NEMA STANDARDS PUBLICATION

NEMA ICS 1

INDUSTRIAL CONTROL AND SYSTEMS GENERAL REQUIREMENTS

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION

NEMA Standards Publication No. ICS 1-2000

Industrial Control and Systems
General Requirements

Published by

National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, VA 22209

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Foreword

This standards publication was prepared by a technical committee of the NEMA Industrial Automation Control Products and Systems Section. It was approved in accordance with the bylaws of NEMA and supersedes the indicated NEMA Standards Publication. This standards publication supersedes ICS 1-1993.

This standards publication provides practical information concerning ratings, construction, test, performance and manufacture of industrial control equipment. These standards are used by the electrical industry to provide guidelines for the manufacture and proper application of reliable products and equipment and to promote the benefits of repetitive manufacturing and widespread product availability.

NEMA standards represent the result of many years of research, investigation, and experience by the members of NEMA, its predecessors, its sections and committees. They have been developed through continuing consultation among manufacturers, users and national engineering societies and have resulted in improved serviceability of electrical products with economies to manufacturers and users.

One of the primary purposes of this standards publication is to encourage the production of reliable control equipment which, in itself, functions in accordance with these accepted standards. Some portions of these standards, such as electrical spacings and interrupting ratings, have a direct bearing on safety; almost all of the items in this publication, when applied properly, contribute to safety in one way or another.

Properly constructed industrial control equipment is, however, only one factor in minimizing the hazards, which may be associated with the use of electricity. The reduction of hazard involves the joint efforts of the various equipment manufacturers, the system designer, the installer and the user. Information is provided herein to assist users and others in the proper selection of control equipment.

The industrial control manufacturer has limited or no control over the following factors, which are vital to a safe installation:

a. Environmental conditions
b. System design
c. Equipment selection and application
d. Installation
e. Operating practices
f. Maintenance

This publication is not intended to instruct the user of control equipment with regard to these factors except insofar as suitable equipment to meet needs can be recognized in this publication and some application guidance is given.

This standards publication is necessarily confined to defining the construction requirements for industrial control equipment and to providing recommendations for proper selection for use under normal or certain specific conditions. Since any piece of industrial control equipment can be installed, operated and maintained in such a manner that hazardous conditions may result, conformance with this publication does not by itself assure a safe installation. When, however, equipment conforming

with these standards is properly selected and is installed in accordance with the National Electrical Code and properly maintained, the hazards to persons and property will be reduced.

To continue to serve the best interests of users of Industrial Control and Systems equipment, the Industrial Control and Systems Section is actively cooperating with other standardization organizations in the development of simple and more universal metrology practices. In this publication, the U.S. customary units are gradually being supplemented by those of the modernized metric system known as the International Systems of Units (SI). This transition involves no changes in standard dimensions, tolerances, or performance specifications.

NEMA standards publications are subject to periodic review. They are revised frequently to reflect user input and to meet changing conditions and technical progress.

Proposed revisions to this standards publication should be submitted to:

Vice President, Engineering Department
National Electrical Manufacturers Association
1300 North 17th Street, Suite 1847
Rosslyn, VA 22209

This standards publication was developed by the Industrial Automation Control Products and Systems Section. Section approval of the standard does not necessarily imply that all section members voted for its approval or participated in its development. At the time it was approved, the Industrial Automation Control Products and Systems Section consisted of the following members:

ABB Control, Inc. – Wichita Falls, TX
Alstom Drives and Controls, Inc. – Pittsburgh, PA
Automatic Switch Company – Florham Park, NJ
Balluff, Inc. – Florence, KY
Carlo Gavazzi, Inc. – Buffalo Grove, IL
CMC Torque Systems – Billerica, MA
Control Concepts Corporation – Beaver, PA
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Omron Electronics, LLC – Schaumburg, IL
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Pepperl + Fuchs, Inc. – Twinsburg, OH
Phoenix Contact, Inc. – Harrisburg, PA
Pittman, a Div. of Penn Engineering & Manufacturing Corporation – Harleysville, PA
Post Glover Resistors, Inc. – Erlanger, KY
RENCO Encoders - Goleta, CA
Regal-Beloit Corporation – Bradenton, FL
Reliance Controls Corporation – Racine, WI
Robert Bosch Corporation – Avon, CT
Rockwell Automation – Milwaukee, WI
R Stahl, Inc. – Salem, NH
Russelectric, Inc. – Hingham, MA
Schneider Automation, Inc. – North Andover, MA
SEW-Eurodrive, Inc. – Lyman, SC
Siemens Energy & Automation – Alpharetta, GA
Square D – Lexington, KY
Texas Instruments, Inc. – Attleboro, MA
Torna Tech., Inc. – St. Laurent, Quebec, Canada
Toshiba International Corporation – Houston, TX
Total Control Products Inc. – Milford, OH
Turck, Inc. – Plymouth, MN
Tyco Electronics/AMP – Harrisburg, PA
WAGO Corp. – Germantown, WI
Weidmuller, Inc. – Richmond, VA
Yaskawa Electric America – Waukegan, IL

DISCLAIMER

The standards or guidelines presented in a NEMA standards publication are considered technically sound at the time they are approved for publication. They are not a substitute for a product seller's or user's own judgment with respect to the particular product referenced in the standard or guideline, and NEMA does not undertake to guarantee the performance of any individual manufacturer's products by virtue of this standard or guide. Thus, NEMA expressly disclaims any responsibility for damages arising from the use, application, or reliance by others on the information contained in these standards or guidelines.

INTRODUCTION

The standards pertaining to general requirements in NEMA Standards Publication ICS 1 are subdivided into the following clauses:

1 General
Referenced Standards
Scope
Normative References

2 Definitions
Terms which supplement the IEC International Electrical Vocabulary (IEV 441) or assist in clarifying the product standard.

3 Classification
Product classifications where they have been established.

4 Characteristics and Ratings
Descriptions of the kinds of ratings applicable to the product and tables of standard ratings for the product where they have been established.

5 Product Marking, Installation and Maintenance Information
Product information to be provided to assist the user in the installation, use and maintenance of the devices.

6 Service and Storage Conditions
A description of service and storage conditions for which the devices are intended.

7 Construction
Marking, color coding and similar production requirements to be incorporated into the product as manufactured, as well as production test requirements where they have been established, i.e., the rules that the manufacturer follows in producing the product.

8 Performance Requirements and Tests
The performance required to pass each design test specified for the product.

This standards publication contains general requirements that are applicable to the majority of products with the scope of the Industrial Automation Control Products and Systems Section. The product standards that make reference to these general requirements include:

NEMA Standards Title Publication No.

ICS 1 Industrial Control and Systems - General Requirements

ICS 2 Industrial Control and Systems - Controllers, Contactors, and Overload Relays, Rated Not More Than 2000 Volts AC or 750 Volts DC

ICS 3 Industrial Control and Systems - Factory-built Assemblies

ICS 4 Industrial Control and Systems - Terminal Blocks

ICS 5 Industrial Control and Systems - Control Circuit and Pilot Devices

ICS 6 Industrial Control and Systems - Enclosures

ICS 7 Industrial Control and Systems - Adjustable Speed Drives

ICS 8 Industrial Control and Systems - Crane and Hoist Controllers

ICS 10 Industrial Control and Systems - AC Transfer Switch Equipment

Industrial Control and Systems

General Requirements

1 General

1.1 Referenced standards

The following standards contain provision which, through reference in this text, constitute provisions of this NEMA Standard Publication. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

American National Standards Institute
11 West 42nd Street
New York, NY 10036

C84.1-1995 *Voltage Ratings for Electric Power Systems and Equipment (60 Hz)*

Z535.4-1998 *Standard for Product Safety Labels*

American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

D-3638-1993 *Test Methods for Comparative Tracking Index of Electrical Insulating Materials*

Institute of Electrical and Electronics Engineers
345 East 47th Street
New York. NY 10017

IEEE 100-2000 *Standard Dictionary of Electrical and Electronics Terms (ANSI C42-100)*

International Electrotechnical Commission
1, Rue de Varembe
Geneva, Switzerland

IEC 112-1979 *Methods for Determining the Comparative and the Tracking Indices of Solid Insulating Materials Under Moist Conditions*

IEC 664-1-1992 *Insulation Coordination for Equipment Within Low-Voltage Systems, Part 1: Principles, Requirements and Tests*

National Fire Protection Association
1 Batterymarch Park
Quincy, MA 02269

ANSI/NFPA 70-1999 *National Electrical Code*

ANSI/NFPA 70E-2000 *Electrical Safety Requirements for Employee Workplaces*

Underwriters Laboratories Inc.
333 Pfingsten Rd.
Northbrook, IL 60062

UL 508 - 1999 *Industrial Control Equipment (17th Ed)*

1.2 Scope

The scope of this publication is the scope of the Industrial Automation Control Products and Systems Section. The purpose of this publication is to consolidate all standards of a general nature in order to obtain uniform application of requirements throughout the range of industrial control and systems equipment.

1.3 Relation to Product Standards

The requirements in this publication shall apply to all other NEMA Standards Publications for industrial control and systems equipment unless otherwise specified.

For each type of product, only two main documents are normally necessary to determine all requirements:

a. This general standard, referred to as ICS 1

b. The specific standard applying to the type of product, hereafter referred to as the "relevant product standard" or "product standard."

2 Definitions

(* indicates definition from ANSI/IEEE Standard 100.)

For the purposes of this publication the following definitions apply:

The terms have been arranged in an alphabetical order that reflects common usage. Specialized definitions applying to specific products appear in the standards publications for those products.

accelerating contactor: A contactor, other than the line or directional contactor, used primarily for the purpose of obtaining a change of accelerating torque.

adaptive control systems*: A control system within which automatic means are used to change the system parameters in a way intended to improve the performance of the control system.

alternating current (AC) contactor: A contactor for the specific purpose of establishing and interrupting an AC power circuit.

ambient temperature*: The temperature of the medium such as air, water, or earth into which the heat of the equipment is dissipated.

NOTES

a. For self-ventilated equipment, the ambient temperature is the average† temperature of the air in the immediate vicinity of the equipment.

b. For air- or gas-cooled equipment with forced ventilation or secondary water cooling, the ambient temperature is taken as that of the ingoing air or cooling gas.

c. For self-ventilated enclosed (including oil-immersed) equipment considered as a complete unit, the ambient temperature is the average† temperature of the air outside of the enclosure in the immediate vicinity of the equipment.

(These notes are not a part of ANSI/IEEE Std 100 definition.)
†The average of temperature readings at several locations.

apparatus: Includes the enclosure, the enclosed equipment, and attached appurtenances.

application test: A test performed by a manufacturer to determine those operating characteristics that are not necessarily established by standards but that are of interest in the application of devices.

automatic reset*: A function that operates to automatically re-establish specific conditions.

auxiliary contacts (switching device)*: Contacts in addition to the main-circuit contacts that function with the movement of the latter.

barrier*: A partition for the insulation or isolation of electric circuits or electric arcs.

block diagram: A diagram made up of a group of interconnected blocks, each of which represents a device or subsystem.

break rating: The value of current for which a contact assembly is rated for opening a circuit repeatedly at a specified voltage and under specified operating conditions.

bus:

a. A set of power supply leads

b. A conductor that provides multiple connections

carryover period: The maximum time of power loss during which a system will remain within specified limits of performance.

clearance: The shortest distance through air between conducting parts, or between a conducting part and the outer surface of the insulating enclosure considered as though metal foil were in contact with the accessible surfaces of the enclosure.

A joint between two parts of an insulating barrier is considered to be part of the surface except where the interstices are completely filled with an insulating material (cement).

combination controller (600 volts or less)*: A full magnetic or semi-magnetic controller with additional externally operable disconnecting means contained in a common enclosure. The disconnecting means shall be permitted to be a circuit breaker or a disconnect switch. Combination starters are specific forms of combination controllers.

conducting parts*; live parts: Those parts that are designed to carry current or that are conductively connected therewith.

connection diagram: See wiring diagram.

construction diagram*: A diagram that shows the physical arrangement of parts, such as wiring, buses, resistor units, etc.

Example: A diagram showing the arrangement of grids and terminals in a grid-type resistor.

contactor: A two-state (ON-OFF) device for repeatedly establishing and interrupting an electric power circuit. Interruption is obtained by introducing a gap or a very large impedance.

contacts*: Conducting parts that co-act to complete or to interrupt a circuit.

continuous periodic rating*: The load that can be carried for the alternate periods of load and rest specified in the rating and repeated continuously without exceeding the specified limitation.

continuous rating*: The maximum constant load that can be carried continuously without exceeding established temperature-rise limitations under prescribed conditions of test and within the limitations of established standards.

control*: Broadly the methods and means of governing the performance of any electric apparatus, machine or system.

control apparatus*: A set of control devices used to accomplish the intended control functions.

control circuit (industrial control)*: The circuit that carries the electric signals directing the performance of the controller, but does not carry the main power circuit.

control-circuit transformer; control-power transformer: A voltage transformer utilized to supply a voltage suitable for the operation of control devices.

control device*: An individual device used to execute a control function.

control sequence diagram: A portrayal of the contact positions or connections which are made for each successive step of the control action.

control sequence table*: A tabulation of the connections that are made for each successive position of the controller.

control system*: A system in which deliberate guidance or manipulation is used to achieve a prescribed value of a variable.

control system diagram: A conceptual diagram of the functional interrelationship of subsystems, usually in block form, that does not include the process equipment or details of circuits and device elements.

controller diagram*: A diagram that shows the electrical connections between the parts comprising the controller and the external connections.

converter*: A network or device for changing the form of information or energy.

corrosion-resistant*: So constructed, protected or treated that corrosion will not exceed specified limits under specified test conditions.

counter: A network or device for storing integers and permitting these integers to be changed by unity or by an arbitrary integer as successive input signals are received.

creepage distance: The shortest distance along the surface of an insulating material between two conducting parts, or between a conducting part and the outer surface of the insulating enclosure considered as though metal foil were in contact with the accessible surfaces of the enclosure.

NOTE A joint between two parts of an insulating barrier is considered to be part of the surface except where the interstices are completely filled with an insulating material (cement).

critically damped: Damping that is sufficient to prevent any overshoot of the output following an abrupt stimulus.

current relay*: A relay that functions at a predetermined value of current. It may be an overcurrent, undercurrent, or reverse-current relay.

damping: The reduction or suppression of the oscillation of a system. See critically damped.

dead time: The time interval between the initiation of an input and the start of the resulting response. Dead time shall be expressed in seconds.

defeater: See interlocking deactivating means (defeater).

definite-purpose controller*: Any controller having ratings, operating characteristics, or mechanical construction for use under service conditions other than usual or for use on a definite type of application.

design test: See type test.

dielectric withstand-voltage tests*: Tests made to determine the ability of insulating materials and spacings to withstand specified overvoltages for a specified time without flashover or puncture. The purpose of the tests is to determine the adequacy against breakdown of insulating materials and spacings under normal or transient conditions.

dimension drawing; outline drawing: A drawing (base plan, floor plan, etc.) which shows the physical space and mounting requirements of a piece of equipment. It shall be permitted to also indicate ventilation requirements and space provided for connections or the location to which connections are to be made.

direct current (DC) contactor: A contactor for the specific purpose of establishing and interrupting a DC power circuit.

disruptive discharge: The phenomena associated with the failure of insulation under electric stress; these include a collapse of voltage and the passage of current; the term applies to electrical breakdown in solid, liquid, and gaseous dielectrics, and combinations of these dielectrics.

disturbance*: An undesired input variable that may occur at any point within a feedback control system.

drift (as applied to devices): As applied to devices such as pressure switches, temperature switches, etc., is a change in operating characteristics over a specified number of operations or time and specified environmental conditions.

drift (as applied to systems): An undesired but relatively slow change in output over a specified time with a fixed reference input and fixed load, with specified environmental conditions. The specified time is normally after the warm-up period.

NOTE Drift shall be expressed in percent of the maximum rated value of the variable being measured.

drum controller*: An electric controller that utilizes a drum switch as the main switching element. A drum controller usually consists of a drum switch and a resistor.

drum switch*: A switch in which the electric contacts are made of segments or surfaces on the periphery of a rotating cylinder or sector, or by the operation of a rotating cam.

dynamic braking: A control function that brakes the drive by dissipating its stored energy in a resistor.

effective actuation time: The time that elapses between initial energization of the control circuit and the time the contacts of a normally open device close and remain closed or the contacts of a normally closed device open and remain open. Effective actuation time includes any contact bounce time or chatter time which occurs due to the operation of the device being tested.

electric contact*: The junction of conducting parts permitting current to flow.

electric controller*: A device or group of devices that serves to govern in some predetermined manner the electric power delivered to the apparatus to which it is connected.

electric motor controller*: A device or group of devices that serve to govern in some predetermined manner the electric power delivered to the motor.

NOTE For example, an electric motor controller may be a contactor or a starter rated in horsepower, kilowatts, or locked-rotor and full-load amperes. (The preceding sentence is not a part of the ANSI/IEEE Std 100 definition.)

electronic contactor: A contactor whose function is performed by electron tube(s) or semiconductor device(s).

electronic direct current (DC) motor controller: A phase-controlled rectifying system using semiconductors or tubes of the vapor- or gas-filled variety for power conversion to supply the armature circuit or the armature and shunt-field circuits of a DC motor, to provide adjustable-speed, adjustable- and compensated-speed, or adjustable- and regulated-speed characteristics.

electropneumatic controller*: An electrically supervised controller having some or all of its basic functions performed by air pressure.

failure of a control component or system: A state or condition in which a control component or system does not perform its essential function(s) when its ratings are not exceeded.

fault current: A current that results from the loss of insulation between conductors or between a conductor and ground.

fault current, low level (as applied to a motor branch circuit): A fault current that is equal to or less than the maximum operating overload.

fault withstandability*: The ability of electrical apparatus to withstand the effects of specified electrical fault current conditions without exceeding specified damage criteria.

full-magnetic controller*: An electric controller having all of its basic functions performed by devices that are operated by electromagnets.

NOTE "Basic functions" usually refers to acceleration, retardation, line closing, reversing, etc. (This note is not a part of the ANSI/IEEE Std 100 definition.)

general-purpose controller: Any controller having ratings, characteristics, and mechanical construction for use under usual service conditions in accordance with the NEMA Standards Publications for Industrial Controls and Systems.

general-use switch*: A switch that is intended for use in general distribution and branch circuits. It is rated in amperes and is capable of interrupting the rated current at the rated voltage.

graphic symbol: Symbols used on single-line (one-line) diagrams, on schematic or elementary diagrams, or, as applicable, on connection or wiring diagrams. Graphic symbols are correlated with parts lists, descriptions, or instructions by means of designations.

ground; earth*: A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth or to some conducting body of relatively large extent that serves in place of the earth.

illustrative diagram*: A diagram whose principal purpose is to show the operating principle of a device or group of devices without necessarily showing actual connections or circuits.

