

UL 991

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Tests for Safety-Related Controls Employing Solid-State Devices

Underwriters Laboratories Inc. (UL)
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The revisions dated August 11, 2000 include a reprinted title page (page1) for this Standard.

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New product submittals made prior to a specified future effective date will be judged under all of the requirements in this Standard including those requirements with a specified future effective date, unless the applicant specifically requests that the product be judged under the current requirements. However, if the applicant elects this option, it should be noted that compliance with all the requirements in this Standard will be required as a condition of continued Listing and Follow-Up Services after the effective date, and understanding of this should be signified in writing.

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UL 991

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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 set of revised requirements.

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.

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FOREWORD

A. This Standard contains basic requirements for 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. These requirements are 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. They are subject to revision as further experience and investigation may show is necessary or desirable.

B. The observance of the requirements of this Standard by a manufacturer is one of the conditions of the continued coverage of the manufacturer's product.

C. A product which complies with the text of this Standard will not necessarily be judged to comply with the Standard if, when examined and tested, it is found to have other features which impair the level of safety contemplated by these requirements.

D. A product employing materials or having forms of construction which conflict with specific requirements of the Standard cannot be judged to comply with the Standard. A product employing materials or having forms of construction not addressed by this Standard may be examined and tested according to the intent of the requirements and, if found to meet the intent of this Standard, may be judged to comply with the Standard.

E. 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.

F. 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 or of electric shock or injury to persons shall be evaluated using appropriate additional component and end-product requirements to maintain the 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 does not comply with this standard. Revision of requirements shall be proposed and adopted in conformance with the methods employed for development, revision, and implementation of this standard.

1.6 revised August 11, 2000

2 Components

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

Exception: 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.*

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

2.3 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.

3.1 revised August 11, 2000

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 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.

5.13 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.

5.13 added August 11, 2000

5.14 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.

5.14 added August 11, 2000

5.15 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.

5.15 added August 11, 2000

5.16 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.

