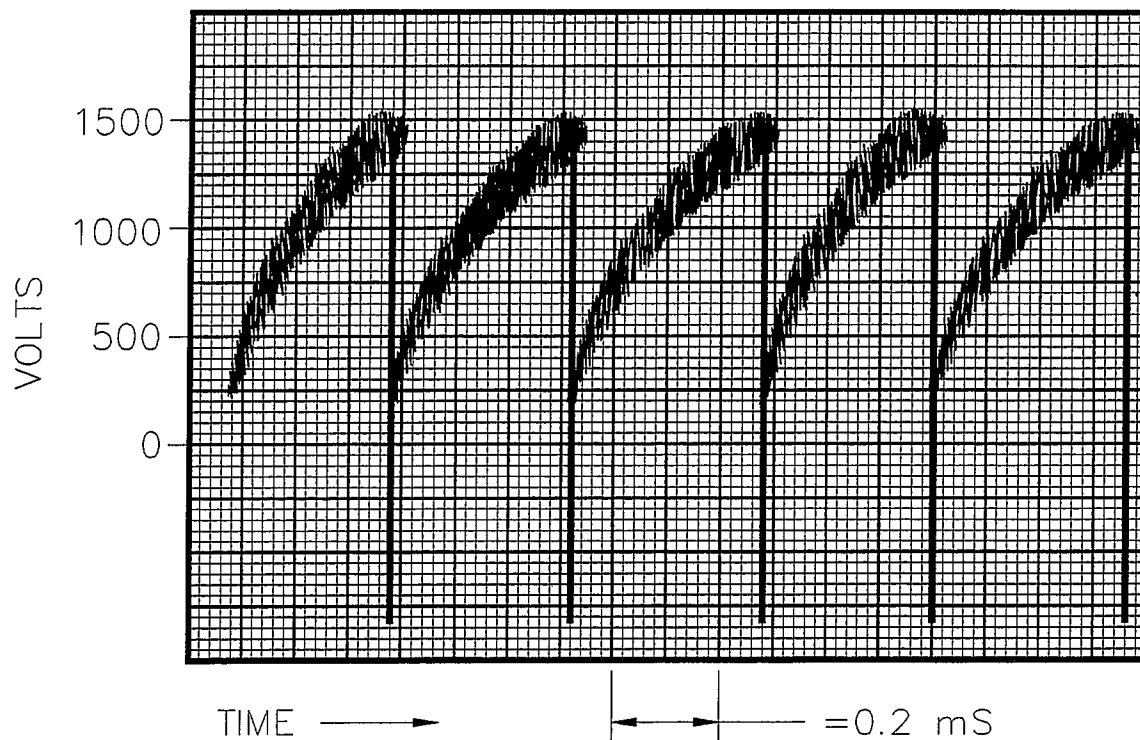
- | | | |
|---------------------------------|---|---|
| CR | — | 120 V 60 Hz relay with normally closed contacts |
| T | — | luminous sign transformer 100 VA 120 V primary, 3 kV secondary |
| R ₁ , R ₂ | — | 50 k Ω 20 W wire-wound resistor |
| R ₃ | — | 300 k Ω 30 W resistor |
| SW | — | ON-OFF switch |
| L | — | red warning lamp |
| D1, D2, | — | 10 kV, 25 mA silicon diodes |
| D3, D4 | | |
| C | — | 1.0 μ F, 5 kV capacitor |
| CRO | — | cathode ray oscilloscope (100 kHz or greater upper bandwidth limit) |
| P | — | 2 kV oscilloscope probe |
| G | — | tungsten contacts (automobile ignition breaker point set with insulated lever attached. Lever provides 2:1 motion reduction so that 2.5 mm motion provided by micrometer screw results in gap adjustment from 0 to 1.25 mm) |

CAUTION — THE VOLTAGES AND POWER AVAILABLE MAY BE DANGEROUS TO HUMAN LIFE. THE EQUIPMENT MUST BE HANDLED WITH CARE. THE RED PILOT LIGHT WARNS OF THE DANGER. THE NORMALLY CLOSED RELAY CONTACTS PROVIDE A RAPID DISCHARGE PATH FOR THE CAPACITOR WHEN THE SWITCH IS OPENED.

14.4 Fast transient (noise) generator

14.4.1 The characteristics of the electrical noise are to be reproduced with controlled voltage amplitude by the test equipment shown in Figure 14.2. Adjustment of the spark gap, G, from 0 to 1.25 mm will produce showering-arc transients from a minimum of 350 volts to more than 2000 volts. The voltage is to be measured by observing an oscilloscope display. A typical oscilloscope display is shown in Figure 14.3.