Illustrative diagrams may use pictures or symbols to illustrate or represent devices or their elements. Illustrative diagrams may be made of electric, hydraulic, pneumatic, and combination systems. They are applicable chiefly to instruction books, descriptive folders, or other media whose purpose is to explain or instruct.

inch: See jog.

industrial control*: The methods and means of governing the performance of an electric device, apparatus, equipment, or system used in industry.

insulation class: The classification of insulation materials for the purpose of establishing temperature limits for the use of the material. (See 8.3.2.1.)

interconnection diagram: A diagram which shows only the external connections between controllers and associated machinery and equipment.

interlock: A device actuated by the operation of some other device with which it is directly associated, to govern succeeding operations of the same or allied devices. Interlocks are either electrical or mechanical.

interlocking deactivating means; defeater*: A manually actuated provision for temporarily rendering an interlocking device ineffective, thus permitting an operation that would otherwise be prevented.

For example, when applied to apparatus such as combination controllers or control centers it refers to voiding of the mechanical interlocking mechanism between the externally operable disconnect device and the enclosure doors to permit entry into the enclosure while the disconnect device is closed.

intermittent periodic duty; intermittent duty: A duty in which the main contacts of an equipment remain closed for periods bearing a definite relation to the no-load periods, both periods being too short to allow the equipment to reach thermal equilibrium. See also periodic rating.

interrupting capability: The maximum value of current that a contact assembly is required to successfully interrupt at a specified voltage for a limited number of operations under specified conditions. The term is usually applied to abnormal or emergency conditions.

inverse time: A qualifying term applied to a relay indicating that its time of operation decreases as the magnitude of the operating quantity increases.

IR-drop compensation: A control function that compensates for voltage drop due to current. The amount of IR-drop compensation shall be expressed in percent of rated voltage.

For example:

$$IR-drop\ compensation\ percent = \frac{Volts\ compensation\ at\ full-load\ current}{Rated\ full-load\ voltage} \times 100$$

isolating switch (means): A switch, or other mechanism, intended for isolating an electric circuit from the source of power.

NOTE It has no interrupting rating, and it is intended to be operated only after the circuit has been opened by some other means.

jog; inch*: A control function that provides for the momentary operation of a drive for the purpose of accomplishing a small movement of the driven machine.

jogging speed*: The steady-state speed that would be attained if the jogging pilot device contacts were maintained closed.

NOTE It may be expressed either as an absolute magnitude of speed or a percentage of maximum rated speed.

live parts: See conducting parts.

logic diagram: A particular form of one-line or single-line diagram of a logic circuit using logic symbols.

low-torque contactor: A contactor used in a motor circuit in addition to a line, directional, plugging, or accelerating contactor, for the purpose of limiting stalled torque of the motor to less than 100 percent of the full load torque by inserting resistance in the circuit.

magnetic brake*: A friction brake that is controlled by electromagnetic means.

magnetic contactor*: A contactor actuated by electromagnetic means.

magnetic control relay: A relay that is actuated by electromagnetic means.

When not otherwise qualified, the term refers to a relay intended to be operated by the opening and closing of its coil circuit, and having contacts designated for energizing or deenergizing, or both, the coils of magnetic contactors or other magnetically operated device.

make rating: The value of current for which a contact assembly is rated for closing a circuit repeatedly under specified operating conditions.

manual controller*: An electric controller having all of its basic functions performed by devices which are operated by hand.

manual reset*: A function that requires a manual operation to reestablish specific conditions.

master switch: A switch which dominates the operation of contactors, relays, or other remotely-operated devices.

motor-circuit switch: A switch rated in horsepower and capable of interrupting the maximum operating overload current of a motor of the same horsepower rating at the rated voltage. Such a switch is intended for use in a motor branch circuit.

multipole (electrical switching device): A term applied to a contact arrangement that includes two or more separate mating contact combinations; that is, two or more single-pole contact assemblies, having a common operating means.

negative feedback*: A feedback signal in a direction to reduce the variable that the feedback represents.

nonoverlapping contacts*: Combinations of two sets of contacts, actuated by a common means, each set closing in one of two positions, and so arranged that the contacts of one set open before the contacts of the other set close.

off delay: The intentional time period introduced between the initiation of an OFF signal and the change in output of the timing device.

For example: In a pneumatic timer, the period of time between the de-energization of the coil and the operation of its timed contacts.

oiltight control-circuit [pilot] devices*: Devices such as push-button switches, pilot lights, and selector switches that are so designed that, when properly installed, they will prevent oil and coolant from entering around the operating or mounting means.

on delay: The intentional time period introduced between the initiation of an ON signal and the change in output of the timing device.

For example: In a pneumatic timer, the period of time between the energization of the coil and the operation of its timed contacts.

one-line diagram; single-line diagram: A diagram that shows, by means of single lines and graphic symbols, the course of an electrical circuit or circuits and the component devices or parts used therein. Physical relationships are usually disregarded.

operate time: The elapsed time between the initial energization of the control circuit and the time the contacts of normally open device first touch or the time the contacts of a normally closed device first open.

operating overload*: The overcurrent to which electric apparatus is subjected in the course of the normal operating conditions that it may encounter.

For example: Those currents in excess of running current that occur for a short time as a motor is started or jogged are considered normal operating overloads for control apparatus. See 4.4.

overcurrent relay: A relay that operates when the current through the relay during its operating period is equal to or greater than its setting.

overlapping contacts*: Combinations of two sets of contacts, actuated by a common means, each set closing in one of two positions, and so arranged that the contacts of one set open after the contacts of the other set have been closed.

overload protection*: The effect of a device operative on excessive current, but not necessarily on short circuit, to cause and maintain the interruption of current flow to the device governed.

part-winding starter*: A starter that applies to voltage successively to the partial sections of the primary winding of an AC motor.

periodic rating*: The load that can be carried for the alternate periods of load and rest specified in the rating, the apparatus starting at approximately room temperature, and for the total time specified in the rating, without causing any of the specified limitations to be exceeded. See also intermittent periodic duty or intermittent duty.

pick-up and seal voltage (magnetically operated device): The minimum voltage, suddenly applied, at which the device moves from its deenergized into its fully energized position.

pick-up voltage or current (magnetically operated device): The voltage or current, suddenly applied, at which the device starts to operate.

pilot duty rating: A generic term formerly used to indicate the ability of a control device to control the coils of other devices.

plugging*: A control function that provides braking by reversing the motor line voltage polarity or phase sequence so that the motor develops a counter-torque that exerts a retarding force.

pole (electrical switching device): A combination of mating contacts that are normally open, or normally closed, or both.

pollution degree: The classification of pollution in terms of type, severity, combinations of pollutants, and frequency of occurrence. Pollution degrees are designated by a conventional number. See Annex A.

positive feedback: A feedback signal in a direction to increase the variable that the feedback represents.

production tests: Those tests that are made at the discretion of the manufacturer on some or all production units for the purpose of maintaining quality and performance.

process diagram; flow diagram: A conceptual diagram of the functional interrelationship of subsystems in block or pictorial form that shows process equipment such as machinery for proper understanding.

pulse: A signal of relatively short duration.

pushbutton station*: A unit assembly of one or more externally operable pushbutton switches, sometimes including other pilot devices such as indicating lights or selector switches, in a suitable enclosure.

rated insulation voltage, U_i: The voltage to which rated impulse withstand voltage, clearances, and creepage distances are referred.

rated operational current, I_e: A value of current, stated by the manufacturer, which takes into account the rated operational voltage, the rated frequency, the rated duty, the overvoltage category, and the type of a protective enclosure.

rated operational voltage, U_e: A value of voltage which, combined with a rated operational current, determines the application of the equipment and to which the various tests and the overvoltage categories are referred. For polyphase circuits, it is stated as the voltage between phases.

rating (controller): An arbitrary designation of an operating limit. It is based on power governed, the duty and service required. A rating is arbitrary in the sense that it must necessarily be established by definite field standards and cannot, therefore, indicate the safe operating limit under all conditions that may occur.

rating (device)*: The designated limit(s) of the rated operating characteristic(s). Such operating characteristics as current, voltage, frequency, etc., may be given in the rating.

regeneration: The transfer of rotational energy through a motor and its control equipment back to its electrical source.

relay:

a. An electric device that is designed to interpret input conditions in a prescribed manner and after specified conditions are met to respond to cause contact operation or similar abrupt change in associated electric control circuits.

b. An electrically controlled, usually two-state, device that opens and closes electrical contacts to effect the operation of other devices in the same or another electric circuit.

c. A device in which a portion of one or more sets of electrical contacts is moved by an armature and its associated operating coil.

Inputs are usually electric, but may be mechanical, thermal, or other quantities. Limit switches and similar simple devices are not relays.

A relay may consist of several units, each responsive to specified inputs, the combination providing the desired performance characteristics.

release time: The time between initial deenergization of the control circuit and the initial opening of a normally open contact or the initial closing of a normally closed contact.

remote control: A control function that provides for initiation or change of a control function from a remote point.

repeat accuracy: A term used to express the degree of consistency of repeat operations under specified conditions.

reset: To restore a mechanism, storage, or device to a prescribed state.

reversible counter: A counter that will count either up or down.

schematic diagram; elementary diagram: A diagram that shows all circuits and device elements of an equipment and its associated apparatus or any clearly defined functional portion thereof.

Such a diagram emphasizes the device elements of a circuit and their functions as distinguished from the physical arrangement of the conductors, devices or elements of a circuit system.

Circuits which function in a definite sequence should be arranged to indicate that sequence.

sealing voltage or current: The voltage or current that is necessary to seat the armature of a magnetic circuit closing device from the position at which the contacts first touch each other.

semimagnetic controller*: An electric controller having only part of its basic functions performed by devices which are operated by electromagnets.

service* (controller): The specific application in which the controller is to be used.

Example: a. General purpose

b. Definite purpose
   1. Crane and hoist
   2. Elevator
   3. Machine tool

short-time capability: The ability of electrical apparatus to operate within specified performance criteria when carrying electrical overloads of a specified current and time duration under specified conditions.

short-time rating*: A rating that defines the load that can be carried for a short and definitely specified time, the machine, apparatus, or device being at approximately room temperature at the time the load is applied.

single-line diagram: See one-line diagram.

single pole (electrical switching device): A contact arrangement in which all contacts connect in one position or another to a common contact.

snap action: A rapid motion of the contacts from one position to another position, or their return. This action is relatively independent of the rate of travel of the actuator.

solid-state contactor: A contactor whose function is performed by semiconductor device(s).

starter (electric motor): A form of electric motor controller that includes the switching means necessary to start and stop a motor in combination with suitable overload protection.

surface-mounted (type): Designed to be secured to and to project from a flat surface.

switch*: A device for opening and closing or for changing the connection of a circuit.

A switch is understood to be manually operated, unless otherwise stated.

system voltage (nominal): The root-mean-square, phase-to-phase voltage by which the electrical distribution system is designated and to which certain operational characteristics of the system are related (ANSI C84.1).

The nominal system voltage is near the voltage level at which the system normally operates. To allow for operating contingencies, systems generally operate at voltage levels about five percent to ten percent below the maximum system voltage for which system components are designed (ANSI C84.1). See: utilization voltage.

three-wire control*: A control function that utilizes a momentary-contact pilot device and a holding-circuit contact to provide undervoltage protection.

time delay*: A time interval that is purposely introduced in the performance of a function.

transient: That part of the change in a variable that disappears during transition from one steady-state operating condition to another.

two-wire control*: A control function that utilizes a maintained-contact type of pilot device to provide undervoltage release.

type test; design test: A test that demonstrates compliance of a product design with applicable standards; it is not intended to be a production test.

undervoltage protection; low-voltage protection*: The effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit.

The principal objective of this device is to prevent automatic restarting of the equipment. Undervoltage or low-voltage protection devices are usually not designed to become effective at any specific degree of voltage reduction.

undervoltage release; low-voltage release*: The effect of a device, operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit but not to prevent the re-establishment of the main circuit on return of voltage.

Undervoltage or low-voltage releases are generally not designed to become effective at any specific degree of voltage reduction.

utilization voltage: The root-mean-square, phase-to-phase or phase-to-neutral voltage at the line terminals of utilization equipment (ANSI C84.1). See: system voltage and rated operational voltage.

ventilated enclosure*: An enclosure provided with means to permit circulation of sufficient air to remove an excess of heat, fumes, or vapors.

For outdoor applications, ventilating openings or louvers are usually filtered, screened, or restricted to limit the entrance of dust, dirt, or other foreign objects.

voltage relay*: A relay that functions at a predetermined value of voltage. It may be an overvoltage relay, an undervoltage relay, or a combination of both.

wiring diagram; connection diagram: A diagram which locates and identifies electrical devices, terminals, and interconnecting wiring in an assembly.

A wiring diagram shall be: 1) in a form showing interconnecting wiring by lines or indicating interconnecting wiring only by terminal designations (wireless diagram), or 2) a panel layout diagram showing the physical location of devices plus either:

a. The elementary diagram;

b. A wiring table;

c. A computer wiring chart;

d. A machine command tape or cards.

The term does not include mechanical drawings, commonly referred to as wiring templates, wiring assemblies, cable assemblies, etc.

wireless connection diagram: A diagram that shows the general physical arrangement of devices in a control equipment and connections between these devices, terminals, and terminal boards for outgoing connections to external apparatus.

Connections are shown in tabular form and not by lines. An elementary (or schematic) diagram may be included in the connection diagram.

3 Classification

Products covered by this publication are classified as components, assemblies or systems. Components are general-purpose mechanical, electromechanical, and solid-state devices used in industrial control applications. Assemblies consist of two or more interconnected components, usually in an enclosure. Systems are assemblies arranged to include one or more feedback loops.

4 Characteristics and ratings

4.1 General

4.1.1 Basis of rating

The ratings of industrial control apparatus are based on an ambient temperature of 40°C.

4.1.2 Rating of control apparatus

In general the rating of control apparatus shall be expressed in volts, amperes, horsepower, kilowatts, or other appropriate units.

4.1.3 Rating of a controller

For the purpose of these standards, the rating of a controller is based upon power governed and the duty service required. Unless specifically stated otherwise, standard ratings do not provide overload capacity.

4.2 Rated operational or utilization voltages (U_e)

Rated operational voltages or utilization voltages (U_e) for industrial control apparatus shall be as follows:

a. AC, 60 hertz, Multiphase — 115, 200, 230, 460, 575, 800, 1,000, 2,300, 4,000, 4,600, and 6,600 volts;

b. AC, 50 hertz, Multiphase — 380 volts;

c. AC, 60 hertz, Single Phase — 115 and 230 volts;

d. AC, 50 hertz, Single Phase — 220 volts;

e. DC — 115, 230 and 550 volts.

AC voltages are based on Publication C84.1 of the American National Standards Institute with the exception of 800 volts and 1,000 volts. The 800 volt utilization voltage applies to equipment installed

in 830Y/480 volt electrical distribution systems typically used for irrigation and oil field pumping. The 1,000 volt utilization voltage applies to equipment installed in 1,040Y/600 volt electrical distribution systems typically used in mines. Voltages shown reflect the fact that industrial control is normally applied at the point of power utilization.

Individual manufacturers may choose to mark coils or control-circuit transformers at the utilization voltage (listed above) or at the corresponding nominal system voltage (120, 208, 240, 480, or 600 volts, 60 hertz). Coils marked with voltage ratings in multiples of 120 volts or in multiples of 115 volts are considered adequate for use on nominal system voltage ratings in multiples of 120 volts.

4.3 Frequency ratings

The reference to "50 and 60 hertz" for AC controllers in this publication should not be construed to mean that the same operating coil can be used on 50 or 60 hertz at the same voltage rating. For example, some 460 volt 60 hertz coils can be used on 380 volts at 50 hertz but not on 440 volts 50 hertz.

4.4 Operating overload

For the purpose of this standard, the maximum operating overload of industrial motors and their control apparatus shall be considered to be:

a. For AC apparatus—6 times normal full—load current;

b. For DC apparatus for full-voltage starting—10 times normal full-load current;

c. For DC apparatus for reduced-voltage starting—4 times normal full-load current;

d. For apparatus where the operating overload is automatically limited—100 percent of the limited value.

These overloads are currents that may persist for a very short time only, usually a matter of seconds.

4.5 Undervoltage release devices (low-voltage release devices)

Undervoltage or low-voltage releases are generally not designed to become effective at any specific degree of voltage reduction.

4.6 Undervoltage protection devices (low-voltage protection devices)

The principal objective of these devices is to prevent automatic restarting of the equipment. Undervoltage or low-voltage protection devices generally are not designed to become effective at any specific degree of voltage reduction.

4.7 Overload devices

Overload devices that deenergize magnetically operated devices shall open the circuit of such devices.

5 Product marking, installation, and maintenance information

5.1 Installation and maintenance

Installation should be performed by a qualified person and in accordance with NFPA 70 (NEC) and properly operated and maintained in accordance with the safety practices of NFPA 70E.

5.2 Apparatus handling guidelines

5.2.1 General

This subclause provides guidelines to help avoid personal injury and equipment damage during installation when handling and moving industrial control equipment.

5.2.2 Guidelines

The manufacturer's instructions, and the instructions listed below, should be followed:

a. Follow the manufacturer's handling instructions for specific equipment.

b. Handle industrial control equipment with care to avoid damage to components and enclosure.

c. Extreme care must be exercised during any movement or placement of the equipment to prevent falling, tipping, or any other uncontrolled movement. Large equipment provided with a shipping skid should not be removed from the skid during handling or moving to minimize tipping and to protect the enclosure from distortion.

d. Know the capabilities of the lifting and moving means available to handle the weight of the equipment.

e. Large equipment may be supplied with lifting means (Figures 5-1 and 5-2) consisting of integral lifting angles, lifting plates, or eye bolts.

   1. Use spreaders (Figure 5-1) to provide the vertical lift and eye bolts and lifting slings so as to avoid failure of the eye bolt or other damage to the equipment frame or its finish.

   2. Select or adjust the rigging lengths to compensate for any unequal weight distribution of load to maintain the equipment in an upright position.

   3. In order to reduce the tension on the rigging and the compressive load on the lifting or spanner bars and spreaders, do not allow the angle between the lifting cables and vertical to exceed 45 degrees. (See Figures 5-1 and 5-2.)

   4. Do not pass ropes or cables through the lift holes in bars, angles, or channels. Use slings with safety hooks or shackles.

f. If industrial control equipment is to be stored for any length of time prior to installation, the equipment should be protected from the environment including the possibility of condensation of moisture inside the enclosure. For specific instructions, consult the manufacturer.

5.3 Terminations

Industrial control apparatus is provided with terminations which are suitable for use with copper wire but which may or may not be suitable for use with aluminum wire. Where industrial control apparatus is field-wired with aluminum wire, care must be taken to use suitable terminations and wiring techniques.