5.16 added August 11, 2000

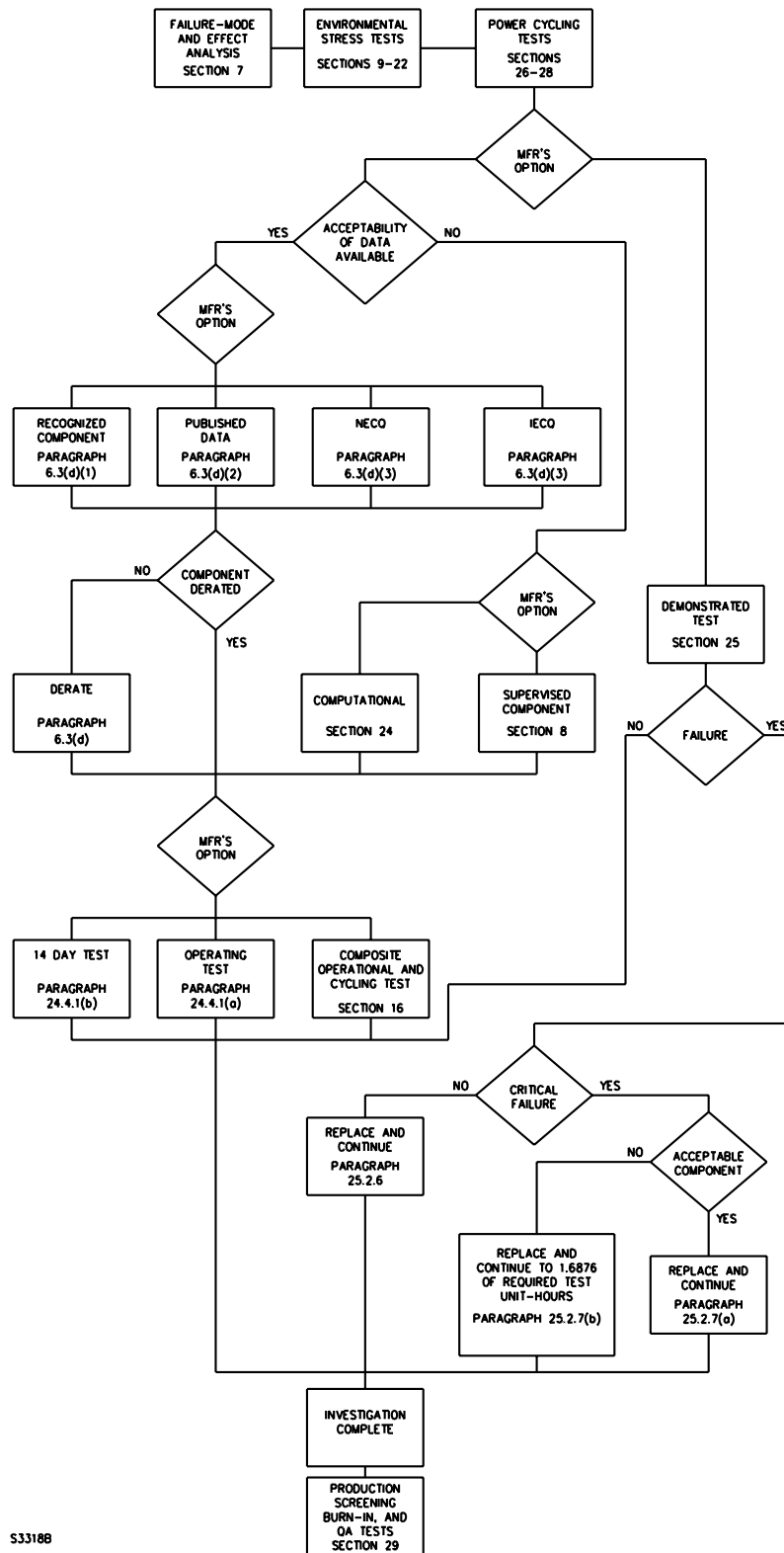
INVESTIGATION

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



S33188

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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

Table 7.1 revised August 11, 2000

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
^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.								

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 performed at rated frequency and at the voltage specified in Table 9.2 with the control installed as intended in the end-product.

9.3 revised August 11, 2000

Table 9.2
Tests voltages

Table 9.2 revised August 11, 2000

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

^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 minute intervals, indicate no change.

9.5 revised August 11, 2000

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 hours, 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.

10.1 revised August 11, 2000

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.

10.2 revised August 11, 2000

11 Power Supply Voltage Dips and Short Interruption Test

11.1 General

11.1 added August 11, 2000

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 11.2 – 11.4. 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.

11.1.1 revised August 11, 2000

11.2 Test voltage levels

11.2 added August 11, 2000

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.

11.2.1 added August 11, 2000

Table 11.1
Test values for voltage dips and interruptions

Table 11.1 revised August 11, 2000

Test	ΔV	Duration, seconds
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 seconds.

11.3 Test Conditions

11.3 added August 11, 2000

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.

11.3.1 added August 11, 2000

11.4 Test procedure

11.4 added August 11, 2000

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.

11.4.1 added August 11, 2000

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.

11.4.2 added August 11, 2000

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.