Figure 14.3
Typical oscillogram of continuous single polarity
transient produced by showering arc electrical noise generator

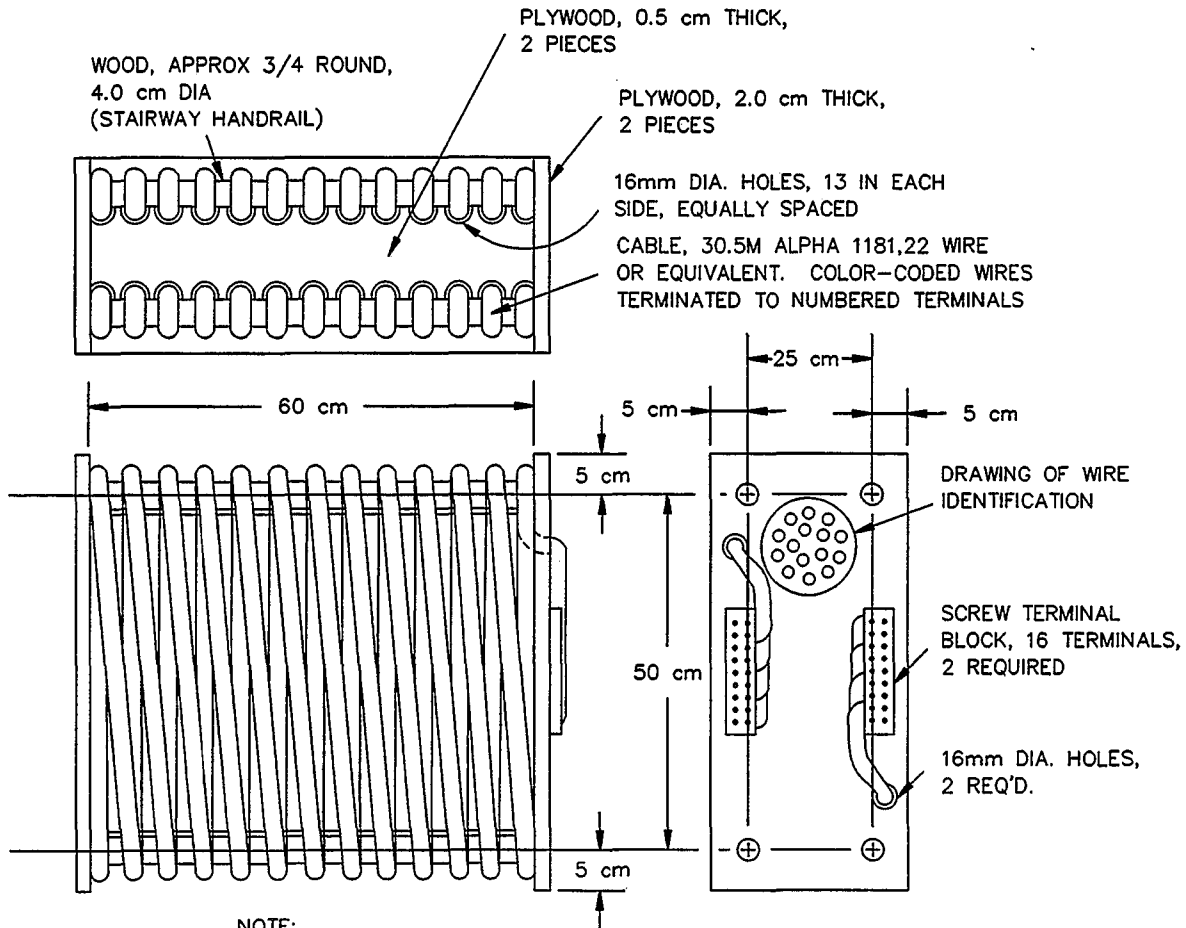


S3208

14.5 Coupling cable assembly

14.5.1 Electrical signals produced by the noise generator are to be coupled into the control circuits by the coupling cable assembly constructed in accordance with Figure 14.4. The conductors in the cable are to be arranged in accordance with Figure 14.5. Connections between the noise generator and spark gap are to be made with cable wires No. 1 and 6 which are diametrically opposite. Two other wires are to be used to make the connections shown in Figure 14.1. These two wires are to be selected using the calibration procedure described in 14.6.1.

Figure 14.4
Cable assembly for coupling noise into signal
and power lines

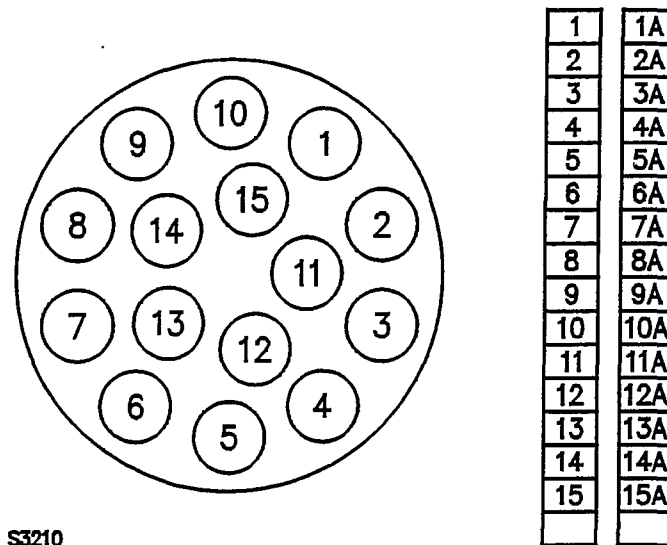


NOTE:

1. ASSEMBLE FRAME WITH WOOD SCREWS AND GLUE
2. FINISH WITH TWO COATS OF SHELLAC
3. MOUNT CABLE

S3209B

Figure 14.5
Noise test conductor arrangement



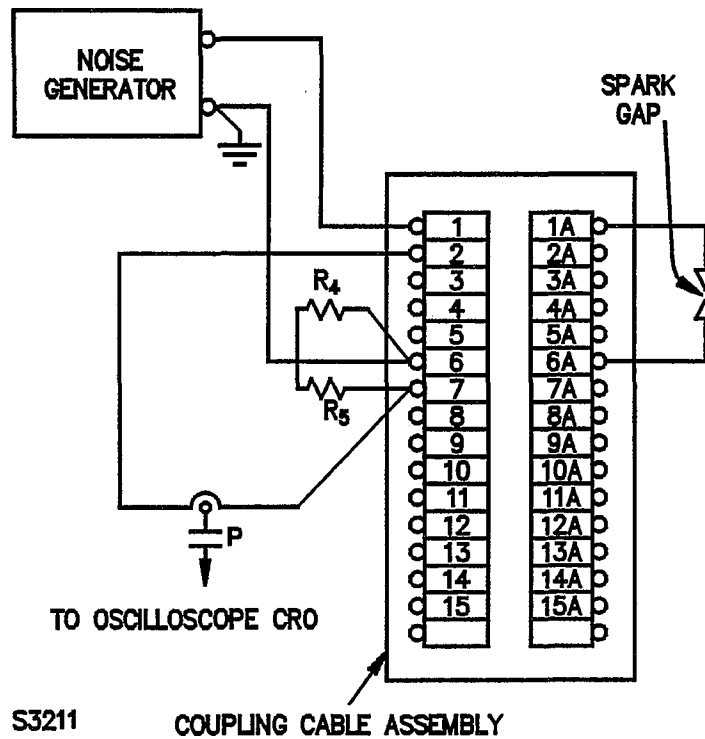
Identify wires with numbers on the terminal block 1, 2, 3, 4,...15 on one end of the cable and numbers plus letters 1A, 2A,...15A on the other end of the cable.

14.6 Calibration procedure for fast transient (noise) generator and coupling cable assembly

14.6.1 The output of the coupling cable assembly is calibrated by selecting the proper pairs of wires to be used as the input and output of the cable assembly in accordance with the following:

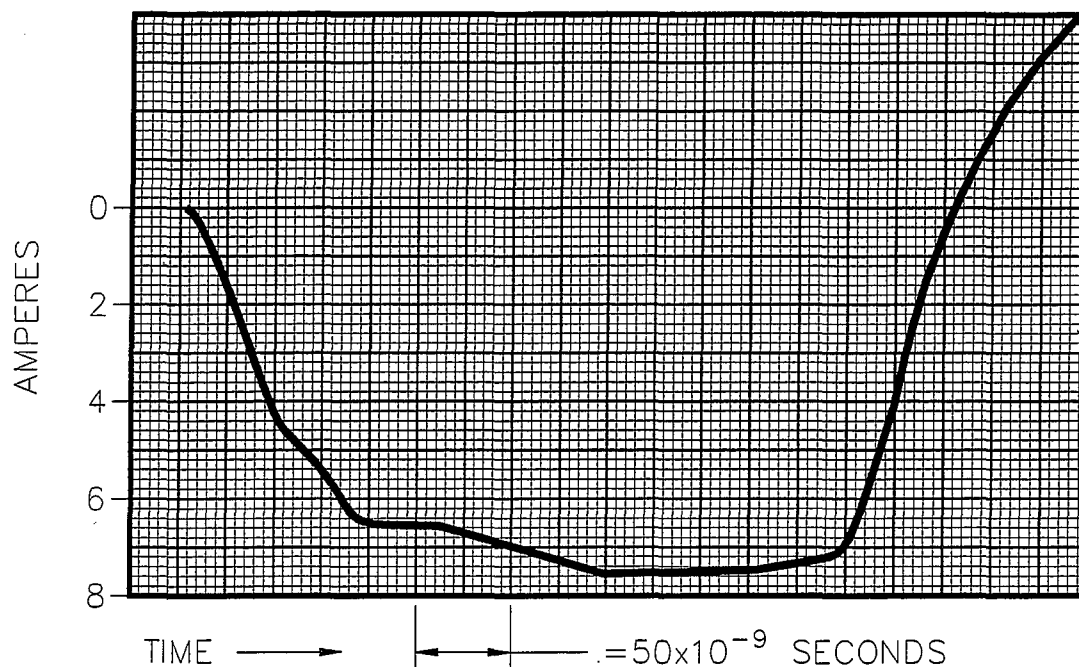
- Connect the test circuit to the terminals as shown in Figure 14.6.
- Adjust the fast transient (noise) generator by means of the spark gap, G, to produce 1500-volt transients similar to the display shown in Figure 14.3.
- After setting the fast transient (noise) generator, make an oscilloscope measurement of the output of the cable assembly as shown in Figure 14.7. This provides a measure of the peak current and the slope of the current in the leading edge of the first current pulse of the oscillation caused by each showering arc transient.
- If the measurements are not within the tolerances shown in Figure 14.7, select a pair of wires other than 2-2A and 7-7A (for example, 10-10A and 5-5A, 2-2A and 5-5A, or 10-10A and 7-7A). If none of these combinations produces the desired result, a pair of wires other than 1-1A and 6-6A is to be used for the input and the above test procedure repeated with other pairs of wires used for the output to determine which pairs of wires give an output within the calibration shown in Figure 14.7.
- Connect the output of the cable assembly to the device under test with a twisted pair of wires not more than 9.8 feet or 3 meters long.