5.4 Preventive maintenance of industrial control and systems equipment

See NEMA Publication ICS 1.3.

6 Service and storage conditions

6.1 Usual service and installation conditions

Unless modified by other standards in this publication, apparatus within the scope of the Industrial Control and Systems Section conforming to these standards shall be capable of operation within its performance specifications under the following conditions:

6.1.1 Range of application temperatures

a. For equipment that is cooled by air, either ventilated or nonventilated, the temperature of the air outside of the enclosure and the ambient temperature shall be above 0°C but shall not exceed 40°C. For enclosed nonventilated equipment that is cooled by natural air convection, the ambient temperature is the temperature of the air outside of the enclosure in the immediate neighborhood of the equipment. For enclosed ventilated equipment, the ambient temperature is the temperature of the incoming air.

b. For equipment that includes water-cooled devices, the ambient temperature surrounding the enclosure shall be above 5°C but shall not exceed 40°C, and the cooling water inlet temperature shall be above 5°C but shall not exceed 30°C.

c. If equipment is to be operated at ambient air temperatures exceeding 40°C or at inlet water temperatures exceeding 30°C, the manufacturer should be consulted.

Enclosed industrial control apparatus is designed to operate where the temperature of the air inside the enclosure is above that of the ambient temperature. The specific temperature differential depends upon the heat generated by components and upon the enclosure design; it generally occurs within the range of 5°C to 25°C. The permissible internal air temperature limit depends upon the temperature rating of the components used.

6.1.2 Altitude

Altitude Class 1 Km designates equipment for installation where the altitude does not exceed 1,000 meters (3,300 feet). Altitude Class 2 Km designates equipment for installation where the altitude does not exceed 2,000 meters (6,600 feet).

Systems using power semiconductors are usually Class 1 Km. Electromagnetic and manual devices are Class 2 Km.

6.1.3 Range of operating voltage and frequency

The rms supply voltage shall not deviate more than 10 percent from the rated nameplate value except that, for systems using semiconductor power converters, it shall not deviate more than 10 percent above nor 5 percent below the rated nameplate value.

The supply frequency shall not deviate more than 1 percent from the rated nameplate value.

6.1.4 Other service and installation conditions

Conditions that equipment will experience should be evaluated in terms of the manufacturer's designated ratings and limitations. Service conditions that are outside the limits described in 6.1 or elsewhere in these publications, should be called to the control manufacturer's attention, since special construction or protection may be required. These may include, but are not limited to, the following:

a. Moisture;

b. Steam;

c. Corrosive conditions;

d. Changes in temperature;

e. Fungus, insects, vermin, dust, and comparable conditions;

f. Nuclear radiation;

g. Unbalanced polyphase power supply system;

h. AC power supply with nonsinusoidal wave form;

i. Vibration and shock;

j. Radio interference including that generated by the equipment;

k. Operating duty;

l. Restriction of ventilation;

m. Radiated or conducted heat from other sources;

n. Electrical noise from other sources, such as strong electromagnetic or electrostatic fields;

o. Power system transient voltages such as those caused by lightning or capacitive and inductive switching.

6.1.5 Environmental protection

Industrial control devices and systems are designed for use in a wide range of environments provided the apparatus is suitably enclosed. (See ICS 6.)

Enclosures cannot protect devices against conditions such as condensation, icing, corrosion, or contamination that originate within the enclosure or that enter via the conduit or unsealed openings.

These internal and external conditions, except for the test limits, require considerations beyond the scope of this publication, and the apparatus manufacturer should be consulted.

6.2 Storage temperature

When equipment is stored, the ambient temperature should be above -30°C but should not exceed 65°C. Where the storage temperature is below the freezing point of the cooling liquid, the coolant should be removed. Where equipment is to be stored for more than 1 week, it may be necessary to cover the equipment and provide a source of heat to prevent condensation. Equipment which is not operated for extended periods may require protection by an internal heater.

7 Construction

7.1 Insulation requirements

Industrial control and systems apparatus shall be designed to provide insulation between live parts under operating and service conditions considered normal for such equipment. This insulation shall be achieved by designs which have air or other insulating material between live parts and ground, and between live parts of opposite polarity. The shortest distance measured through air between two conducting parts is called clearance. The shortest distance along the surface of an insulating material between two conducting parts is called creepage distance. For joints and inserted barriers, the creepage distances are measured through the joint, unless the parts are so cemented or heat-sealed or tightly secured mechanically together that ingress of moisture or dirt into the joint is not likely to occur.

The clearances and creepage distances specified are those considered necessary to provide insulation under conditions of overvoltages resulting from faults, lightning, switching, and other transient phenomena which are likely to occur in installations where industrial control and systems equipment is utilized. These minimum distances also take into consideration:

a. The probability of some form of pollution reducing their effectiveness;

b. A safety factor which considers the consequences of power follow-through in the event of a fault (available let-through energy) and the need to provide continuity of service.

7.2 Spacings

NOTE For an alternate concept for determining spacing and for tests to verify the performance, see Annex A.

7.2.1 General requirements

The clearance and creepage distances between non-arcing uninsulated live parts and:

a. Nonarcing uninsulated parts of different voltage

b. Metal parts (other than enclosure walls) which may be grounded when the equipment is installed

c. Exposed ungrounded metal parts

d. The walls of a metal enclosure (including fittings for conduit or armored cable) shall be not less than those shown in Tables 7-1 or 7-2, as applicable.

Table 7-1 applies for general use on all power systems where the transient voltages are not controlled or known.

Table 7-2 applies where provision is made to limit random surge and transient peak voltages to a total of not more than 300 percent of the instantaneous peak working voltage or 300 volts, whichever is greater. This limitation on surge and transient peak voltages applies between uninsulated live parts and ground when the apparatus is subjected to the 1.2/50 microsecond impulse test specified in Annex A. See Annex B for typical impulse generator circuit.

7.2.2 Exceptions

a. Table 7-2 spacings are not required where surge suppression means are used to limit random surge and transient peak voltages to not more than 300 volts peak and meet the test requirements of Annex A. However, provision shall be made to preserve the integrity of the spacings throughout the service life of the equipment through the use of means of protection from pollution and mechanical forces that could bridge clearances or cause leakage currents across creepage distances and the use of materials that will not deteriorate with age, moisture or leakage current. In addition, external connections shall comply with the minimum spacing requirements of Table 7-2.

b. The clearances and creepage distances given in Tables 7-1 and 7-2 do not apply to internal parts of hermetically sealed or encapsulated components; however, the external connections on such components shall have the clearance and creepage distances specified in this publication, unless the components are in accordance with the NEMA standards for these components and those standards cover industrial applications.

c. The clearance and creepage distances given in Tables 7-1 and 7-2 do not apply to snap switches, lampholders, and similar wiring devices used as part of industrial control equipment, provided such devices are not employed in motor circuits.

d. This standard does not apply to the internal spacings of rotating electric motors, or to motor control center bus spacings, or to the open gaps of contacts.

Table 7-1
Clearance and Creepage Distances for General Use Where Transient Voltages are not Controlled or Known

Group	Voltage Rating Volts[1] (rms or DC)	Minimum Clearance and Creepage Distances, (inches) mm					
		To Other than Enclosure Walls				To Walls of Metal Enclosure[3]	
		Clearance[2] Through Air	Clearance[2] Through Oil	Creepage Along Surface Air	Creepage Along Surface Oil	Clearance Through Air or Oil	Creepage Along Surface Air or Oil
A. General Industrial Control	0-50	(0.125) 3.2	(0.125) 3.2	(0.125) 3.2	(0.125) 3.2	(0.50) 12.7	(0.50) 12.7
	51-150	(0.125) 3.2	(0.125) 3.2	(0.25) 6.4	(0.25) 6.4	(0.50) 12.7	(0.50) 12.7
	151-300	(0.250) 6.4	(0.250) 6.4	(0.375) 9.5	((0.25) 6.4	(0.50) 12.7	(0.50) 12.7
	301-600	(0.375) 9.5	(0.375) 9.5	(0.50) 12.7	(0.50) 12.7	(0.50) 12.7	(0.50) 12.7
	601-1000	(0.55) 14.0	(0.45) 11.4	(0.85) 21.6	(0.625) 15.9	(0.80) 20.3	(1) 25.4
	1001-1500	(0.70) 17.8	(0.60) 15.3	(1.2) 30.5	(0.70) 17.8	(1.2) 30.5	(1.65) 41.9
	1501-2000	(1) 25.4	(0.75) 19.0	(2) 50.8	(1) 25.4	(2) 50.8	(3) 76.2
	2001-2500[6]	(1) 25.4	(0.75) 19.0	(2) 50.8	(1) 25.4	(2) 50.8	(3) 76.2
	2501-5000[6]	(2) 50.8	(1.5) 38.1	(3.5) 88.9	(2) 50.8	(3) 76.2	(4) 102
	5001-7200[6]	(2) 50.8	(1.5) 38.1	(3.5) 88.9	(2) 50.8	(3) 76.2	(4) 102
B. Industrial control with per pole and total load restrictions[4]							
	51-300	(0.063) 1.6	(0.063) 1.6	(0.125) 3.2	(0.125) 3.2	(0.25) 6.4	(0.25) 6.4
	301-600	(0.188) 4.8	(0.188) 4.8	(0.375) 9.5	(0.375) 9.5	(0.50) 12.7	(0.50) 12.7
C. Industrial control with per pole restrictions[5]							
	51-150	(0.125) 3.2	(0.125) 3.2	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4
	151-300	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4	(0.25) 6.4

[1] Where the repetitive peak voltage on which the device is used is more than 1.5 times the rms volts, the peak voltage shall be divided by $\sqrt{2}$ to obtain an equivalent rms rating in volts.

For grounded power systems, such as three-phase four-wire systems, the clearance and creepage distances to ground shall be governed by the voltage to ground.

[2] The spacings between screw-type wiring terminals of opposite polarity shall not be less than (0.25 inch) 6.4 mm if the terminals are in the same plane.

[3] For the purpose of this requirement, a metal piece attached to the enclosure is considered to be a part of the enclosure if deformation of the enclosure is likely to reduce the spacings between the metal piece and uninsulated live parts.

For subassembly enclosures where clearance and creepage distances are rigidly maintained and when mounted inside another enclosure, the distances for "to other than enclosure walls" shall be permitted to be used instead of "to walls of metal enclosure" but in no case shall they be less than (0.10 inch) 2.5 mm.

[4] The maximum per pole ratings shall be limited to 1 HP or less; 720 VA or less: 15A at 51-150V; 10A at 151-300V; 5A at 301-600V. For multipole devices, intended to control more than one load, the total load controlled at one time is limited to two times these values.

[5] The maximum per pole rating is limited to 1HP or less; 2000VA or less; 15A at 51-150V; 10A at 151-300V.

[6] Because of the effect of configurations of metal parts, spacings in excess of those listed for these ratings may be required to meet the requirements of the impulse voltage tests in ICS 3.

Table 7-2
Clearance and Creepage Distances for Use Where Transient Voltages are Controlled and Known

Group	Instantaneous Peak working voltage	Minimum clearance and creepage distance, (Inch) mm			
		To other than enclosure walls[2]		To walls of metal enclosure[4]	
		Clearance[3] through air	Creepage along Surface in air	Clearance through air	Creepage along surface
E. For general use where transient voltages are known and controlled by apparatus or specified by external means	0—50	(0.030) 0.76	(0.030) 0.76	(0.50) 12.7	(0.25) 6.4
	51—225	(0.075) 1.9	(0.10)2.5	(0.50) 12.7	(0.50) 12.7
	226—450	(0.15) 3.8	(0.20) 5.1	(0.50) 12.7	(0.50) 12.7
	451—900	(0.30) 7.6	(0.40) 10.2	(0.50) 12.7	(0.50) 12.7
	901—1400	(0.438) 11.1	(0.625)15.9	0.75) 19.0	(1) 25.4
	1401—2100	(0.625) 15.9	(1) 25.4	(1) 25.4	(1.5) 38.1
	2101—3500	(1) 25.4	(1.6) 40.6	(2) 50.8	(3) 76.2
	3501—7000	(2) 50.8	(3.5) 88.9	(3) 76.2	(4) 102
F. For use where transient voltages are known and controlled by apparatus or specified by external means and the power supplying the circuit under consideration is limited to a short circuit of 10 kVA or less.[5]	0—30	(0.030) 0.76	(0.030) 0.76[6]	(0.50) 12.7[8]	(0.25) 6.4
	31—50	(0.030) 0.76	(0.030) 0.76	(0.50) 12.7[8]	(0.25) 6.4
	51—225	(0.060) 1.5	(0.060) 1.52	(0.50) 12.7	(0.50) 12.7
	226—450	(0.10) 2.5	(0.10) 2.5	(0.50) 12.7	(0.50) 12.7
	451—900	(0.20) 5.1	(0.20) 5.1	(0.50) 12.7	(0.50) 12.7
	901—1400	(0.30) 7.6	(0.3) 7.6	(0.50) 12.7	0.75) 19.0
	1401—2100	(0.45) 11.4	(0.4) 11.4	(0.50) 12.7	(1) 25.4
G. For use where transient voltages are known and controlled by apparatus or specified by external means and the power supplying the circuit under consideration is limited to a short circuit of 500 VA or less.[5]	0—36	(0.012) 0.30	(0.012) 0.30[7]	(0.50) 12.7[8]	(0.25) 6.4
	37—72	(0.016) 0.40	(0.016) 0.40[7]	(0.50) 12.7[8]	(0.25) 6.4
	73—100	(0.030) 0.76	(0.030) 0.76[7]	(0.50) 12.7[8]	(0.25) 6.4
	101—225	(0.045) 1.1	(0.045) 1.1	(0.50) 12.7	(0.50) 12.7
	226—450	(0.060) 1.5	(0.060) 1.5	(0.50) 12.7	(0.50) 12.7
	451—900	(0.10) 2.5	(0.10) 2.5	(0.50) 12.7	(0.50) 12.7

[1] For grounded power systems, such as three-phase four-wire systems, the clearance and creepage distances to ground shall be governed by the voltage to ground.

[2] The clearance and creepage distances of (0.10 inch) 2.5 mm and less are particularly intended for use on printed circuit boards or small devices where the distances are precision controlled.. They shall not be used on main power circuits, such as bus and contactors.

[3] The spacings between screw-type wiring terminals of opposite polarity shall not be less than (0.25 inch) 6.4 mm if the terminals are in the same plane.

[4] For the purpose of this requirement, a metal piece attached to the enclosure is considered to be a part of the enclosure if deformation of the enclosure is likely to reduce the spacings between the metal piece and uninsulated live parts.

For subassembly enclosures where clearance and creepage distances are rigidly maintained and when mounted inside another enclosure, the distances for "to other than enclosure walls" shall be permitted to be used instead of "to walls of metal enclosure" but in no case shall they be less than (0.10 inch) 2.5 mm.

[5] Maximum short-circuit voltamperes is determined as the product of the open-circuit voltage and the short circuit current available at the supply terminals when protective devices are bypassed.Spacing in signal or control circuits originating from the power circuits shall be in accordance with Group A or E up to the point where circuit conditions permit the use of spacing in accordance with Group F or G. Products designed in accordance with Groups F and G spacings include a supply which limits the short-circuit VA to values shown.

[6] Smaller creepage distances are permissible for this voltage range if the live parts of different potential are rigidly attached to an insulating surface and provided suitable precautions are applied for environmental protection.

[7] Pollution shall be taken into account through the use of larger dimensions, protective coating or enclosures, mounting orientation, protective maintenance, or by other acceptable means. Pollution is any material or condition which supplies conductive particles or ions, or both, to an electric field, changing the normal condition of the electric field at rated temperature, atmospheric pressure, and relative humidity.

[8] Where deflection of an enclosure wall cannot reduce the through-air spacing to the enclosure wall, the spacing through air shall be permitted to be (0.25 inch) 6.4 mm.

7.2.3 Measurement of spacings

Figures 7-1 through 7-12 show how clearance and creepage distance shall be measured for various situations involving ridges or grooves between conductive parts.

7.3 Terminations

Control devices intended to be renewable shall be provided with convenient means for making conductor connections.

Terminals shall be provided on or adjacent to all operating coils for contactors and relays.

7.4 Protection of semiconductors in circuits

Semiconductors may be used to control current in the power circuits of industrial control equipment. Such equipment after installation should have a disconnecting means and overcurrent protection as required by NFPA 70 (NEC).

Where the rating of the power-circuit supply exceeds 2.5 kW, 7.4.1 through 7.4.4 shall apply:

7.4.1 Disconnecting means for semiconductor circuits

Disconnecting means, where provided as part of the industrial control equipment, shall be capable of interrupting operating overloads.

7.4.2 Overcurrent protection for semiconductor circuits

Where overcurrent protection for semiconductors in power circuits is provided as part of the equipment, it shall conform to the following:

a. Fault overcurrent protection means, where provided, shall be capable of limiting the half-cycle peak currents and let-through energy under fault conditions to not more than the half-cycle surge current (electrical withstandablility) rating or the rupture rating of the semiconductors. Where overcurrent protection is provided only to limit let-through current and energy up to the rupture rating, the equipment shall be so marked.

b. Running overload protection means, where provided, shall sense current that is greater than rated and respond in such a way as to eliminate the overload within the time-current rating of the semiconductors.

c. The overcurrent protective means, where provided, shall isolate the faulted circuit or component to prevent additional subsequent damage.

Where overcurrent protection is not provided for semiconductors as part of the equipment in power circuits, information shall be provided that specifies the maximum peak current and maximum let-through energy that the semiconductors can withstand without damage and that suggests a means of obtaining the appropriate overcurrent protection.

Surge current rating is that value of half-cycle peak current that a device can withstand and have its characteristics remain the same. This half-cycle load is not repeatable. The device should be allowed to cool before it is subjected to the overloaded system. The rupture rating of a semiconductor is that value of current or let-through energy, or both, that the device can withstand without rupturing due to

electromagnetic force or heat but not necessarily without altering the electrical characteristics of the device.

7.4.3 Transient voltage protection

The peak reverse voltage of semiconductors shall be more than 2.5 times the nominal rms voltage of the circuit in which the semiconductors are used and means shall be provided to limit transient overvoltages to the voltage ratings of the semiconductors. Information shall be provided that expresses the design capability of the transient voltage protection means in terms of maximum energy (joules), maximum transient voltage magnitude, or maximum rate of change of current, or both, in addition to the maximum allowable rate of change of voltage.

Experience has shown that semiconductors with peak reverse voltage ratings of approximately 2.5 to 3.0 times their nominal application voltage can be protected against damage by transients by reasonable and economical means. The appropriate design capability of the transient voltage protection means is a function of the energy available to the circuit and the manner in which transients will be generated.