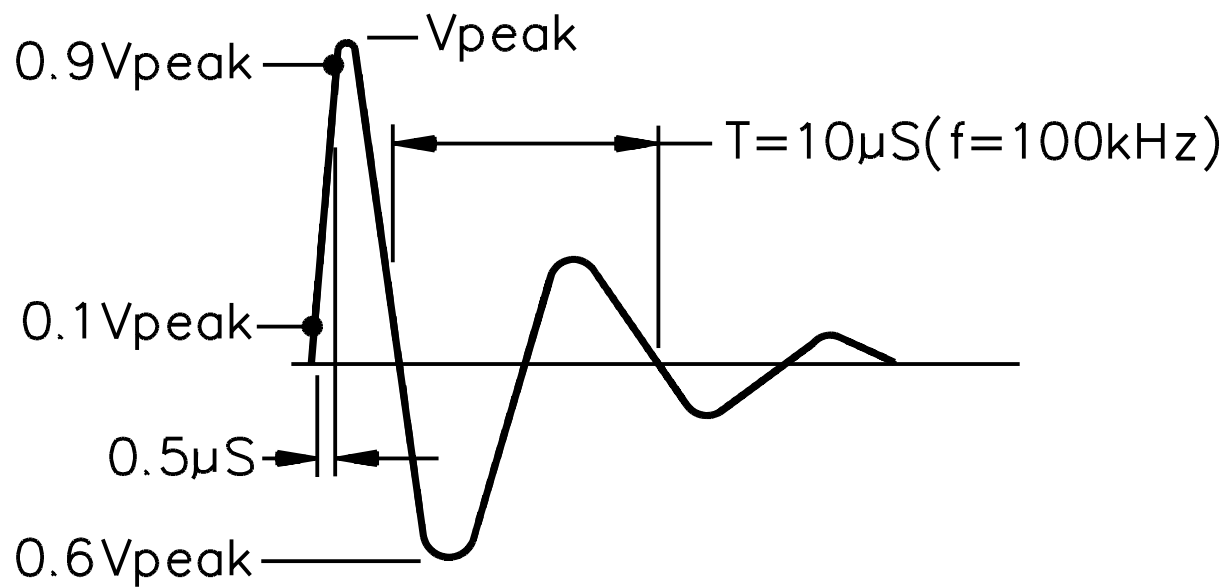
11.4.3 added August 11, 2000

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.

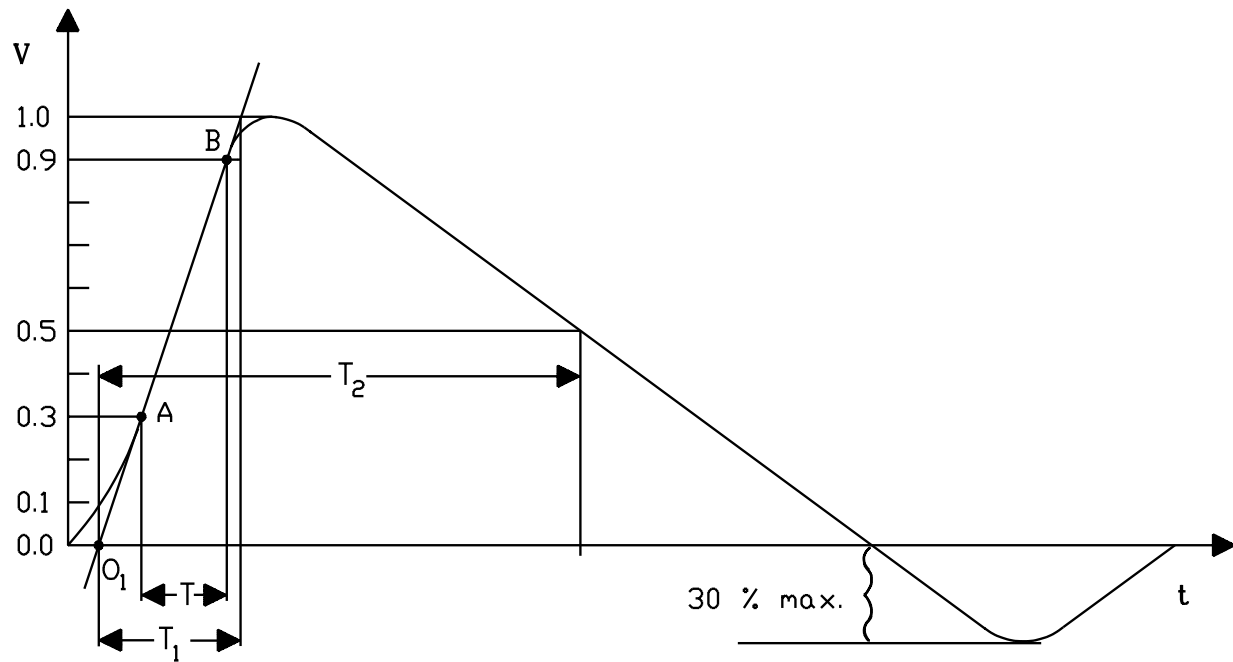
12.2 The control is to be connected to a transient generator, capable of producing the impulse waveshapes shown in Figures 12.1 and 12.2. Typical transient generator circuits are shown in Figures 12.3 and 12.4; other test circuits that produce the required waveshape may also be used.