Figure 14.6
Connection and parts for coupling cable assembly



- R₄, R₅ — 270 k Ω \pm 10% 1 W carbon composition
P — Current probe for oscilloscope, 50 MHz or greater upper bandwidth limit. Use Tektronix CT-2 current probe or one of equivalent characteristics.
CRO — Oscilloscope, 50 MHz or greater upper bandwidth limit.

Figure 14.7
Current pulse oscillogram for coupling cable assembly



S3212

Peak Current = 6 Amperes Minimum

Leading Edge Rise Time from 1 to 3 Amperes = 25×10^{-9} Seconds Maximum

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 volts, as delivered into a 200 ohm load. A transient waveform at 2400 volts is to have a pulse rise time of 100 volts per microsecond, a pulse duration of approximately 80 microseconds, and an energy level of approximately 1.2 joules. Other applied transients are to have peak voltages representative of the entire range of 100 to 2400 volts but not equal to the clamping voltage of any transient suppressing device in the circuit, with pulse durations from 80 to 1110 microseconds, and energy levels not less than 0.03 joule or greater than 1.2 joules. 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:

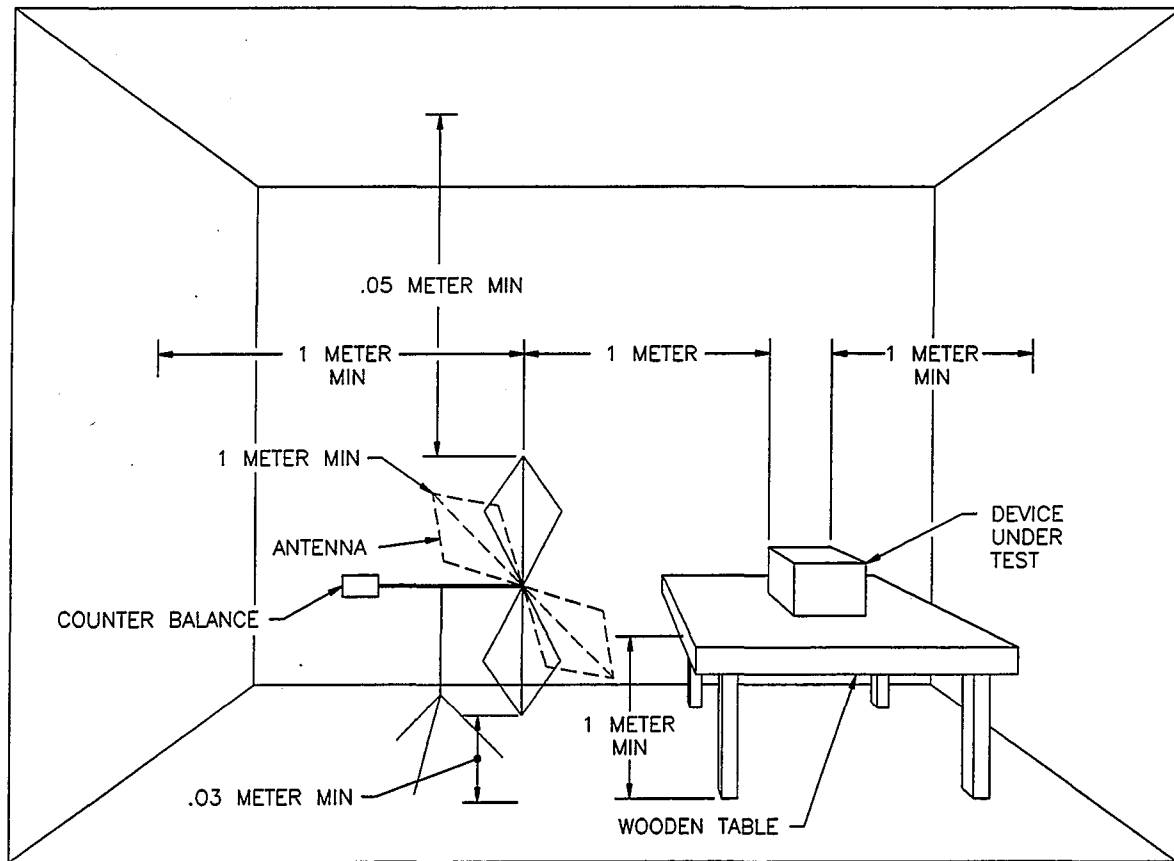
- a) Sixteen pulses (two at each transient voltage level specified in 14.7.2) between each circuit lead or terminal and earth ground, consisting of eight pulses of one polarity, and eight of the opposite polarity, and
- b) Sixteen pulses (two at each transient voltage level specified in 14.7.2) between 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 14.8. 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-foot or 1-meter 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 14.8
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 megahertz, the test is to be run with an amplitude modulation of 90 percent with a 1000 hertz 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 14.1, 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 14.1
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 14.2 specifies test levels for low and moderate exposures. Unless otherwise indicated in the end-product standard, a field strength of 3 volts per meter 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 14.2
Transmission levels