7.4.4 Protection against loss of forced cooling

Where forced cooling medium is used, control means shall be provided to protect the semiconductor against loss of such cooling.

7.5 Control-circuit overcurrent protection

The following are general requirements for control-circuit overcurrent protection in circuits rated 600 volts or less. For specific requirements, see individual product standards.

7.5.1 Common control source without control-circuit transformer

Where the control-circuit power is supplied from the load side of the motor branch-circuit short-circuit protective device, the control-circuit conductors shall be protected as follows:

7.5.1.1 Control-circuit conductors that do not extend beyond the motor controller enclosure

The control-circuit conductors are considered to be protected where the branch-circuit short-circuit protective device rating or trip setting does not exceed the values shown in Table 7-3.

Where the rating or trip setting of the short-circuit protective device (SCPD) exceeds the values in Table 7-3, the control-circuit conductors shall be protected by an overcurrent protective device of the maximum rating given in Table 7-4.

Table 7-3
Branch-Circuit Short Circuit Protection

Control-Circuit Wire Size, AWG	Maximum Size of Branch-Circuit Protective Device, Amperes
22	12
20	20
18	25
16	40
14	100
12	120

Table 7-4
Overcurrent Protection

Control-Circuit Wire Size, AWG	Maximum Protective Device, Amperes
22	3
20	5
18	7
16	10
14	20
12	25

7.5.1.2 Overcurrent protection for short direct leads

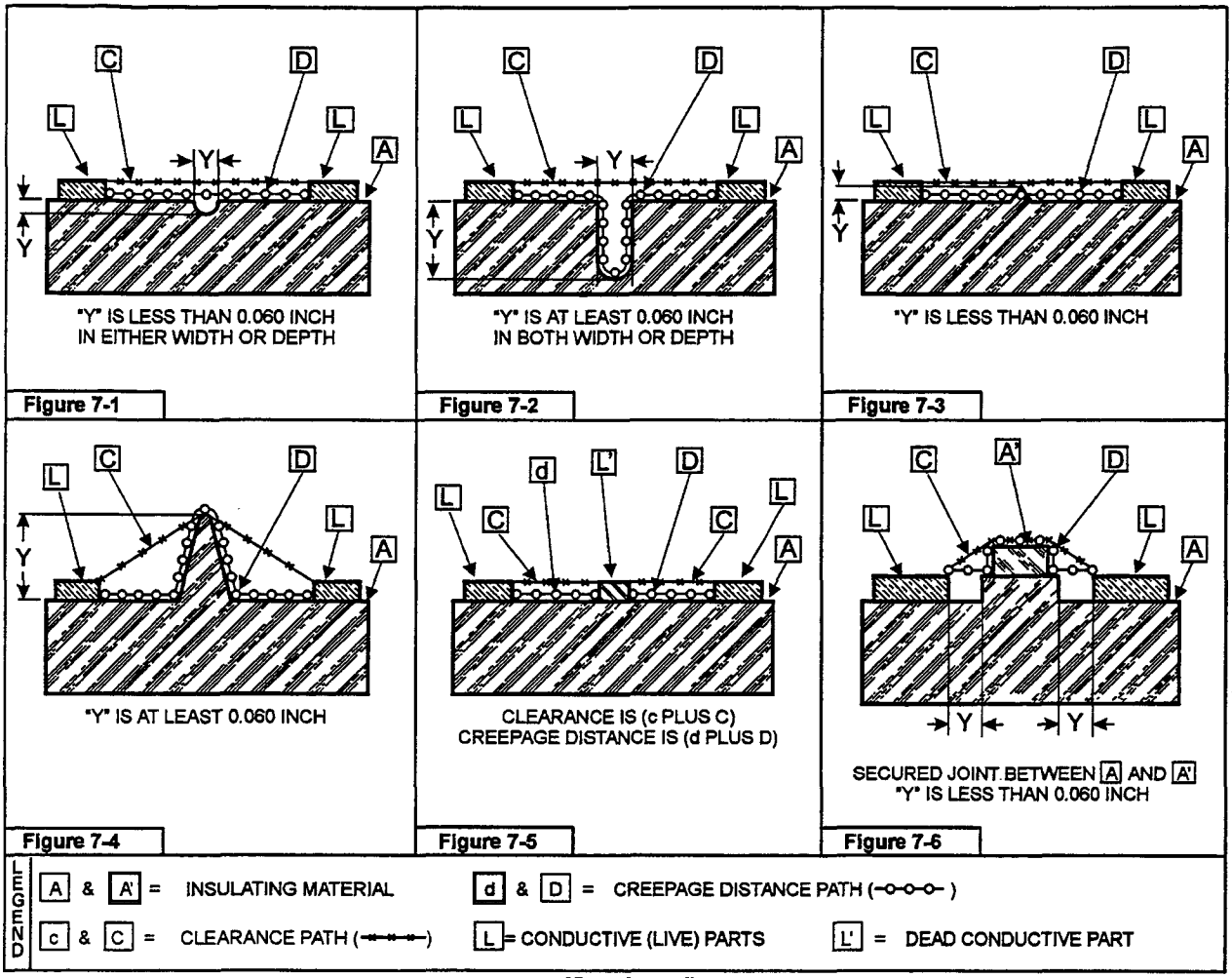
The overcurrent protection required for conductors by 7.5.1.1 shall be permitted to be omitted for short direct leads, generally not exceeding 12 inches in length, that do not extend beyond the motor controller enclosure.

7.5.1.3 Control-circuit conductors that extend beyond the motor controller enclosure

The control-circuit conductors shall be considered to be protected where the branch-circuit SCPD rating or trip-setting does not exceed the values shown in Table 7-5.

Where the rating or trip-setting of the SCPD exceeds the values shown in Table 7-5, the control-circuit conductors shall be protected by an overcurrent protective device of the maximum rating given in Table 7-4. The overcurrent device shall be located within the enclosure.

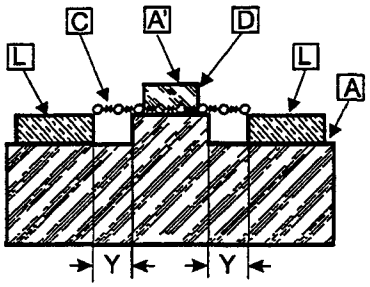
CLEARANCE AND CREEPAGE DISTANCE



0.060" = 1.52 mm

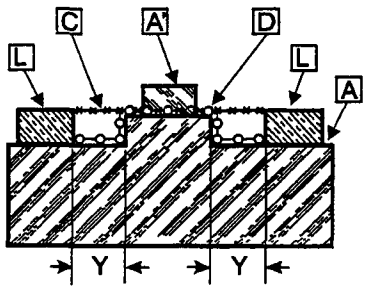
(Continued)

CLEARANCE AND CREEPAGE DISTANCE



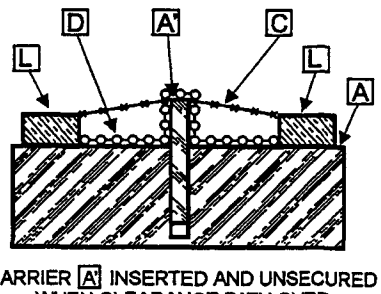
UNSECURED JOINT BETWEEN A AND A'
"Y" IS LESS THAN 0.060 INCH

Figure 7-7



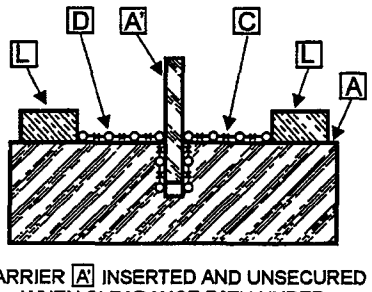
UNSECURED JOINT BETWEEN A AND A'
"Y" IS AT LEAST 0.060 INCH

Figure 7-8



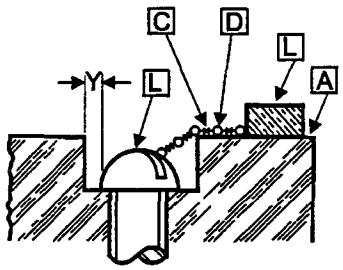
BARRIER A' INSERTED AND UNSECURED
WHEN CLEARANCE PATH OVER
THE BARRIER IS LESS THAN PATH
UNDER THE BARRIER

Figure 7-9



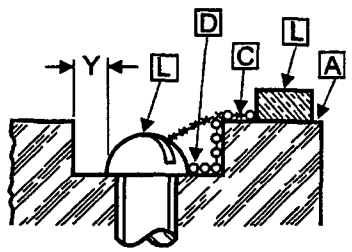
BARRIER A' INSERTED AND UNSECURED
WHEN CLEARANCE PATH UNDER
THE BARRIER IS LESS THAN PATH
OVER THE BARRIER

Figure 7-10



"Y" IS LESS THAN 0.060 INCH AND
UNIFORM AROUND THE SCREW HEAD

Figure 7-11



"Y" IS AT LEAST 0.060 INCH AND
UNIFORM AROUND THE SCREW HEAD

Figure 7-12

LEGEND

A & A' = INSULATING MATERIAL

d & D = CREEPAGE DISTANCE PATH (-o-o-o-)

c & C = CLEARANCE PATH (-*-*-*-)

L = CONDUCTIVE (LIVE) PARTS

L' = DEAD CONDUCTIVE PART

0.060" = 1.52 mm

Table 7-5
Branch-circuit Short-circuit Protection

Control-circuit Wire size, AWG	Maximum size of Branch-circuit Protective device, Amperes
22	3
20	5
18	7
16	10
14	45
12	60

7.5.2 Common control source with control-circuit transformer

Where a control-circuit transformer is provided, its primary shall be connected on the load side of the branch-circuit short-circuit protective device.

If the control circuit is to be grounded, the ground connection shall be made at a transformer secondary lead or terminal.

7.5.2.1 Control transformer primary-circuit conductor protection

Requirements for overcurrent protection of primary-circuit conductors shall be the same as specified in 7.5.1.1 for control-circuit conductors where a control-circuit transformer is not used.

The above paragraph does not negate the need for control-circuit transformer overcurrent protection where required by 7.5.2.2. However, the same overcurrent protective device shall be permitted to be used for both control-circuit transformer protection and primary-circuit conductor protection where its rating satisfies each requirement.

7.5.2.2 Control-circuit transformer protection

7.5.2.2.1 Primary current less than 2 amperes

Where the rated primary current is less than 2 amperes, the primary shall be protected by an overcurrent protective device in each ungrounded leg rated at not more than 500 percent of the rated primary current.

7.5.2.2.2 Primary current equal to or greater than 2 amperes, less than 9 amperes

Where the rated primary current is equal to or greater than 2 amperes and less than 9 amperes, the primary shall be protected by an over-current protective device rated at not more than 167 percent of the rated primary current.

7.5.2.2.3 Primary current 9 amperes or more

Where the rated primary current is 9 amperes or more, the primary shall be protected by an overcurrent protective device rated at not more than 125 percent of the rated primary current. However, where 125 percent of the rated primary current does not correspond to a standard rating of a fuse or nonadjustable circuit breaker, the next higher standard rating of the protective device shall be permitted to be used.

7.5.2.2.4 Transformer protected by other means

An overcurrent protective device shall not be required where the transformer is protected by other means, such as an integral thermal protector, which meets the requirements of UL 508.
An overcurrent protective device shall not be required where the transformer supplies a Class 1 power limited, Class 2 or Class 3 remote control-circuit conforming with the requirements of NFPA 70 (NEC).

An overcurrent protective device shall not be required where the transformer rated less than 50 VA, is protected by an impedance limiting means, is an integral part of controller, and is located within the controller enclosure.

Transformers that are protected by an impedance and rated less than 50 VA are special purpose components typically used for low voltage power supplies and such in electronic circuits.

7.5.3 Control transformer secondary-circuit conductor protection

7.5.3.1 Two-wire, single-voltage secondary

Where the control-circuit transformer has a two-wire, single-voltage secondary, the ungrounded secondary-circuit conductors are considered to be protected where the primary-circuit overcurrent protective device rating or the control-circuit transformer protection does not exceed the ratio of the secondary voltage to the primary voltage, multiplied by the maximum protective device rating shown in Table 7-4 for the secondary conductor size.

7.5.3.2 Tapped or multiple-winding secondary or no protection on primary side

Protection of ungrounded secondary conductors is required per Table 7-4 where the control-circuit transformer has a tapped or multiple-winding secondary or where protection is not provided on the primary side as permitted by other paragraphs of this standard, unless secondary conductors meet the requirements of 7.5.1.2.

7.5.4 Special applications

The requirements of 7.5 do not apply for applications identified in NFPA 70 (NEC) where a hazard would be created by the opening of the control circuit.

7.5.5 External control source

Control circuits of two or more motor controllers may be supplied from a common source and the conductors may be protected by common overcurrent devices at the source, where all conductors are the same size.

Control circuits supplied from a source external to the motor controller may require overcurrent devices within the controller, for example, where the conductor size is reduced.

Where overcurrent protection is provided, conductors shall be protected in accordance with their ampacities, in accordance with Table 7-4.

7.5.6 Interrupting ratings

Protective devices used in control circuits shall have interrupting ratings not less than the available short-circuit current at the protective device location in the circuit.

7.5.7 Accessory kits

Where a protective device is not assembled as part of the controller, an accessory kit, intended for installation in the controller enclosure, shall be available and information shall be provided with the controller to identify the proper kit to be used.

7.6 Color coding of wiring

Where wired with thermoplastic insulated wire and where NEMA standard color coding is specified, the color code for industrial control wiring shall be:

a. Line and load circuits (AC and DC), power and motor circuits — black

b. Control circuits

   1. AC — red

   2. DC — blue

c. Connection to primaries of control transformers — black

Color coding, where specified, applies to the wiring between devices that are interconnected to form a control assembly and not to the wiring which is an integral part of the devices.

Where solenoids, brakes, and similar devices are employed as a part of the controller system, the panel wiring shall be color coded in the same manner as the power circuits. However, the panel wiring shall be color coded in the same manner as the control circuit where solenoids, brakes, and similar devices are either:

a. Operated at line voltage and fused by control-circuit fuses

b. Operated from a voltage lower than the line voltage.

The colors green and white have been recognized in equipment and distribution circuit work. Green usually indicates an equipment grounding conductor, and white indicates the grounded neutral conductor of the circuit.

7.7 Markings of coils

Coils that are applied at their continuous ratings on single coil devices shall contain the following minimum information:

a. Rated voltage;

b. Rated frequency (for AC coils),"DC" (for DC coils);

c. Manufacturer's name or trademark;

d. Manufacturer's ordering number.

It is recommended that the coils be so mounted that the manufacturer's ordering number will be visible when the coil is in place on the device.

7.8 Product safety labels

7.8.1 *General*

In the design of product safety labels, use of ANSI Z535.4 and any applicable referenced standards is recommended except that the choice of a signal word or words should be entirely at the discretion of the product manufacturer rather than as specified in the standard.

7.8.2 Warning symbol

Where warning labels alerting the users to potential hazards of electrical shock or burn are furnished with enclosed industrial controls and systems, it is recommended they include a symbol for electrical hazards as shown and proportioned in Figure 7-13.

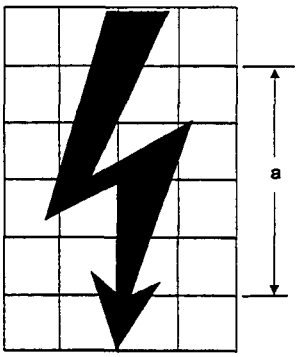
The warning label of a size appropriate for the enclosure should be located on the front of the enclosure. Where practicable, the label should be mounted where it remains visible after a door is opened or a cover removed.

Where space permits, a format similar to Figure 7-14 is recommended. For small devices, the warning symbol only (Figure 7-13) is recommended. Suitable explanatory instruction on how to avoid the hazard should be shown on the warning label or in other instructions. For example, *"Turn Off Power Before Working On This Equipment."*

The label should be applied in such a manner as to have a degree of permanence and legibility commensurate with the environment and application for which the equipment is intended.

7.8.3 Other labels or markings

The use of this symbol on the front of enclosed electrical control equipment is not intended to rule out the use of other labels or markings, either internal or external, that are required to comply with other nationally recognized standards, laws, or regulations, or that may be deemed necessary by the manufacturer.



Symbol proportion – height = 1.48 a
width = 0.58 a

Figure 7-13
Symbol Denoting Hazard of Electrical Shock or Burn

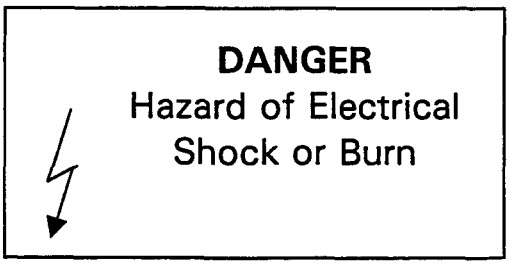


Figure 7-14
Typical Warning Label

8 Performance requirements and tests

Clause 8 covers performance requirements, tests and test procedures including design (type), production, and application tests. For product-specific design test requirements, see the appropriate product standards.

8.1 Design tests, general

Design tests shall be performed, as applicable, on one or more representative new samples of apparatus, to demonstrate the conformance of a product design with these standards.

The apparatus to be tested shall be mounted and wired as intended for use in service.

Where an enclosure is provided as part of the apparatus, tests shall be made with the apparatus in its enclosure.

8.2 Test conditions

8.2.1 Altitude

Temperature tests shall be made at any altitude of 1,000 meters (3,300 feet) or less for Class 1 Km apparatus and 2,000 meters (6,600 feet) or less for Class 2 Km apparatus, and no correction shall be applied to the observed temperature rise.

8.2.2 Ambient temperature during tests

Temperature rise tests shall be made at any ambient temperature between 10°C and 40°C. It is assumed that the temperature rise is identical for all ambient temperatures between 10°C and 40°C.

The ambient temperature shall be measured by several thermometers or thermocouples placed at different points around the apparatus, and protected from drafts and abnormal heat radiation. For forced cooled equipment, thermometers or thermocouples shall be located in the incoming path of the cooling medium.

The ambient temperature during a test is the average of the ambient readings taken at equal intervals of time during the last quarter of the duration of the test. The ambient temperature during this period shall have stabilized to within a range of 2°C.

8.2.3 Copper conductor size selection for testing

The performance of a given industrial control product is often significantly influenced by the size of the wires attached to its terminals while being tested.

8.2.4 Control-circuit devices

For control-circuit devices, copper wire should be selected in accordance with ICS 5.

8.2.5 Power-circuit devices

For power-circuit devices, copper wire should be selected in accordance with Table 8-1A or 8-1B.