Figure 12.1
100 kilohertz ring wave
(open circuit voltage)



S3204

Figure 12.2
Impulse waves
 (Open-circuited generator voltage wave (1.2/50 μ s))
 Figure 12.2 revised August 11, 2000



SM1171A

NOTES

1 Front time: $T_1 = 1.67 \times T = 1.2 \mu\text{s} \pm 30$ percent

2 Time to half value: $T_2 = 50 \mu\text{s} \pm 20$ percent

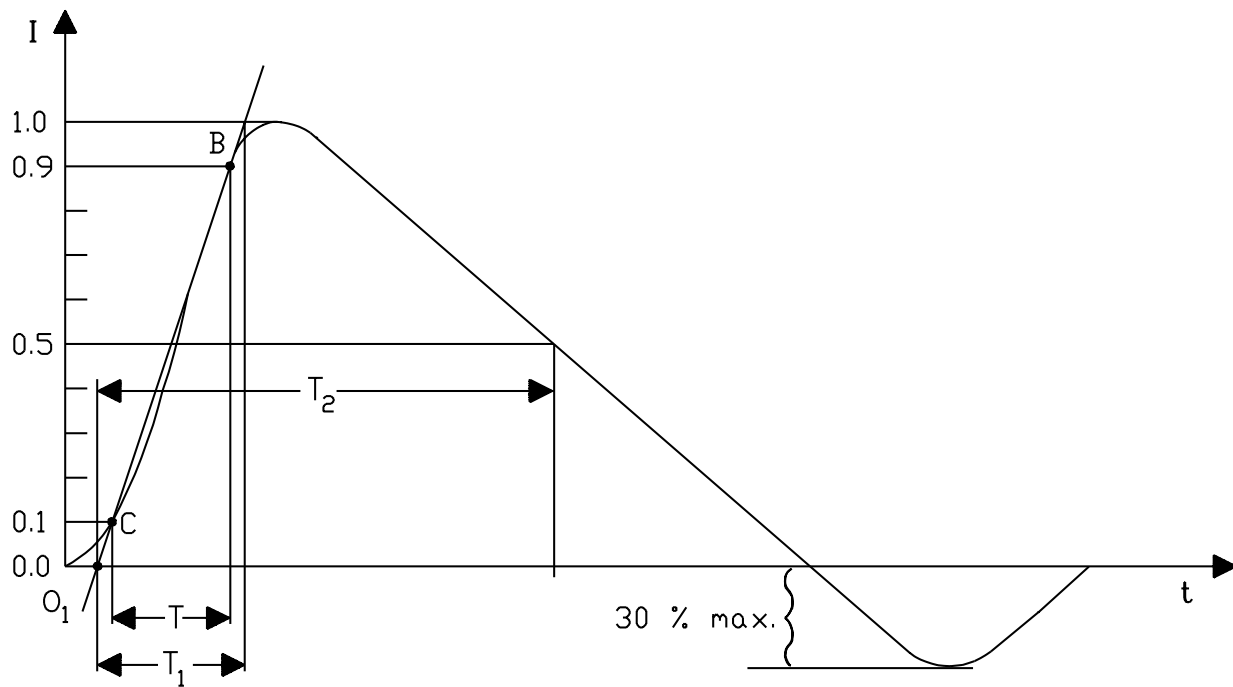
3 Line AB is the virtual rise time line formed with points A and B