| EMI level | Field strength, volts/meter |
|-----------------------------------|-----------------------------|
| 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 14.1 that is 90 percent amplitude (pulse or square wave) modulated at approximate frequency of, but no less than, 10 kilohertz. 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 microseconds. At least three keying cycles per frequency octave are to be conducted.

15 Electrostatic Discharge Test

15.1 General

15.1.1 After being subjected to electrostatic discharges described in this section, a control shall be energized for 72 hours 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 hours, and the test is to be conducted, in an ambient temperature of $23 \pm 3^{\circ}\text{C}$ or $73 \pm 5^{\circ}\text{F}$, 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 hour after removal from the conditioning chamber.

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

15.1.3 A control is to be mounted in its intended mounting position and connected to a source of supply in accordance with Table 9.2. If a control is intended to be installed on an electrically conductive plate or mounting bracket, the plate or bracket is to be connected to earth ground.

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

15.2 Electrostatic Discharge Probe

15.2.1 The relevant characteristics of the electrostatic discharge probe are:

- a) Energy storage capacitor: 100 picofarads ± 10 percent.
- b) Discharge resistor: 1500 ohms ± 5 percent.
- c) Output voltage: Variable between 4 – 20 kilovolts.
- d) Discharge tip: 8 mm diameter ± 0.05 mm.

15.3 Air Discharge Test

15.3.1 The air discharge test is to be conducted in increasing 2-kilovolt 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.

15.3.2 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.

15.3.3 The charged probe is to be brought to the preselected test point until a discharge through air occurs. 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 alternating polarity between each successive discharge. The interval between successive single discharges is to be at least 5 seconds. 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 kilovolts.

15.3.4 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.

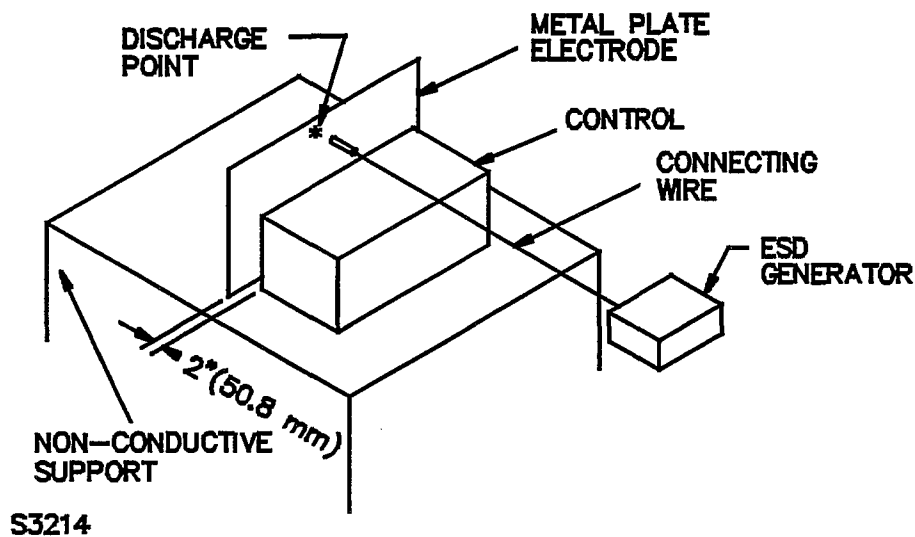
15.4 Electric field test

15.4.1 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 inches from one of the surfaces of the control according to Figure 15.1 and is to be insulated from ground. The test probe is to be:

- a) Attached to the electrostatic discharge generator by four feet of 18 AWG or 1.02 mm diameter insulated wire suitable for the voltages involved, and
- b) Charged to 20 kilovolts.