Table 8-1A
Copper Conductor Size for Controller Testing*

Controller Size	Continuous Current Rating Amperes	Water Insulation Temperature°C	Temperature Rise Test**	Temperature Rise and Short Time Capability†	Make and Break Tests and Fault Withstandability Tests of Motor Controller (3PH 60H_z) 200V	230V	380V(50H_z)	460V	575V
00	9	60 or 75	14AWG	14AWG	14AWG	14AWG	14AWG	14AWG	14AWG
0	18	60 or 75	12AWG	10AWG	14AWG	14AWG	14AWG	14AWG	14AWG
1	27	60	10AWG	8AWG	8AWG	10AWG	10AWG	12AWG	14AWG
1	27	75	10AWG	8AWG	10AWG	10AWG	10AWG	12AWG	14AWG
2	45	60	6AWG	4AWG	8AWG	6AWG	6AWG	6AWG	8AWG
2	45	75	8AWG	6AWG	8AWG	6AWG	6AWG	8AWG	8AWG
3	90	60	2AWG	0AWG	1AWG	1AWG	1AWG	3AWG	4AWG
3	90	75	3AWG	2AWG	3AWG	3AWG	2AWG	4AWG	6AWG
4	135	75	0AWG	00AWG	0AWG	00AWG	0AWG	00AWG	1AWG
5	270	75	300MCM	500MCM	300MCM	350MCM	300MCM	350MCM	250MCM
6	540	75	2-300MCM	2-500MCM	2-300MCM	2-350MCM	2-300MCM	2-350MCM	2-250MCM
7	810	75	3-300MCM	3-500MCM	-	3-350MCM	-	3-350MCM	3-250MCM
8	1215	75	4-350MCM	4-500MCM	-	3-350MCM	-	3-350MCM	3-250MCM
9	2250††								

* One size 6 and larger where parallel conductors are used, the conductor sizes are based on the use of not more than three conductors per conduit.
** Use wire sizes in this column where controller does not include overload relays and, in addition, includes a current rating equal to the continuous current rating.
† Use wire sizes in this column when controller includes overload relay section tables for currents up to the continuous current rating. Different wire sizes may apply for temperature rise test when different maximum currents are implied.
†† *Busbar or cable-connected, as specified between control manufacturer and use.*

Table 8-1B
For Controllers Rated in Amperes
Maximum Copper Conductor Size for
Controller Power Circuit Testing at Not More Than 2000 Volts*

75°C Conductor		Controller Rated Continuous Current	Controller Rated for Motor and Resistive Heating Loads Rated Current**	Controller Rated for Resistive Loads Other than Resistive Heating Rated Current
Size	Ampacity			
14AWG	15	0-15	0-12	0-15
12AWG	20	16-20	13-16	16-20
10AWG	30	21-30	17-24	21-30
8AWG	50	31-50	25-40	31-50
6AWG	65	51-65	41-52	51-65
4AWG	85	66-85	51-68	66-85
3AWG	100	86-100	69-80	86-100
2AWG	115	101-115	81-92	101-115
1AWG	130	116-130	93-104	116-130
1/0AWG	150	131-150	105-120	131-150
2/0AWG	175	151-175	121-140	151-175
3/0AWG	200	176-200	141-160	176-200
4/0AWG	230	201-230	161-184	201-230
250 kcmil	255	231-255	185-204	231-255
300 kcmil	285	256-285	205-228	256-285
350 kcmil	310	286-310	229-248	286-310
400 kcmil	335	311-335	249-268	311-335
500 kcmil	380	336-380	269-304	336-380
600 kcmil	420	381-420	305-336	381-420
(2)4AWG	460	421-460	337-368	421-460
(2) 250 kcmil	510	461-510	369-408	461-510
(2) 300 kcmil	570	511-570	409-456	511-570
(2) 350 kcmil	620	571-620	457-496	571-620
(2) 400 kcmil	670	621-670	497-536	621-670
(2) 500 kcmil	760	671-760	537-608	671-760
(2) 600 kcmil	840	761-840	609-672	761-840
(3) 350 kcmil	930	841-930	673-744	841-930
(3) 400 kcmil	1005	931-1005	745-804	931-1005
(3) 500 kcmil	1140	1006-1140	805-912	1006-1140
(3) 600 kcmil	1260	1141-1260	913-1008	1141-1260

NOTES—Conductor sizes shown are for use in temperature rise tests, short-time capability tests, make and break tests, endurance tests, and fault withstandability tests.

* Applies to other than Class A controllers designed by NEMA size and base on not more than three conductors per conduit.

** Motor applications where ampacity of conductor must be not less than 125% of nominal motor full-load current and for controllers marked "Resistance" Heating (Space Heating).

8.2.6 Specified wires

Tables 8-1A and 8-1B are based on ampacity values as shown in NFPA 70 (NEC) for three copper conductors in conduit for an ambient temperature of 30°C using a 60°C or 75°C Wire insulation temperature as specified by the controller manufacturer with No. 14 AWG wire minimum and 500 kcmil wire as a maximum. Size 9 controllers are tested with bus bar or cable.

a. The wire specified for temperature rise tests for other than motor and resistance heater loads of motor controllers is the smallest wire having an ampacity equal to or greater than the continuous current rating of the controller.

b. The wire specified for temperature rise and short-time capability tests for motor and resistance heater loads is the smallest wire having an ampacity equal to or greater than 1.25 times the continuous current rating of the controller.

c. The wire specified for make and break design testing and for fault withstandability (short-circuit) testing is the smallest wire having an ampacity equal to or greater than 1.25 times the full-load motor current.

d. For power apparatus other than motor controllers, the wire size is the smallest wire having an ampacity equal to or greater than the rated continuous current of the apparatus. Conductor sizes are based on NFPA 70 (NEC) ampacity table for three copper conductors in raceway or cable with 60°C or 75°C wire insulation temperature as specified by the controller manufacturer.

e. It is sometimes necessary for the controller manufacturer to specify wire size as well as insulation temperature in order to maintain overload relay calibration. In such cases, all tests are conducted using the conductor specified.

8.3 Temperature rise

8.3.1 Temperature rise test procedure

For temperature rise tests, operating coils and heat generating components shall be energized and contacts shall carry rated current.

The wire size shall be in accordance with Table 8-1A or 8-1B unless wire size is specified by the control manufacturer. The type of insulation is not specified, but its color shall be black. Where the insulation temperature specified by the controller manufacturer is 60°C/75°C, the wire size selection shall be for 75°C insulation.

8.3.2 Temperature rise of coils

The temperature rise of coils above the ambient temperature, when the coils are tested in accordance with their ratings while mounted in the device with which they are intended to function, shall not exceed the values given in Table 8-2. The temperature rise of shunt coils shall be determined by the resistance method. The temperature rise of series coils shall be determined by either the resistance method or direct measurement, whichever is more practicable.

Table 8-2
Limit of Temperature Rise Above Ambient Temperature (40°C Maximum), Degrees C

Insulated shunt coils	Resistance	70	85	105	No limit specified	160
Insulated series coils	Direct Measurement	50	65	85	No limit specified	125
Insulated series coils	Resistance	70	85	105	No limit specified	160
Single-layer series with uninsulated or enameled exposed surfaces	Direct Measurements	...	90**	...	No limit specified	...

NOTES

* The temperature rises shown in this table are based on many years of satisfactory experience and many tests by the industrial control industry with coils designed to, and operated at, the temperature rise limits indicated.

** This applies to coil having a fiber or some other similar insulating sleeve or collar which insulated the coil from the frame or core.

8.3.2.1 Insulation classes

The temperature limits on which the ratings of electrical apparatus are based are largely determined by the character of the insulation materials used.

Insulation is considered to be "impregnated" when a suitable substance provides a bond between components of the structure and also a degree of filling and surface coverage sufficient to give adequate performance under the extremes of temperature, surface contamination (moisture, dirt, etc.) and mechanical stress expected in service. The impregnant must not flow or deteriorate enough at operating temperature so as to seriously affect performance in service.

The electrical and mechanical properties of the insulation must not be impaired by the prolonged application of the limiting insulation temperature permitted for the specific insulation class. The word "impaired" is used here in the sense of causing any change which could disqualify the insulating material for continuously performing its intended function, whether creepage spacing, mechanical support, or dielectric barrier action.

For the purpose of establishing temperature limits, insulating materials are classified as follows:

8.3.2.1.1 Class A insulation

Materials or combinations of materials such as cotton, silk, and paper where suitably impregnated or coated or where immersed in a dielectric liquid such as oil. Other materials or combinations of materials shall be permitted to be included in this class if, by experience or accepted tests, they can be shown to be capable of operation in control equipment at the temperature rises shown in Table 8-2.

8.3.2.1.2 Class B insulation

Materials or combinations of materials such as mica, glass fiber, etc., with suitable bonding substances. Other materials or combinations of materials, not necessarily inorganic, shall be permitted to be included in this class if, by experience or accepted tests, they can be shown to be capable of operation in control equipment at the temperature rises shown in Table 8-2.

8.3.2.1.3 Class C insulation

Insulation that consists entirely of mica, porcelain, glass, quartz, and similar inorganic materials. Other materials or combinations of materials shall be permitted to be included in this class if, by experience or accepted tests, they can be shown to be capable of operation in control equipment at temperatures above 220°C.

8.3.2.1.4 Class O insulation

Materials or combinations of materials such as cotton, silk, and paper without impregnation. Other materials or combinations of materials shall be permitted to be included in this class if, by experience or accepted tests, they can be shown to be capable of operation in control equipment at the temperature rises in Table 8-2.

8.3.2.1.5 Class H insulation

Materials or combinations of materials such as silicone elastomer, mica, glass fiber, etc., with suitable bonding substances such as appropriate silicone resins. Other materials or combinations of materials shall be permitted to be included in this class if, by experience or accepted tests, they can be shown to be capable of operation in control equipment at the temperature rises shown in Table 8-2.

8.3.2.2 Temperature by resistance method

The average coil temperature can be determined by measuring its resistance, where the resistance at some other temperature is known. The calculations are based on the fact that metals have zero resistance at "inferred absolute zero," which for electrical grade copper is -234.5°C, and for electrical grade aluminum is -225°C.

Thus—

For copper:

$$\frac{R_2}{R_1} = \frac{T_2 + 234.5}{T_1 + 234.5} \text{ and } T_2 = \frac{R_2}{R_1}(234.5 + T_1) - 234.5$$

For aluminum:

$$\frac{R_2}{R_1} = \frac{T_2 + 235}{T_1 + 235} \text{ and } T_2 = \frac{R_2}{R_1}(225 + T_1) - 225$$

Where:

R_1 and R_2 are resistances, measured in ohms, and T_1 and T_2 are corresponding coil temperatures in degrees Celsius.

The temperature rise is the difference between the calculated temperature and the ambient temperature.

8.3.3 Temperature rise of current-carrying parts

8.3.3.1 Temperature rise of contacts

The temperature rise of contacts above the ambient temperature, when the contacts are tested in accordance with their ratings, shall not exceed the following:

a. Silver and silver-based contacts—the temperature rise is limited solely by the necessity to avoid damage to the contacts themselves or to adjacent parts.

   Damage is any deterioration such as loosening of parts, cracking, flaking of material, loss of temper of springs, annealing of parts, etc., which would impair the normal life of the device.

b. Copper contacts

   1. Laminated brush contacts — 50°C.

   2. Solid contacts in air (8-hour duty) — 65°C

c. Contacts in oil — 65°C

d. All other contacts in air (8-hour duty) — 65°C

The temperature rise shall be determined by direct measurement. (See 8.3.3.4.)

This standard does not apply to contacts which are mounted directly on resistor elements.

8.3.3.2 Temperature rise of buses and connecting straps

The temperature rise of buses and connecting straps, above the ambient temperature, when this equipment is tested in accordance with its rating, shall not exceed 65°C. The temperature rise shall be determined by direct measurement. (See 8.3.3.4.)

This standard does not apply to connectors to a source of heat (for example, resistors, thermal heaters, power-tube anodes, power semiconductors, or magnetic devices with insulation Classes B or higher).

8.3.3.3 Temperature rise of field wiring terminals

The temperature rise of field wiring terminals, above the ambient temperature, when the equipment is tested in accordance with its rating, shall not exceed the values shown in Table 8-3.

Table 8-3
Maximum Temperature Rise Of Field Wiring Terminals

Conductor Insulation Rating Specified By Controller Manufacturer	Temperature Rating of Conductor*	Maximum Temperature Rise Of Terminal
60°C	60°C	50°C
60°C/75°C	60°C/75°C	50°C/65°C
75°C only	75°C	65°C

*for conductor size selected from NFPA 70 (NEC), Table 310-16. The temperature rise shall be determined by direct measurement. (See 8.3.3.4.)

8.3.3.4 Temperature by direct measurement

Temperature shall be determined by thermocouples applied to the hottest points accessible to a thermocouple or by other methods giving equivalent results. The junction of a thermocouple shall be in intimate thermal contact with the part under evaluation to assure reading the true temperature of the part to be measured.

The size of thermocouple wires should be small enough so that they will not conduct sufficient heat away from the part and materially change its temperature. Wire size 30 AWG is recommended. Where the part whose temperature is to be measured is a spring loaded part, such as a movable contact, the thermocouple wires should be arranged so as not to materially affect the spring loading.

The temperature of stationary parts shall be measured during the progress of the test. Temperatures of movable parts shall be taken during the test where practicable and, in any case, as soon as possible after completion of the test run. The highest figures obtained shall be used.

Where ratings require test for very short periods or at very heavy loads, the specified rating shall be permitted to be replaced for test purposes by an equivalent continuous rating, or by an equivalent periodic rating having a longer duration than that specified in the following paragraphs:

a. Rated Operational Current, I_e — The temperature test shall be continued until the temperature rise has attained a steady final value as indicated by no more than 2 percent change in temperature rise in three successive readings taken at intervals of 10 percent of the previously elapsed duration of the test, but not less than 10-minute intervals.

b. Intermittent Periodic Duty or Intermittent Duty — The temperature test shall be made in accordance with the periods of load and rest specified by the rating of the apparatus and shall be continued for the total time required by the rating, with the final temperature reading taken at the end of the last `ON' period.

c. Operational Current Rating (Equivalent to Intermittent Periodic Duty or Intermittent Duty) — An operational current rating equivalent to the periodic rating shall be calculated for devices which carry intermittent heavy loads for short periods by the following formula:

$$I_{equivalent} = \frac{\sqrt{I_1^2 t_1 + I_2^2 t_2 + I_3^2 t_3 + ... I_n^2 t_n}}{t_1 + t_2 + t_3 + ... t_n}$$

Where:

The sum of $t_1 + t_2 + t_3$,etc., through t_n totals the averaging period, including "t" when I is zero.

8.4 Dielectric withstand

8.4.1 Dielectric test fundamentals

A representative new sample apparatus designed in accordance with the spacing requirements of Clause 7, having appropriate insulation material, proper configuration, and properly assembled will pass the dielectric tests described in 8.4.

A representative new sample apparatus designed in accordance with Annex A will pass the dielectric tests in Annex A under normal laboratory conditions.

Insulation deterioration during the service life of electrical apparatus results from various combinations of such causes as progressive aging, moisture, mechanical damage, and excessive voltage stress. In addition, the electrical apparatus is usually exposed to pollution and transient overvoltages. Because of the impracticability of making tests involving all these factors, it has been the practice to test new insulation at a voltage appreciably greater than its rated insulation voltage.

A dielectric test consists of the application of a voltage higher than the rated insulation voltage for a specific time for the purpose of determining the adequacy against breakdown of insulation under the transient overvoltage conditions which are likely to be encountered in normal installations.

A contactor make and break design test, short time capability test, etc., is often followed by a power frequency (50, 60 hertz or DC) dielectric test as a check on possible insulation deterioration.

Power frequency dielectric tests may be used as production tests to check for pinched wires, tramp metal, etc.

Impulse tests are dielectric tests conducted to simulate overvoltage due to lightning or switching. The impulse is a single voltage pulse with a specified rise time, decay time, and crest value.

PRECAUTIONS - Since the dielectric test voltage is greater than rated voltage, care must be taken not to apply the test voltage in a manner that simulates energization of a circuit. For example, a power frequency dielectric test voltage higher than the rated voltage of a starter coil should not be applied across the terminals of the coil. Higher than rated voltage applied to a coil winding is not considered an adequate check for shorted turns. Power frequency dielectric testing of coils should be limited to checking for isolation between coil and external metal parts such as the magnet assembly of a relay or between coils that should be isolated, such as the primary and secondary windings of a control transformer. Likewise, power frequency dielectric test voltages should not be applied across meter terminals, lamp terminals, motor terminals, semiconductor components, varistors, and the like. For apparatus assemblies that include such components, the recommendation of the applicable standard should be used.

8.4.2 Points of application

The output of the power frequency high voltage (dielectric) tester shall be applied:

a. Between each field wiring terminal which is designed to be isolated from the chassis and the chassis (ground). Field wiring terminals of circuits containing contacts shall be tested with the contacts in both the open and closed positions.

b. Between terminals of opposite polarity. Where a power frequency dielectric test is used with conductive components such as thyristors, coils, varistor, etc., connected between these terminals, one side shall be disconnected in order to prevent damage to these components.

c. Between each circuit and each other circuit which is designed to be isolated from each other. The input terminals of each circuit rated less than 51 volts AC rms or DC shall be shorted and tied to a common point and the isolation from each other circuit rated more than 50 volts AC rms or DC, verified.

d. Between each circuit which is designed to be isolated from the chassis, and the chassis (ground).

8.4.3 Dielectric tests

Some products may be constructed with capacitance coupling which results in undesirable AC current while undergoing a power frequency dielectric test. This undesired current may be very small but sufficient to damage (overheat or overvoltage, or both) components or may appear to be a high leakage current. In such cases, a DC test voltage equivalent to the peak AC value specified may be used.

8.4.4 Test apparatus

Power frequency design dielectric testing shall be done with a high voltage dielectric strength tester having a means of adjusting output voltage. The test apparatus shall have a means to eliminate overshoot or transients.

The AC test voltage shall be 50 or 60 hertz and shall approximate a sine-wave. The test voltage shall not drop more than 10 percent when the load is increased from zero to the indicating current.

The light or buzzer, or both, used to indicate breakdown shall have a response time of not more than 25 milliseconds at an output current of 2 milliamperes per 1,000 volts applied and should be calibrated to indicate failure with an output current between 1.5 and 2.0 milliamperes per 1,000 volts applied (the indicating current).

8.4.5 Measurement of test voltage

The test voltage shall be measured by a voltmeter. In measuring the voltage, the voltmeter shall derive its voltage from the high voltage circuit either directly or, for AC, through an auxiliary ratio transformer, or from the voltmeter winding of the testing transformer.

8.4.6 Duration of test voltage

The test voltage for all switching and control apparatus shall be applied continuously for a period of 60 seconds. Apparatus or devices shall be permitted to be tested for 1 second with a test voltage which is 20 percent higher than the 60-second test voltage.