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 O_1 is the virtual origin point

Figure 12.2 (Cont'd)
Impulse waves
 (Short-circuited generator current wave (8/20 μ s))



SM1172A

NOTES

1 Front time: $T_1 = 1.25 \times T = 8 \mu\text{s} \pm 20$ percent

2 Time to half value: $T_2 = 20 \mu\text{s} \pm 20$ percent

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

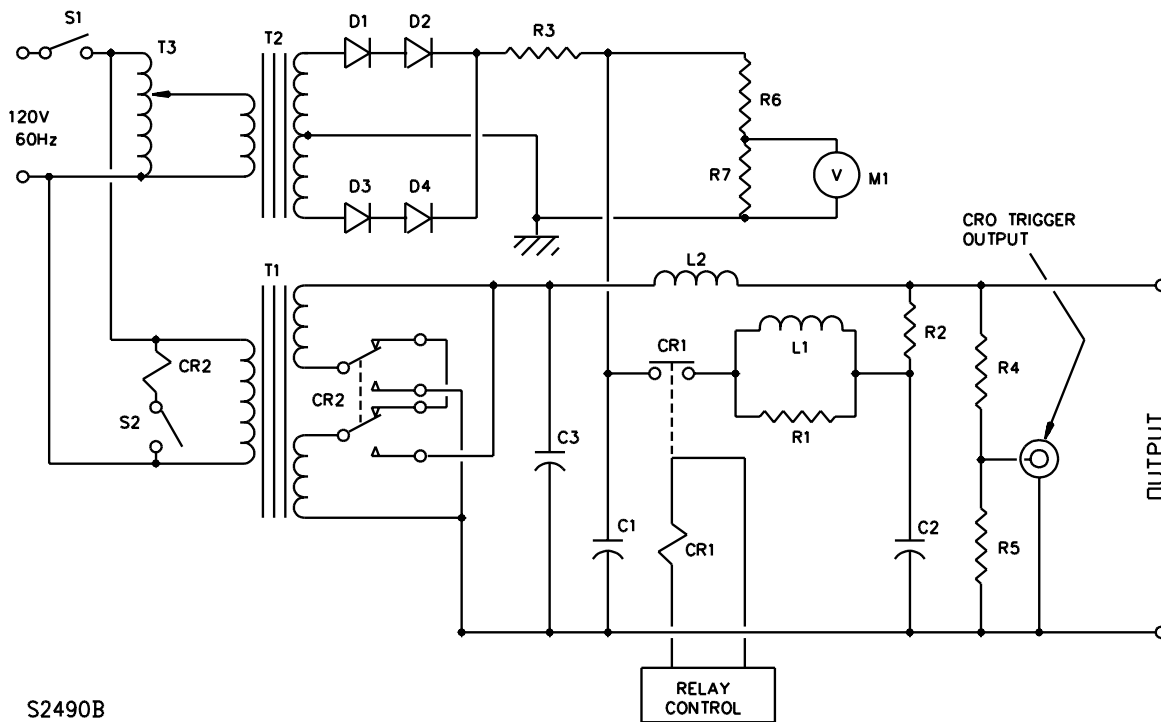
4 C is the point on line BC at 10 percent of the peak value

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

6 O_1 is the virtual origin point

Figure 12.3
Surge generator circuit
(Ring Wave)