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 inch 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.

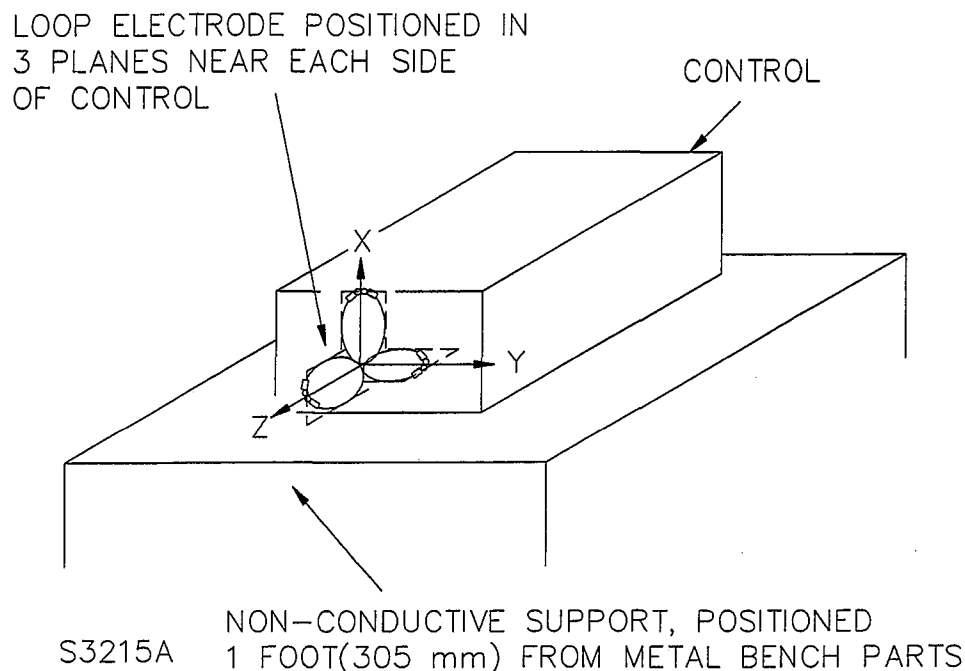
Figure 15.1
Electric field test method



15.5 Magnetic field test

15.5.1 The control is to be tested in a magnetic field created by static discharge. The test probe is to be charged to 20 kilovolts. The magnetic field is produced by forming an approximately 12-inch 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 inches 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 15.2. Controls that fit within the loop are to be tested within the loop; for such controls, six discharges are sufficient and the 2-inch limit does not apply.

Figure 15.2
Magnetic field test method



16 Composite Operational and 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 thirty minutes during each 24 hour 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 hour period shall also include at least one period of 30 seconds 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 per minute and the extremes of temperature are to be maintained for approximately 1 hour.

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°C or 158°F for a period of 24 hours, cooled to a room temperature of $23 \pm 3^\circ\text{C}$ or $73 \pm 5^\circ\text{F}$ for at least 1 hour, and then exposed to a temperature of minus 30°C or minus 22°F for at least 3 hours and finally warmed up to room temperature for a minimum of 3 hours.

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 minutes, and there is to be a period of not less than 10 minutes 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 International Electrotechnical Commission Publication 68-2-30(1980), "Damp Heat, Cyclic" with the following parameters:

- a) *Severity level:*
 - 1) *Upper temperature: $40 \pm 2^{\circ}\text{C}$ or $104 \pm 4^{\circ}\text{F}$*
 - 2) *Number of cycles: 6*
- b) *Stabilizing temperature: $20 \pm 5^{\circ}\text{C}$ or $68 \pm 9^{\circ}\text{F}$*
- c) *Test cycle: Variant 2*
- d) *State of specimen during conditioning: Unenergized*
- e) *Intermediate measurements: none required*
- f) *Recovery conditions: Two hours at standard laboratory atmosphere ($15 - 35^{\circ}\text{C}$ or $59 - 95^{\circ}\text{F}$, 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 | H1 | H2 | H3 | H4 | H5 | H6 |
|---------------------------------|--|--|---|---|---|-----------------------------|
| Temperature | $30 \pm 2^{\circ}\text{C}$ $86 \pm 4^{\circ}\text{F}$ | $30 \pm 2^{\circ}\text{C}$ $86 \pm 4^{\circ}\text{F}$ | $40 \pm 2^{\circ}\text{C}$ $104 \pm 2^{\circ}\text{F}$ | $40 \pm 2^{\circ}\text{C}$ $104 \pm 2^{\circ}\text{F}$ | $40 \pm 2^{\circ}\text{C}$ $104 \pm 2^{\circ}\text{F}$ | 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 | 336 hours | |

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 hours exposure to each of the specified humidity levels. The time required to reach the level is not to exceed 1 hour.

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 hours of exposure at maximum RH, the control is to be energized and checked to determine that it operates as intended.