8.4.7 Ambient test conditions

Dielectric tests shall be conducted at room temperature and up to 95 percent relative humidity at a test location up to 2,000 meters in altitude, with the apparatus under test de-energized.

8.4.8 Test values

The voltage used for power frequency dielectric testing shall be as shown in Table 8-4.

Working voltage is the voltage to which the parts concerned are subjected under conditions of normal use when the equipment is applied on a circuit having a nominal system voltage corresponding to the equipment rated voltage. See clause 4.

For parts supplied with a voltage different from the main system voltage, working voltage is the voltage measured across the parts in normal service.

For testing isolation between circuits having different voltage ratings, the test voltage shall be based on the higher rating.

For clearances only, and for point to plane electrodes, the empirical data have shown that a power frequency dielectric test of "P" volts rms is approximately equivalent to an impulse dielectric test crest voltage of 1.85P. A power frequency dielectric test has a higher energy content than an equivalent impulse dielectric test. As a matter of convenience a power frequency test may be substituted for an impulse test where the tested apparatus can withstand the higher energy content.

Table 8-4
Power Frequency Dielectric Test Voltages for General Use
(where transient voltages are not known and controlled)

Voltage Rating, Volts (RMS) or DC	Test Voltage (RMS) for Groups A, B, and C
0-50	500 volts
51-600	1,000 Volts + (2 x nominal voltage rating)
601-5,000	2,000 Volts + (2-1/4 x nominal voltage ratings)

8.4.9 Test criteria

An apparatus which is tested for loss of isolation or insulation is considered to have met the performance requirements where all of the following criteria are met:

a. The light or buzzer indicator set in accordance with 8.4.4 does not operate.

b. There is no indication, such as smoke, odor, sparkover or sustained arcing, that the insulation is deteriorating.

8.4.10 Impulse test

Industrial control and systems apparatus designed in accordance with Table 7-2 shall be capable of withstanding the impulse withstand voltage test of Annex A. (See Annex B for typical test circuit).

The purpose of this test is to verify that clearances will withstand specified transient over-voltages.

An impulse test voltage of 1.2/50 microsecond wave shape (1.2 microsecond rise, 50 microsecond decay to 50 percent of peak value) shall be used to simulate overvoltage due to lightning or switching operations.

8.5 Vibration

8.5.1 Requirements

Vibration withstand tests, when specified in a product standard, shall require industrial control equipment to be capable of operating in its intended manner after being subjected to a sinusoidal vibration of a specified excursion, over a specified range of frequencies that change at a specified rate for a specified time period.

For equipment with contacts the vibration withstand test requirement shall additionally include a maximum time period for contact change of state (from open to closed or vice versa) during the test.

The amplitude and highest frequency combine to produce a maximum acceleration. A typical vibration withstandability requirement should include:

Excursion (double amplitude)_____inches (millimeters), peak-to-peak

Frequency: _____hertz, linear (or logarithmic) ramp

Duration: _____minute

Maximum acceleration: _____g

Maximum contact discontinuity: _____milliseconds

Other evaluation criteria:_____

The vibration caused by an earthquake is usually at a frequency less than 60 hertz. The natural frequency of a large rigidly mounted punch press is likely to be greater than 1,000 hertz.

8.5.2 Test method

The equipment being tested shall be mounted as intended for service except no conduit shall be attached to enclosed devices nor shall auxiliary supports such as capillary tubes for temperature switches, pipes for pressure switches, couplings for rotary cam or speed switches, etc., be attached.

The device being tested shall be unwired except as required to monitor contact operation. The equipment being tested shall be vibrated in each of three mutually perpendicular planes, one plane to be parallel to the plane of the panel to which the device is mounted for the specified time period. Devices with contacts shall be tested in both the operated and unoperated states. The test load specified in 8.9.1.1 shall be used to detect circuit discontinuity.

8.5.3 Test criteria

Equipment that is capable of operating in its intended manner after the vibration withstand test and has no essential adjustment disturbed is considered to have met the vibration withstand test requirements. In addition, equipment with contacts must not have a contact change of state (from

open to closed or vice versa) for a longer time period than specified in the vibration withstand requirement.

8.6 Shock

8.6.1 Requirements

When shock withstand requirements are specified for industrial control equipment, they shall be expressed as a requirement to withstand without damage or excessive contact discontinuity four half sine shock pulses of a specified acceleration amplitude delivered over a specified time period (duration) in each direction along three mutually perpendicular axes, as six separate tests.

The velocity change (V_i) associated with an ideal half sine shock pulse is related to the specified pulse peak amplitude (A) and the specified pulse duration (D) as follows: $(V_i) = 2AD\pi$.

A typical shock withstandability requirement should include:

Half sine wave duration (D):_____milliseconds

Peak acceleration (A) on X axis _____g

Peak acceleration (A) on Y axis _____g

Peak acceleration (A) on Z axis _____g

Maximum contact discontinuity:_____milliseconds

Other evaluation criteria:_____

Definitions of axes X, Y and Z:_____

8.6.2 Test method

The equipment being tested shall be mounted as intended for service, except that no conduit shall be attached to enclosed devices nor shall auxiliary supports such as capillary tubes for temperature switches, pipes for pressure switches, couplings for rotary cam or speed switches, etc., be attached. The equipment being tested shall be unwired except as required to monitor contact operation. The leads to monitor contact operation and energize coils shall be the minimum cross section considered necessary to safely handle the electrical load. They shall be extremely flexible and have sufficient slack that they do not have a dampening effect on the device being tested. No accelerometer shall be attached to the equipment under test. The equipment being tested shall be mounted in place of an identical item used to calibrate the shock machine. Four shocks of the specified peak acceleration and duration shall be applied in each direction along each of the three mutually perpendicular axes. Devices with contacts shall be tested with one-half the number of shocks in each of the operated and unoperated states. The load specified in 8.9.1.1 shall be used to detect contact discontinuity. Contacts are considered to be open or closed when the device is deenergized by virtue of the state they assume after the device is mounted for test, e.g., a normally open contact on a vertical action magnetic relay may become a closed contact when the device is deenergized and mounted upside down on a free fall shock machine.

8.6.3 Shock machine calibration

The device being tested or an identical device in terms of mass and center of gravity shall be mounted as prescribed for testing except that no leads for coils or contacts shall be attached. An accelerometer

having a fundamental resonant frequency greater than 30,000 hertz shall be rigidly secured to the mounting panel for the device being tested as near as possible to an attachment point for the specimen but not on the specimen itself. Instrumentation shall be used to convert the accelerometer output to an oscillogram or retained oscillograph trace of acceleration versus time. The shock machine shall be adjusted to produce a trace within the 15 percent tolerances shown in Figure 8-1 and thus produce an actual velocity change (V) which is within 10 percent of the velocity change (V_i) of an ideal acceleration (shock) pulse. The actual velocity change (V) is calculated by the formula: $V = 2 (A_{actual}) (D_{actual}) \div \pi$, provided A_{actual} falls within the limits (0.85 to 1.15) shown in Figure 8-1.

8.6.4 Test criteria

If after completing the prescribed number of shock pulses the equipment is damaged or has disturbed an adjustment essential to its proper operation, the equipment is considered to have failed.

In addition, where the device being tested had a contact which changed state (from open to closed or vice versa) for a longer time period than specified in the shock withstand requirements, the device is considered to have failed. Equipment which is not damaged by the 24 shock pulses and does not have a contact discontinuity which exceeds the specified limit is considered to have met the shock withstand requirements.

8.7 Electrical noise

Exposing solid-state devices to excessive electrical noise may damage the devices or cause malfunction of the equipment which they control. The electrical noise tests described in Annex E are designed to test solid-state logic input and output modules and power supplies that interface with control power sources.

8.8 Operating voltage tests

The ability of an operating coil which is part of a control device to withstand a specified percentage above its rated voltage shall be verified by applying the specified overvoltage until the temperature of the coil has stabilized in a 40°C ambient. There shall be no evidence of insulation deterioration during the test.

The ability of a device with an operating coil to perform successfully at less than rated voltage shall be demonstrated by applying the specified undervoltage suddenly to the coil after the coil has reached a constant temperature at rated coil voltage in a 40°C ambient, or an equivalent coil temperature.

8.9 Application tests

Application tests are those tests performed by a manufacturer to determine those operating characteristics which are not necessarily established by standards.

8.9.1 Bounce time for control-circuit devices

Where the contacts of a control-circuit device control the input to an extremely fast relay or solid-state logic system it is important to know maximum contact bounce or chatter time so that appropriate action can be taken to preclude false operation of the fast acting devices. Thus it is maximum contact bounce time that is of interest in control-circuit devices. This maximum should include secondary bounce where it is present.

Contact bounce time is the period of time between the initial closing of a circuit by a set of contacts and the start of continuous current conduction by the contacts. This bounce time is sometimes

referred to as distributed bounce time. The contact bounce of electromagnetic devices should be determined throughout the operating voltage range. That bounce which occurs as contacts first close and rebound is called primary contact bounce. That bounce which occurs as a result of the actuation means seating or rebounding in electromechanical devices is called secondary bounce. In some cases, secondary bounce will occur before primary bounce has subsided. In other cases, contacts will be at rest when secondary bounce occurs.

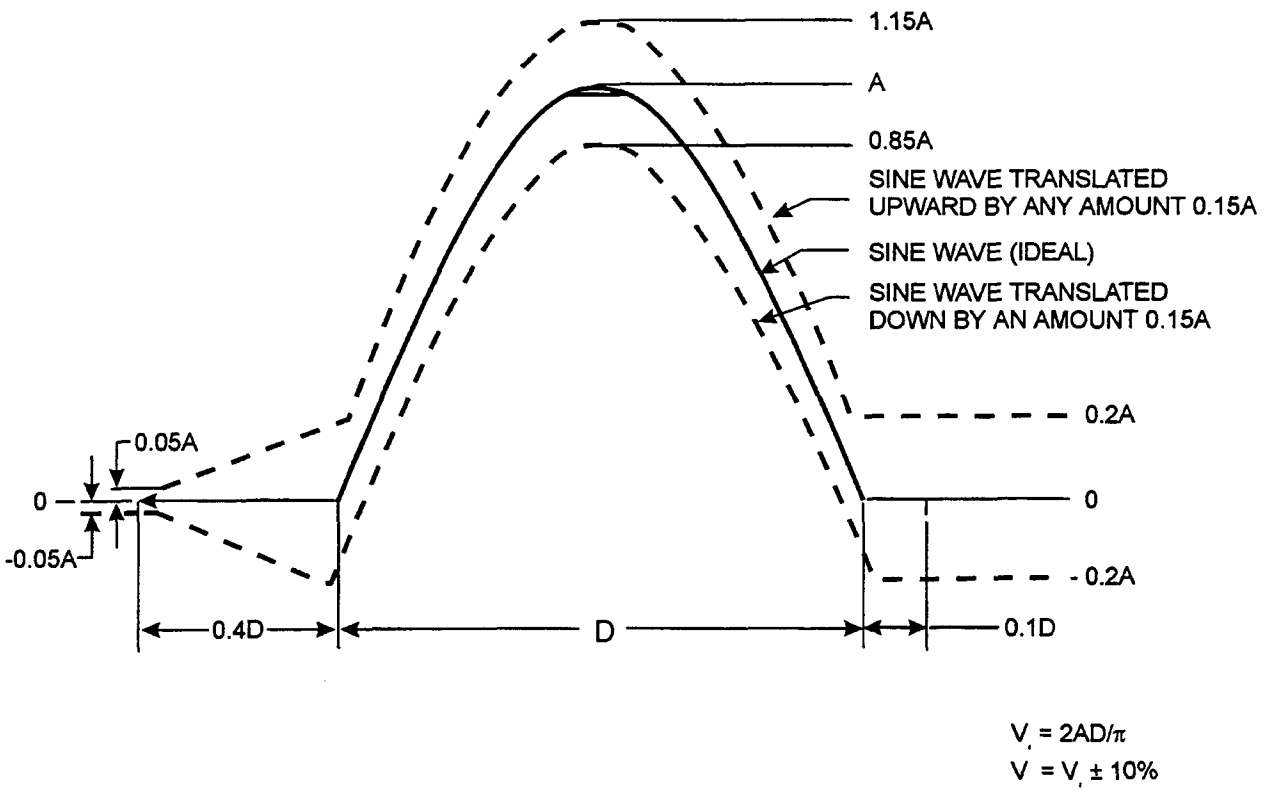
Because contact bounce is the result of so many variables, each apt to be operating in a different manner at different times, a single device is likely to show a different contact bounce time from operation to operation, and from pole to pole with normally open poles performing differently from normally closed poles.

8.9.1.1 Test load

A test load of 100 milliamperes maximum at 24V DC maximum measured under closed circuit conditions should be used to measure contact bounce time.

8.9.1.2 Test apparatus

The contacts being evaluated should be connected as shown in Figure 8-2. A filter consisting of R2 and C1 as shown may be added to negate the inductance of the power supply and slow the rise and fall times of the test signal.



NOTE - The oscillogram should include a time about 3D long with the pulse located approximately in the center. The integration to determine velocity change should extend from 0.4D before the pulse to 0.1D beyond the pulse. The acceleration amplitude of the ideal half sine pulse is A and its duration is D. Any measured acceleration pulse which can be contained between the broken line boundaries is a normal half sine pulse of nominal amplitude A and nominal duration D. The velocity change associated with the measured acceleration pulse is V.

Figure 8-1

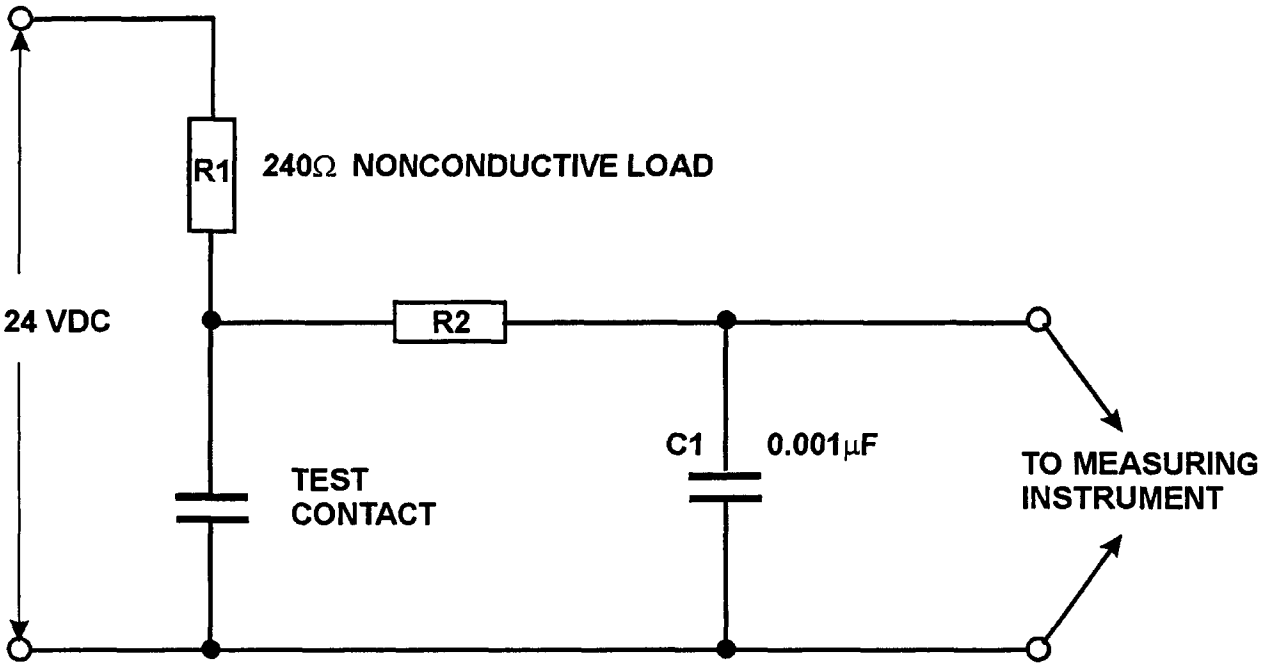


Figure 8-2
CONTACT BOUNCE TEST CIRCUIT

The instrument used to measure contact bounce duration should permanently record or retain the bounce signal trace until manually removed or reset, have a frequency response of at least 10 kHz and be capable of detecting a series of bounces each 25 microseconds or longer in duration.

No other test equipment such as motion transducers, accelerometers, etc., should be attached to the test device while contact bounce time is being measured.

The instrument should be triggered by the leading edge of the bounce signal, not by the voltage applied to the coil. (See Figure 8-2.) To prevent false triggering at the oscilloscope, an external circuit may be required either to:

a. Prevent arming of the oscilloscope trigger circuit until just before contact touch

b. Blank the trace (i.e., reduce the intensity below visible level) at all times except during the anticipated contact bounce time interval

8.9.1.3 Test conditions

The test device should be mounted as intended for use in service with all parts of the device at room temperature. An electrically operated device should be supplied with coil voltage varied throughout the standard range of the operating voltage. The rate of operation should be slow enough to assure that the contacts have stopped moving before starting the next operation.

8.9.1.4 Number of operations

The test device should be randomly energized to obtain the full range of contact bounce time. For electrically operated devices, 300 operations per pole with operating voltage being varied through the

range is considered adequate. A storage oscilloscope connected to record the contact bounce time of each operation without erasing previous traces is recommended as the most efficient manner in which to record these data. The storage oscilloscope should be one which has a high contrast between background and trace, a suitable grid, and a bistable storage mode, as opposed to a variable persistence mode. New devices should be operated at least 50 times without recording data to mechanically seat the contacts in order to obtain more consistent readings.

8.9.1.5 Test results

Contact bounce time measurements are expressed as representative maximum values in whole milliseconds for the poles tested. Test equipment and variable characteristics between similar devices preclude a high degree of accuracy.

8.9.2 Determination of operating characteristics of contactors and relays

The operating characteristics of electromagnetic contactors and relays should be determined at both extremes (high and low) of the standard operating voltage range.

8.9.2.1 Operate time

Operate time is the elapsed time measured from initial control circuit energization to the initial touch of normally open contacts or initial break of normally closed contacts.

8.9.2.2 Effective actuation time

Effective actuation time is the elapsed time measured from initial control circuit energization to the time the contacts of a normally open device close and remain closed or the contacts of a normally closed device open and remain open. Effective actuation time includes any contact bounce or chatter time occurring due to the operation of the device being tested.

8.9.2.3 Release time

Release time is the elapsed time measured from initial control circuit deenergization to the initial opening of a normally open contact or the initial closing of a normally closed contact.

8.9.2.4 Instrumentation

Operating characteristics are measured with equipment having adequate response time such as oscillographs, storage oscilloscopes, or digital electronic counters.