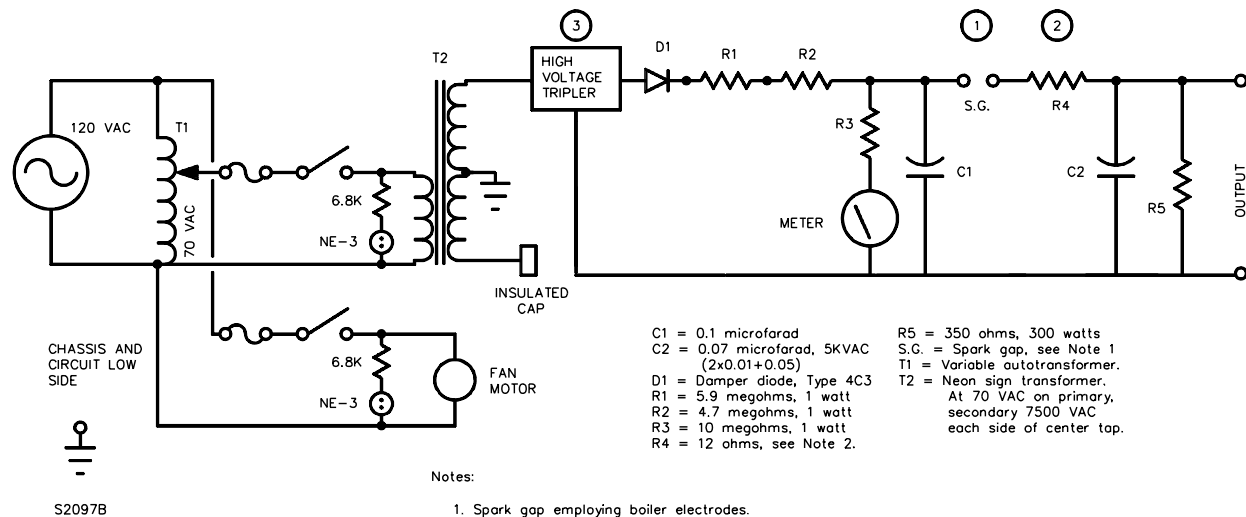
Figure 12.3 revised August 11, 2000



- C1 – Capacitor, 0.025 microfarads, 10 kilovolts
- C2 – Capacitor, 0.006 microfarads, 10 kilovolts
- C3 – Capacitor, 10 microfarads, 400 volts
- CR1 – Relay, coil 24 volts, dc. Contacts, 3-pole, single throw, each contact rated 25 amperes, 600 volts, ac maximum: All three poles wired in series
- CR2 – Relay, coil 120 volts, ac. Contacts DPDT. Provides either 120 volts or 240 volts test circuit.
- D1 – D4 – Diodes, 25 kilovolts PIV each
- L1 – Inductor, 15 microhenries [33 turns, No. 22 AWG wire, wound on 0.835 inch (21.2 mm) diameter PVC tubing]
- L2 – Inductor, 70 microhenries [45 turns, No. 14 AWG wire, wound on 2.375 inch (60.33 mm) diameter PVC tubing]
- M1 – Meter, 0 - 20 volts, dc
- R1 – Resistor, 22 ohms, 1 watt, composition
- R2 – Resistor, 12 ohms, 1 watt, composition
- R3 – Resistor, 1.3 megohms (12 in series, 110 kilohms each, 1/2 watt)
- R4 – Resistor, 47 kilohms (10 in series, 4.7 kilohms each, 1/2 watt)
- R5 – Resistor, 470 ohms, 1/2 watt
- R6 – Resistor, 200 megohms, 2 watt, 10 kilovolt
- R7 – Resistor, 0.2 megohms (2 in series, 100 kilohms each, 2 watts, carbon)
- S1 – Switch, SPST
- S2 – Switch, SPST, key-operated, 120 volts, ac, 1 ampere
- T1 – Transformer, 2 kilovoltamperes, 120 volts primary, 1:1 (120 volts or 240 volts output)
- T2 – Transformer, 90 voltamperes, 120/15,000 volts
- T3 – Variable autotransformer, 2.5 amperes

Figure 12.4
Surge generator circuit
(Impulse Wave)

Figure 12.4 revised November 11, 1996



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.

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