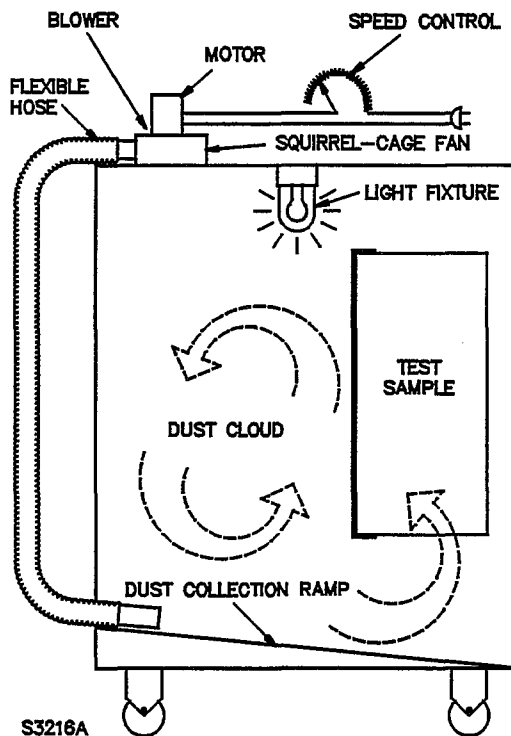
20 Dust Test

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 cubic feet or 0.17 m³, 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 ounces of cement per cubic foot or 1.5 kilograms 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 minutes 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 feet per minute or 15 meters per minute. 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 |
|------------------|--------------------|-------------------|-----------------|
| | Inch | 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 hertz.

Table 21.1
Vibration classes

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

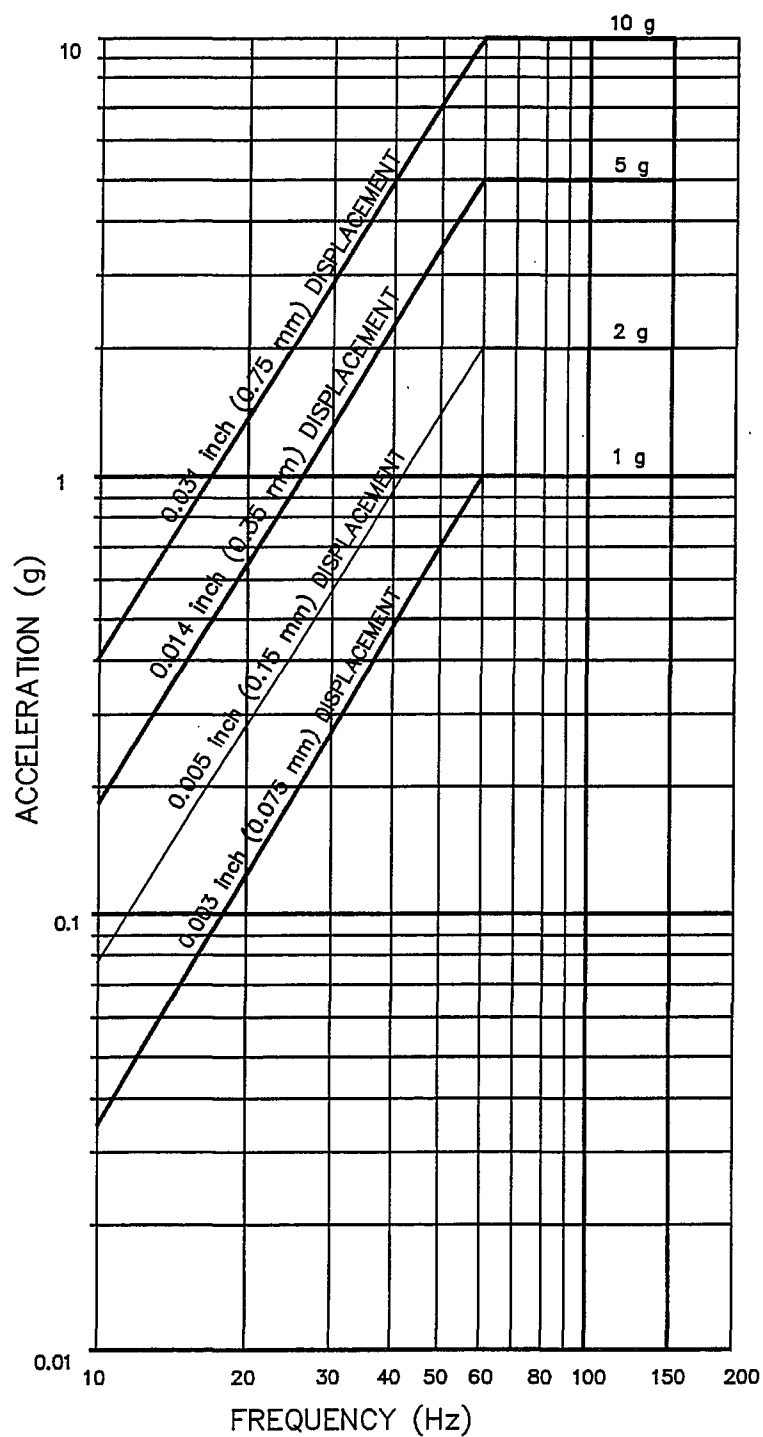
21.3.2 The applied motion is to be sinusoidal and result in the fixing points of the control moving in phase and in straight parallel lines. The motion is to attain the specified maximum displacement amplitude as frequency is increased from 10 hertz until a crossover point at 60 hertz is reached which 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 hertz. 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 hertz and ± 2 percent above 50 hertz. 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 minutes. 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