8.10 Production tests

8.10.1 Factory test for industrial systems

An industrial automatic system may consist of a number of coordinated subsystems, components and sensors. The overall system, including its subsystems, may be tested as a unit. Where this is not done, reasonably equivalent reference inputs, sensors and directly controlled variables shall be used to make factory adjustments and to check sequencing and overall operation.

The purpose of simulation during factory testing is to aid the manufacturer in making factory adjustments and checks. In most circumstances, it is not the purpose to demonstrate final performance by simulation nor to make final adjustments.

8.10.2 Performance testing, general

Manufacturers of industrial control equipment establish performance criteria for each of their products and conduct the checking they consider necessary to provide assurance that products shipped meet

these performance criteria. This checking may include adjustments, settings, visual inspection, dielectric, operating and similar tests. Performance testing may be on a 100 percent or on a sample basis, depending upon the product involved, and the control of parts which make up the product.

Annex A
SPACINGS VERIFIED BY TESTING
(Informative)

A-1 General

A-1.1 Status

Annexes A, B, C and D are being developed as a performance standard that covers an alternative system of design requirements and verification tests related to electrical spacings. The concept is described in Annex A. Annex B shows a typical impulse generator circuit. Annex C contains examples of clearance and creepage measurements. Annex D is a flowchart that outlines the procedure for determining clearance and creepage distances.

A-1.2 Scope

Annex A is concerned with spacings (clearance and creepage distances) of industrial control equipment for installation in low-voltage distribution systems which include services, feeders, and branch circuits. The concept of insulation coordination is introduced in this annex. It is a concept under which the insulation characteristics of the components of a system are designed or selected to minimize undesired incidents due to voltage stresses. Voltage stresses are caused by transient overvoltages which can exist in the network system to which the equipment is connected. These overvoltages are caused by external events such as lightning and network switching. Transient overvoltages may also be generated within the equipment itself, mainly from operation of the equipment.

A-1.3 Introduction

A-1.3.1 Uncoordinated insulation system

An uncoordinated insulation system implies the selection of the electrical insulation characteristics of equipment with levels of sparkover voltage of clearances and the breakdown voltage of solid insulation that are unknown. This occurs because most existing product standards, based primarily on experience, specify dimensional requirements for equipment design, but do not specify tests to measure the ability of the equipment to withstand conditions of transient overvoltages. Such standards are considered to be "Design Standards." Furthermore, the various products in an installation may have their design based on different Design Standards, each reflecting different experience. In an uncoordinated system, it is therefore possible for a clearance to have a voltage breakdown level that is higher than the voltage breakdown level of its associated solid insulation, or the solid insulation of another component. Consequently, the sparkover of clearances or the breakdown of solid insulation can occur at random locations and at unknown transient overvoltage levels.

A-1.3.2 Coordinated insulation system

A coordinated insulation system implies the design or selection of the electrical insulation characteristics of equipment with regard to its application and to its micro-environmental conditions. Consideration should be given to the continuity of service desired, to the safety of persons and property, to the overvoltages which can appear within the system, and to the location and characteristics of the transient overvoltage protective devices.

An insulation system is considered to be coordinated when it passes the impulse withstand test voltage requirements of Tables A-7-1 and A-7-2.

When an insulation system is coordinated, the solid insulation materials involved should have a voltage breakdown level which is higher than the breakdown voltage level of either the associated overvoltage protective device or the clearance on which the coordination is based. (See Table A-7-2). Thus the overvoltage protective devices or clearances in air (a renewable insulation) provide a degree of protection for the non-renewable solid insulation. The design basis for a coordinated insulation system is a Performance Standard.

A-1.4 Performance standards

Performance Standards for coordinated insulation systems are uniformly based on fundamental research data. They permit the designing of insulation systems that significantly minimize the random sparkover of clearances or breakdown of solid insulation. Performance Standards specify requirements for equipment design to withstand specific transient voltages, and they also specify tests that measure the ability of the equipment insulation to withstand the voltage stresses caused by those transient voltages.

In addition to their common data base and performance tests, Performance Standards incorporate new concepts of interrelated influencing factors including insulation material groups, transient overvoltage protective devices, overvoltage categories, macro-environmental conditions, and micro-environmental conditions. Knowledge of and suitable application of these factors also can improve insulation performance. Thus, in order to use insulation to its full advantage, it will be advisable for persons using performance standards to acquire in-depth knowledge of principles of insulation coordination and influencing factors. A study of IEC Report 664 is recommended for this purpose.

A-1.5 Units of measurement

Where a value for measurement is followed by another value in different units and enclosed in parentheses, the first value is a requirement. The parenthetic value is provided for information, and may be only an approximation because of the precision of the conversion formula and rounding rules.

A-2 Definitions

clearance: See Clause 2.

creepage distance: See Clause 2. Creepage distance is sometimes referred to as creepage.

coordination of insulation: The coordination of insulating characteristics of electrical equipment on the one hand with the expected overvoltages and with the characteristics of overvoltage protective devices, and on the other hand with the expected micro-environmental conditions and the pollution protective means.

environmental category: The classification of the macro-environment in which a device or equipment is intended to be installed. The categories are designated by a conventional number.

homogeneous (uniform)(electric) field: An electric field which has an essentially constant voltage gradient between electrodes, such as that between two spheres where the radius of each sphere is greater than the distance between them.

inhomogeneous (non-uniform)(electric) field: An electric field which does not have an essentially constant voltage gradient between electrodes.

macro-environment: The ambient physical and electrical environmental conditions in which a product is installed.

micro-environment: The physical environmental conditions immediately surrounding the clearance or creepage under consideration.

overvoltage category: The classification of the levels of transient overvoltages which can occur between interfaces within a low voltage distribution system. The categories are designated by a conventional number.

pollution: Any addition of contaminants, solid, liquid, or gaseous (ionized gases) and moisture that may produce a reduction of dielectric strength or surface resistivity.

pollution degree: The classification of pollution in terms of type, severity, combinations of pollutants, and frequency of occurrence. Pollution degrees are designated by a conventional number.

rated impulse withstand voltage, U_{imp}: The peak value of an impulse voltage, of prescribed form and polarity, that the equipment is capable of withstanding without breakdown under specified conditions of test and to which the value of the clearances is referred.

recurring peak voltage: Overvoltages generated within an equipment as a result of its operation or within associated equipment. For example, these peak voltages may be required for the operation of the equipment or they may occur as a consequence of its operation. These voltages are repetitive as compared to lightning-related transient voltages which occur infrequently.

routine test: A production test to which each individual device is subjected during or after manufacture to verify that it complies with certain criteria.

sampling test: A production test of a number of devices taken at random from a batch.

type test: A design test (See Clause 2) of one or more devices made to a specific design to verify that the design meets certain specifications or standards.

A-3 Classification

This clause describes interrelated influencing factors (classifications) that relate to insulation coordination.

A-3.1 Overvoltage category

A-3.1.1 For insulation coordination, locations between interfaces within a low voltage distribution system have been classified into four categories, according to the levels of transient overvoltages which may occur within these locations. The insulation levels required for these categories normally follow each other in descending order of magnitude of the impulse withstand voltage as the categories are located further away from the source of transient voltages.

A-3.1.2 When an equipment is subjected to a transient overvoltage, that overvoltage will impinge on the entire equipment. Where the operational voltage is not transformed to a higher level and where the equipment is equipped with an internal interface, that portion of the equipment which is downstream of the interface may be in a lower overvoltage category, and may be subjected to a lower transient overvoltage.

A-3.1.3 Low voltage industrial control equipment should be assigned one or more of the overvoltage categories shown in Table A-3-1.

Table A-3-1
Overage Categories

Category No.	Description
IV	**Primary Supply Level** Overhead lines and cable systems including distribution and its associated overcurrent protective equipment (equipment installed at the service entrance).
III	**Distribution Level** Fixed wiring and associated equipment (not electrical loads) connected to the primary supply level, Category IV
II	**Load Level** Appliances and portable equipment, etc., connected to the distribution level, Category III
I	**Signal Level** Special equipment or parts of equipment such as low-voltage electronic logic systems, remote control, signaling, and power-limited circuits connected to the load level, Category II

A-3.2 Overvoltage category interface elements

The transition from one overvoltage category to the next lower category (from one impulse withstand voltage level to a lower impulse withstand voltage level) is justified by the effect of transient limiting elements that perform an interface function. Typical elements that perform an interface function are:

a. An overvoltage protective device

b. A transformer with isolated windings and secondary load (capable of diverting, dissipating, or absorbing energy of surges)

c. A busbar system with a multiplicity of branches (capable of diverting energy of surges)

d. A capacitance, for example, a cable or a capacitor (capable of absorbing energy of surges). While capacitance may be used to absorb the energy of an impulse, the effects or subsequent release of the stored energy back into the circuit should be considered.

e. A resistance or similar damping device (capable of dissipating energy of surges)

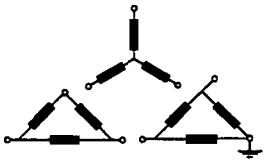
A-3.3 *Material groups*

Material groups for solid insulation are classified according to their Comparative Tracking Index (CTI) values in Table A-3-2.

Table A-3-2
Material Group

CTI Values	I	II	IIIa	IIIb
Equal or Greater Than	600	400	175	100
Less Than	-	600	400	175

Table A-4-1
Rated insulation voltage corresponding
To the rated operational voltage

Rated Operational Voltage U_e(1)				Rated Insulation Voltage
				
AC rms(2)(6)	AC rms(2)(3)(4)	AC rms	AC rms	U_iAC
---	---	12.5,24,25,30, 42,48	60-30	rms(5) 50
66/115	66	60	---	100
208Y/120,127/220	115,120,127	110,120	220-110,240-120	150
220/380,230/400, 240/415,260/440,480Y/277, 460Y/265	220,230,240, 260,277	220	440-220	300
347/600,380/660, 400/690, 415/720,480/830	347,380,400,415, 440,480,500, 577,600	480,600	960-480	600
---	660,690,720, 830,1,000	1,000	---	1,000 0

NOTES

1. These values correspond to the nominal voltage of the supply system.
2. Caution: For rated operational voltage marking requirements, see Clause A-5.
3. For ungrounded systems or systems with one phase grounded, the phase-to-ground voltage is to be considered equal to the phase-to-phase voltage.
4. Phase-to-ground voltage of ungrounded or impedance grounded systems equals the phase-to-phase voltage because the operating voltage to ground of any phase may, under service conditions, approach full-phase voltage. This is because the actual voltage to ground is determined by the insulation resistance and capacitive reactance of each phase-to-ground; thus low (but acceptable) insulation resistance on one phase may in effect ground it and raise the other two to full-phase volts above ground.
5. These standard levels of rated insulation voltage have been established as a practical means of reducing the number of levels of rated impulse withstand voltages, clearance, and creepage distances. The standard levels of rated insulation voltage represent ranges of voltages from phase-to-ground derived from the rated operational voltage.
6. In U.S. standards, these voltages are expressed as 480Y/277, etc. In IEC standards, voltages are expressed as 220/380, etc.

The CTI ratings refer to the values obtained, in accordance with ASTM D-3638 and IEC 112 (Method A). The CTI may be obtained using the insulating parts of the device or separate samples of the material used.

A-3.4 Partial discharge

Another factor influencing solid insulation is its ability to withstand partial discharges at voltage withstand values associated with its application. In the most severe case, this would be the voltage associated with its clearance. In other instances, it may depend on exposure to periodically recurring peak voltages generated within the equipment itself.

A-4 Rated insulation voltage

A-4.1 Clearances

A-4.1.1 For multiphase AC systems, rated insulation voltage is derived from the phase-to-phase voltage in column 1 or 2 of Table A-4-1.

A-4.1.2 For DC systems, the rated insulation voltage is equal to the DC rated operational voltage, U_e, or DC working voltage within an equipment.

A-4.2 Creepage

A-4.2.1 Rated insulation voltage for phase-to-phase distances and phase-to-ground distances are derived from the phase-to-phase voltage in Column 1 or 2 of Table A-4-1.

A-4.2.2 For equipment marked for connection exclusively to grounded-wye systems, a lower level of U_i may be derived from the phase-to-ground voltage in Table A-4-1, Column 1.

A-4.2.3 For equipment marked for connection exclusively to grounded-wye systems, the phase-to-phase voltage may be permitted to exceed the rated insulation voltage. See Table A-4-1, Note 2.

A-5 Marking of voltage rating

Equipment should be marked with a straight voltage rating to indicate its suitability for connection to all grounded and ungrounded systems, e.g. 480 V AC; or it should be marked with a slash voltage rating to indicate its suitability for connection exclusively to grounded-wye systems, e.g. 480Y/277V AC. See Table A-4-1, Note 6. Equipment marked 480Y/277V AC is not suitable for use on a 480 volt delta system.

A-6 Service and installation conditions

A-6.1 Macro-environment

A-6.1.1 The macro-environment of an installation is typically the ambient condition within an entire room, or office or workshop. It is the source of the type, severity, and frequency of pollution to which the micro-environment of a device or equipment may be subjected. As a practical means of reducing the number of levels of severity which a designer should consider, the climatic environmental conditions are classified into four levels, each of which has a distinct effect upon the performance of solid insulation. These four levels are Climatic Environmental Category I, II, III, and IV as shown in Table A-6-1.

Table A-6-1
Climatic Macro-Environmental Conditions

Climatic Environmental Category (EC)	Condition Description	Location Example
I	Air temperature—controlled continuously Humidity—controlled continuously Dust—removal by continuous filtering Condensation—none	Manufacturing process clean room
II	Air temperature—controlled but not continuously Humidity—uncontrolled Dust—uncontrolled, quantity small Condensation—occasional, brief	Office, residential, light commercial building
III	Air temperature—may be controlled but not continuously Humidity—uncontrolled Dust—uncontrolled, quantity moderate Condensation—frequent	Industrial or heavy commercial building
IV	Air temperature—uncontrolled Humidity—uncontrolled Dust—uncontrolled, quantity large Condensation--continuous	Unenclosed or partially enclosed location

A-6.1.2 NEMA standard industrial control equipment should be suitable for installation in Climatic Environmental Category III.

A-6.2 Micro-environment

A-6.2.1 In general, this is the environment inside the enclosure of a product. Within a product, there can be more than one micro-environment.

A-6.2.2 Pollution (of the micro-environment) is an environmental influencing factor which can cause a hygroscopic material to conduct excessive internal leakage current. It can also cause a material to degrade (track or erode) as a consequence of arcing along a leakage current path on its surface.

A-6.2.3 The frequency of condensation is especially important because pollution normally has a long-term effect as a consequence of repetitive events (arcing) which successively degrade the surface of insulation leading to a failure by tracking. Pollution can rarely have a one-time effect on the surface of insulation.

A-6.2.4 The effect of a combination of pollutants is significant. Dust, even conductive dust, may not adversely affect creepage. The pressure between dust particles and between dust particles and the surface of the insulating material is extremely low, and the contact resistance is, therefore, extremely high. Conductive moisture is necessary to bridge the particles and cause conduction.

A-6.2.5 Degree of pollution has been classified into four levels which correspond to the four environmental categories. These four levels are Pollution Degrees 1, 2, 3, and 4 as shown in Table A-6-2.

Table A-6-2
Micro-Environmental Conditions

Pollution Degree (PD)	Condition Description	Influencing Factors, Modification, Design
1	Moisture—none, always dry Dust—insignificant Effect of pollution—none	PD 1 can occur in EC I. In macro-environments which are more severe than EC I, PD 1 is commonly provided at the micro-environment by the use of coatings, encapsulations, hermetic sealing, and similar treatments which exclude conductive pollution from the micro-environment.
2	Moisture—occurs occasionally Dust—Quantity sufficient to become conductive when moist Effect of pollution—tracking or erosion at a slow rate*	PD 2 can occur in EC II. In macro-environments which are more severe than EC II, PD 2 can be provided within suitably enclosed products where means such as ventilation and local heating are provided to control humidity and condensation.
3**	Moisture—occurs frequently Dust—quantity sufficient to become conductive when moist Effect of pollution—tracking or erosion at a moderate rate*	PD 3 can occur in EC III. In macro-environments which are more severe than EC III, PD 3 can be provided within suitable enclosures which provide protection from exposure to precipitation, dust and water.
4	Moisture—occurs continuously Dust—quantity sufficient to become conductive when moist. Effect of pollution—tracking or erosion at a high rate*	PD 4 can occur within some enclosures installed in unprotected outdoor locations, EC IV. A suitable enclosure can be used to reduce the PD from 4 to 3.

* Rate of tracking or erosion is also dependent on the properties of the insulation material (see Table A-3-2) and the function of ribs (see A-7.3.4).

** Pollution Degree 3 is the basis for the clearances and creepage requirements in A-7.2 and A-7.3 of this standard. See A-6.3.

A-6.3 Relationship of the macro-environment to the micro-environment

The design and performance requirements for creepage in A-7.3 are based on the suitability of equipment for installation in Climatic Environmental Category III (macro-environment) and consequential Pollution Degree 3 within the micro-environment. The relationship of climatic environmental categories to pollution degrees is shown in Table A-6-3.

Table A-6-3
Relationship of Climatic Environmental Categories to Pollution Degrees

Classification of Micro-Environment Climatic Environmental Category	Classification of Micro-Environment Pollution Degree			
	1	2	3	4
I	(a)			
II	(b)	(a)	(c)	
III		(b)	(a)	(c)
IV			(b)	(a)

NOTES

(a) Conditions at micro-environment may be the same as that of macro-environment, e.g., Environmental Category I and Pollution Degree 1.

(b) Conditions at micro-environment can be less severe than the macro-environment. See influencing factors in Table A-6-2.

(c) Conditions at micro-environment can also be worsened by the presence of production residues and internally generated pollution. Internally generated pollution can be caused by abrasion or arcing caused by operating the device or equipment. This pollution, in the presence of moisture, can become conductive.

A-7 Construction

A-7.1 Insulation requirements

A-7.1.1 Insulation requirements for equipment for use in general-purpose applications where transient voltages are not controlled by a transient limiting means

A-7.1.1.1 All voltage systems are to be assumed to be either ungrounded or to have one phase grounded. See Table A-4-1, Column 2.

A-7.1.1.2 Clearances between ground and live parts, between poles, and between circuits, should withstand a value of impulse voltage corresponding to the rated insulation voltage derived from Table A-4-1 and the assigned overvoltage category or categories in Table A-7-1.