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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-foot or 1.8- by 1.2-m, nominal 3/4-inch or 20 mm thick plywood board that is secured in place at four corners. A single 3-foot-pound 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 pound or 0.54 kg, 2 inch or 51 mm diameter steel sphere either:

- a) Swung through a pendulum arc from a height of 2.54 feet or 775 mm, or
- b) Dropped from height of 2.54 feet to apply 3 foot-pounds of energy depending upon the mounting of the equipment.

COMPUTATIONAL INVESTIGATION AND DEMONSTRATED METHOD

23 General

23.1 An electronic device may be judged by the procedures under the Computational Investigation or the Demonstrated Method to determine that it has been constructed in a manner to achieve a reasonable level of performance with respect to the intended use of the control. Failure of any single noncritical component shall not increase the thermal or electrical stresses of any critical component beyond the stress levels used to calculate the failure rate of the critical component, unless the failure of the noncritical component results in a trouble indication considered to be acceptable in the end-product standard.

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.

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 (λ_p) 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.

| 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 | |

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

- a) The tables in Military Handbook Number 217, 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 hours/year ^{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. | | |

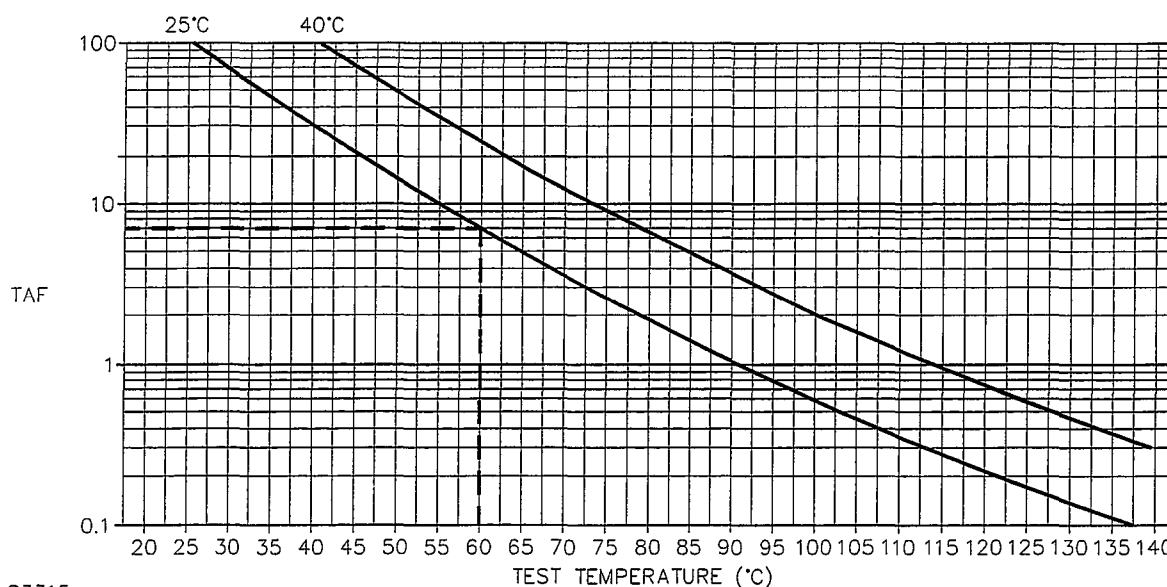
Table 25.2
Test acceleration factor equations

| Use ambient | Equation |
|--|---|
| Any | $TAF = \ln^{-1} \left[\left(\frac{1}{T_t} - \frac{1}{T_a} \right) 7543.23 + 4.6052 \right]$ |
| 40°C | $TAF = \ln^{-1} \left(\frac{7543.23}{T_t} - 19.4830 \right)$ |
| 25°C | $TAF = \ln^{-1} \left(\frac{7543.23}{T_t} - 20.6949 \right)$ |
| 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



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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 may 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.

PRODUCTION TESTS

29 General

29.1 To verify continued compliance with these requirements, acceptable tests shall be conducted during the production of controls. These tests shall consider, but not be limited to, component screening and burn-in as well as a quality assurance program.

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 plainly and permanently marked with the manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the device may be identified, a distinctive catalog number or the equivalent, and 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.