Table A-7-1
Clearances of Equipment for General Purpose Applications Where Test Voltage Values Are Functionally Equivalent to Measured Minimum Clearances Specified in Table 7-1 of ICS 1 (2,000 Meter Altitude, Pollution Degree 3*)

Insulation Voltage AC rms or	Overvoltage Category II		III		IV**	
	Rated Impulse Withstand Voltage††	Clearance	Rated Impulse Withstand Voltage††	Clearance	Rated Impulse Withstand Voltage††	Clearance
DC	kV	mm(in.)	KV	mm(in.)	KV	mm(in.)
50	2.7	1.6(0.063)	4.3	3.2(0.135)	...	...
100	2.7	1.6(0.063)	4.3	3.2(0.125)	11.0	12.7(0.50)
150	2.7	1.6(0.063)	4.3	3.2(0.125)	...	...
300	2.7	1.6(0.063)	6.8	6.4(0.250)	16.0	19.0(0.75)
600	5.6	4.8(0.188)	8.8	9.5(0.375)	20.0	25.4(1.00)
1,000	...	...	12.0	14.0(0.55)	...	...

* Pollution does not basically influence clearances, however, small clearances can be bridged completely by solid particles, dust, and water. Therefore, minimum clearances such as 1.6 mm and 3.2 mm are specified according to the degree of pollution and impulse voltage which may be present in the micro-environment.

** For industrial control equipment used at the service entrance (transition from Overvoltage Category IV to III), Overvoltage Category IV is required only for the main (line) terminals of service entrance equipment.

† For the relationship of rated insulation voltage to rated operational voltage and voltage phase-to-ground, see Clause A-4.

†† Impulse withstand voltages are given for inhomogeneous field conditions. The values of impulse withstand voltage are from IEC Report 664, Table A1.
See A-8.4.1.3 for altitude correction factors.

A-7.1.1.3 Solid insulation of equipment should withstand the impulse withstand voltage of the associated clearances of requirement A-7.1.1.2.

A-7.1.1.4 Creepage distances are to be in accordance with A-7.3.

A-7.1.2 Insulation requirements for equipment for use in a system where transient voltages are controlled by transient limiting means

A-7.1.2.1 Clearances between ground and live parts, between poles, and between circuits, should withstand the value of impulse withstand voltage corresponding to the rated insulation voltage derived from Table A-4-1 and the assigned overvoltage category or categories in Tables A-7-2, A-7-7 or A-7-8. The impulse withstand voltage is not to be less than the maximum voltage of the transient limiting means.

A-7.1.2.2 Equipment may be assigned several overvoltage categories either at the same rated operational voltage or at different rated operational voltages.

A-7.1.2.3 Solid insulation of equipment should withstand the impulse withstand voltage of the associated clearance requirement A-7.1.2.1.

A-7.1.2.4 Equipment should not generate recurring peak voltages higher than the value corresponding to the lowest impulse withstand voltage rating per requirement A-7.1.2.1.

A-7.1.2.5 Because recurring peak voltages are repetitive, they may, in conjunction with the properties of the insulation material and pollution, accelerate the degradation of the insulation material.

A-7.1.2.6 For any equipment or a device incorporating a transient overvoltage protective device, the impulse sparkover and the discharge voltage should not exceed the value of the impulse withstand voltage to ground corresponding to the stated overvoltage category.

A-7.1.2.7 Equipment is to have creepage distances in accordance with A-7.3.

A-7.2 Clearances

A-7.2.1 Within equipment

A-7.2.1.1 Clearances, except for printed wiring boards, are to be in accordance with Tables A-7-1 or A-7-2.

A-7.2.1.2 Clearances for printed wiring boards are to be in accordance with A-7.4.

A-7.2.1.3 Clearances which are smaller than those in Tables A-7-1 and A-7-2 are permitted, provided they are verified by performance testing in accordance with Clause A-8.

A-7.2.1.4 Clearances in Table A-7-1 were taken from Table 7-1 of ICS 1. Table A-7-1 is provided to permit these clearances to be verified either by linear measurement or by a performance test in accordance with Clause A-8.

A-7.2.2 Clearances to enclosure walls

A-7.2.2.1 Clearances to the walls of a metal enclosure are to be in accordance with Tables A-7-1, A-7-2 and A-7-7 except for those portions of the walls which can be deflected and, thereby, reduce a clearance. Attached metal parts are to be considered to be part of a wall.

A-7.2.2.2 Clearances to deflectable enclosure walls were taken from Table 7-1 of ICS 1. They are to be in accordance with the values in Table A-7-3.

A-7.3 Creepage

A-7.3.1 Creepage for insulation subject to long-term stress

A-7.3.1.1 The minimum values of creepage for Pollution Degree 3 and without the use of ribs are given in Table A-7-4. Creepage values shown in Table A-7-4 have been determined for insulation intended to be under stress for a long time (or continuously).

A-7.3.1.2 For inorganic insulating materials (which do not track), for example, glass or ceramics, creepage need not be greater than their associated inhomogeneous field clearance, except for equipment in Overvoltage Category IV. See Table A-7-2.

Table A-7-2
Clearances of Equipment for Applications Where Transient Voltages Are Controlled by Transient Limiting Means
(2,000 Meter Altitude, Pollution Degree 3)

	Overvoltage Categories							
	I		II		III		IV	
Rated Insulation Voltage* AC rms or DC	Rated Impulse Withstand Voltage** kV	Clearance† mm(in.)	Rated Impulse Withstand Voltage** kV	Clearance† mm(in.)	Rated Impulse Withstand Voltage** kV	Clearance† mm(in.)	Rated Impulse Withstand Voltage** kV	Clearance† mm(in.)
50	0.33	0.8(0.031)	0.5	0.8(0.031)	0.8	0.8(0.031)	1.5	0.8(0.031)
100	0.5	0.8(0.031)	0.8	0.8(0.031)	1.5	0.8(0.031)	2.5	1.5(0.059)
150	0.8	0.8(0.031)	1.5	0.8(0.031)	2.5	1.5(0.059)	4.0	3.0(0.117)
300	1.5	0.8(0.031)	2.5	1.5(0.059)	4.0	3.0(0.117)	6.0	5.5(0.215)
600	2.5	1.5(0.059)	4.0	3.0(0.117)	6.0	5.5(0.215)	8.0	8.0(0.312)
1,000	4.0	3.0(0.117)	6.0	5.5(0.215)	8.0	8.0(0.312)	12.0	14.0(0.546)

* For the relationship of rated insulation voltage to rated operational voltage and voltage phase-to-ground, see Clause A-4.

** See Table A-8-1 for altitude correction factors.

† Pollution does not basically influence clearances, however, small clearances can be bridged completely by solid particles, dust, and water. Therefore, minimum clearances such as 0.8 mm are specified according to the degree of pollution and the impulse withstand voltage which may be present in the micro-environment.
Clearances are given for inhomogeneous field conditions from IEC Report 664; however, smaller clearances should be permitted as stated in A-7-2.1.

Table A-7-3
Clearances to Deflectable Enclosure Walls

	Overvoltage Category	
Rated Insulation Voltage AC rms or DC	I In.(mm)	II,III,IV In.(mm)
50	0.5(12.7)	0.5(12.7)
100	0.5(12.7)	0.5(12.7)
150	0.5(12.7)	0.5(12.7)
300	0.5(12.7)	0.5(12.7)
600	0.5(12.7)	0.5(12.7)
1,000	...	0.8(20.3)

Table A-7-4
Creepage For Equipment Subject To
Long Term Stress (Pollution Degree 3)

Rated Insulation Voltage* AC rms or DC	Creepage Over Categories, I, II, III Material Groups			Overvoltage Category IV† Material Groups		
	I mm(in.)	II mm(in.)	IIIa&IIIb mm(in.)	I mm(in.)	II mm(in.)	IIIa&IIIb mm(in.)
50	1.5(0.059)	1.7(0.066)	1.9(0.074)	1.7(0.066)	1.9(0.074)	2.1(0.082)
100	1.8(0.070)	2.0(0.078)	2.2(0.086)	2.0(0.078)	2.2(0.086)	2.5(0.098)
150	2.0(0.078)	2.2(0.086)	2.5(0.098)	3.2(0.125)	3.6(0.140)	4.0(0.156)
300	4.0(0.156)	4.5(0.176)	5.0(0.195)	6.3(0.246)	7.1(0.277)	8.0(0.312)
600	8.0(0.312)	9.0(0.351)	10.0(0.390)	12.5(0.488)	14.0(0.546)	16.0(0.624)
1,000	12.5(0.488)	14.0(0.546)	16.0(0.624)	20.0(0.780)	22.0(0.858)	25.4(1.000)

* For the relationship of rated insulation voltage to rated operational voltage and voltage phase-to-ground, see Clause A-4. For equipment marked for connection exclusively to grounded wye systems, see A-4.2.

† For industrial control equipment used at the service entrance (transition from overvoltage Category IV to III) overvoltage Category IV is required only for the main (line) terminals.

Table A-7-5
MINIMUM WIDTH OF GROOVES

Pollution Degree	Minimum Width of Grooves* Mm(in.)
1	025(0.010)
2	1.0(0.39)
3	1.5(0.059)
4	2.5(0.100)

* If the associated clearance is less than 3mm, the minimum groove width is permitted to be reduced to 1/3 of the associated clearance.

A-7.3.1.3 The minimum creepage distance is not to be less than the associated clearance, regardless of the material group of the solid insulation.

A-7.3.2 Function of grooves and ribs

Grooves or ribs may be added to the surface of solid insulation to provide the required creepage between conductor parts without increasing the clearance between those parts.

A-7.3.3 Use of grooves

A-7.3.3.1 Grooves may function as collectors of dust and moisture; consequently, small grooves can be completely bridged by pollution. See Annex C, Example 1. Minimum width of grooves to avoid bridging and to enable the surface of the groove to function as a portion of a creepage distance is given in Table A-7-5. The minimum width is based on the degree of pollution which may be present in the micro-environment. For the measurement rules for grooves, see A-7.3.5.

A-7.3.3.2 Creepage distances, including the surface of grooves, are not to be less than the values in Table A-7-4.

A-7.3.4 Use of ribs

Ribs considerably decrease the formation of leakage current because they diminish the effects of contamination and decrease drying-out time. Creepage distances can therefore be reduced to 80 percent of the values in Table A-7-4 provided the minimum height is 2 mm. See Annex C, Example 4. However, creepage (including the surface of ribs) cannot be less than the associated clearance. See Annex C, Example 8. The minimum width of the base of a rib is determined by mechanical requirements.

A-7.3.5 Measurement rules for creepage and clearance

These rules do not differentiate between grooves on the surface of solid insulation and gaps between discrete parts of solid insulation, or between insulation material groups. See Table A-3-2. Furthermore:

A-7.3.5.1 The bottom of a V-shaped groove is to be assumed to be bridged with an insulating link of X mm width moved into the most unfavorable position. See Annex C, Example 3.

A-7.3.5.2 Where the distance across the top of a groove is X mm or more, creepage is measured along the contour of the grooves. See Annex C, Example 3.

A-7.3.5.3 Creepage and clearance measured between parts moving in relation to each other are measured when these parts are in their most unfavorable positions.

A-7.3.5.4 Examples of the measurement for clearances and creepage are provided in Annex C.

A-7.4 Printed wiring boards

A-7.4.1 For insulation requirements, see A-7.1.2.

A-7.4.2 In addition, maximum recurring peak voltages are to be limited to the values in Table A-7-6 to prevent the degradation of insulation by partial discharges (corona).

Table A-7-6
Maximum Recurring Peak Voltage Related to Spacings on Uncoated Printed Wiring Boards (2,000 Meter Altitude)

Spacings mm(in.)	Maximum Recurring Peak, kV*	Spacings mm(in.)	Maximum Recurring Peak, kV*
0.025(0.001)	0.33	1.5(0.059)	1.14
0.04(0.002)	0.33	1.6(0.062)	1.15
0.1(0.004)	0.33	1.8(0.070)	1.25
0.2(0.008)	0.40	3.0(0.117)	1.65
0.25(0.010)	0.45	3.2(0.125)	1.7
0.4(0.016)	0.60	5.0(0.195)	2.20
0.5(0.020)	0.64	5.5(0.215)	2.30
0.75(0.029)	0.80	9.0(0.312)	2.80

*Recurring peak voltage values are based on statistical evaluation of partial discharge data.

A-7.4.3 Electrical spacings for printed wiring boards should be in accordance with the values in Tables A-7-7 and A-7-8. For clearances to the walls of metal enclosures, see A-7.2.2.

Table A-7-7
Uncoated Printed Wiring Board Spacings (Clearance and Creepage Distances) for Equipment Where Transient Voltages are Intentionally Controlled by a Transient Limiting Means* (2,000 Meters Altitude)

Rated Insulation Voltage**,† AC rms or DC Volts	Overvoltage Category I: Impulse Withstand Voltage kV	I: Spacings for Pollution Degrees†† 1 mm (in.)	I: Spacings for Pollution Degrees†† 2 mm (in.)	Overvoltage Category II: Impulse Withstand Voltage kV	II: Spacings for Pollution Degrees†† 1 mm (in.)	II: Spacings for Pollution Degrees†† 2 mm (in.)	Overvoltage Category III: Impulse Withstand Voltage kV	III: Spacings for Pollution Degrees†† 1 mm (in.)	III: Spacings for Pollution Degrees†† 2 mm (in.)
50	0.33	0.025(0.001)	0.2(0.008)	0.5	0.04(0.002)	0.2(0.008)	0.8	0.1(0.004)	0.2(0.008)
100	0.50	0.1(0.004)	0.2(0.008)	0.8	0.1(0.004)	0.2(0.008)	1.5	0.5(0.020)	0.5(0.020)
150	0.80	0.25(0.016)	0.4(0.016)	1.5	0.5(0.020)	0.5(0.020)	2.5	1.5(0.059)	1.5(0.059)
300	1.50	0.75(0.029)	1.6(0.062)	2.5	1.5(0.059)	1.6(0.062)	4.0	3.0(0.117)	3.0(0.117)
600	2.50	1.8(0.070)	3.2(0.125)	4.0	3.0(0.117)	3.2(0.125)	6.0	5.5(0.215)	5.5(0.215)
1,000	4.00	3.2(0.125)	5.0(0.195)	6.0	5.5(0.215)	5.5(0.215)	8.0	8.0(0.312)	8.0(0.312)

* The spacings given were derived from IEC Publication 664A Table IV, however, some values of spacings were increased so that no creepage can be smaller than its associated clearance necessary to withstand the required impulse withstand voltage.

** For insulation coordination within an equipment, creepage distances for printed wiring boards for IEC 664A Table IV, Pollution Degree 1, corresponding to the working voltage within the equipment should be permitted to be used. In this case, the limiting impulse withstand voltage can be found in IEC Publication 664 Table A1 under Case A impulse values corresponding to the creepage distance (clearance) value under consideration.

† For the relationship of rated insulation voltage to rated operational voltage and voltage phase-to-ground, see Clause A-4.

†† Pollution Degree 3, creepage from Table A-7-5 should be used.

Table A-7-8
Coated Printed Wiring Board Spacings (Clearances And Creepage Distances) For Equipment Where Transient Voltages Are Intentionally Controlled By A Transient Limiting Means

Rated Insulation Voltage*† AC rms or DC Volts	Overvoltage Category I: Impulse Withstand Voltage Volts	I: Spacings for Pollution Degree 1 mm (in.)	Overvoltage Category II: Impulse Withstand Voltage Volts	II: Spacings for Pollution Degree 1 mm (in.)	Overvoltage Category III: Impulse Withstand Voltage Volts	III: Spacings for Pollution Degree 1 mm (in.)
50	330	0.025 (0.001)	500	0.025 (0.001)	800	0.025 (0.001)
100	500	0.1 (0.004)	800	0.1 (0.004)	1,500	0.1 (0.004)
150	800	0.25 (0.010)	1,500	0.25 (0.010)	2,500	0.25 (0.010)
300	1,500	0.75 (0.029)	2,500	0.75 (0.029)	4,000	0.75 (0.029)
600	2,500	1.8 (0.070)	4,000	1.8 (0.070)	6,000	1.8 (0.070)
1,000	4,000	3.2 (0.125)	6,000	3.2 (0.125)	8,000	3.2 (0.125)

* For insulation coordination within an equipment, creepage distances for printed wiring boards from IEC 664A Table IV, Pollution Degree 1, corresponding to the working voltage values within the equipment should be permitted to be used. In this case, the limiting impulse withstand voltage can be found in IEC Publication 664 Table A1 under Case A impulse values corresponding to the creepage distance (clearance) value under consideration.

† For the relationship of rated insulation voltage to rated operational voltage and voltage phase-to-ground, see Clause A-4.

A-7.4.4 Uncoated printed wiring boards

A-7.4.4.1 Spacings for Pollution Degree 1, Overvoltage Categories II and III, can be smaller than those in Table A-7-7 providing they can withstand their associated impulse withstand voltages; however, they should not be smaller than the Pollution Degree 1 spacings for Overvoltage Category I.

A-7.4.4.2 Because of "environmental/chemical" effects which can diminish or bridge small spacings, for Pollution Degree 2, it is not recommended that spacings less than 0.2 mm be used in industrial control equipment.

A-7.4.4.3 The Comparative Tracking Index (CTI) of the board material should be:

Pollution Degree 1, CTI $\geq$ 100

Pollution Degree 2, CTI $\geq$ 175

A-7.4.5 Coated printed wiring boards

A-7.4.5.1 Spacings in Table A-7-8 are for Overvoltage Category I, Pollution Degree 1. The use of suitable coatings permits the application of the boards in other degrees of pollution and overvoltage categories.

A-7.4.5.2 Spacings in Table A-7-8 apply to the coated portions of the board. Uncoated areas such as solder pads or components are to meet the requirements of A-7.4.4 according to the pollution degree of the uncoated areas.

A-7.4.5.3 The Comparative Tracking Index (CTI) of the board base material is based on the pollution degree for the uncoated areas of the board. See A-7.4.4.3 for the CTI of the base material.

A-7.4.5.4 Coating performance requirements are under consideration.

A-8 *Performance requirements and tests*

A-8.1 Clearances

A-8.1.1 Design verification

A-8.1.1.1 Clearances which are designed to be equal to or greater than the values in Tables A-7-1, A-7-2 or A-7-3 require verification of their magnitude. Verification of the values in Tables A-7-1 and A-7-2 is to be either by linear measurement or by impulse withstand voltage test at a level corresponding to the clearances in the tables. For pre-test conditioning of solid insulation associated with a clearance, see A-8.3.2.

A-8.1.1.2 Verification of the values in Table A-7-3 is to be by linear measurement.

A-8.1.2 *Performance verification*

A-8.1.2.1 General

Clearances which are designed to be less than the values in Tables A-7-1, A-7-2, A-7-7 or A-7-8 require type test and sample or routine test verification of their performance. Verification is to be by an impulse withstand voltage test at a level corresponding to the clearance in Tables A-7-1, A-7-2, A-7-7, or A-7-8. See Annex B for typical impulse generator circuit.

A-8.1.2.2 Printed wiring boards
Clearances from Table A-7-7 are verified under clean and dry conditions.

Clearances from Table A-7-8 are verified, prior to coating the board, under clean and dry conditions.

A board, coated but without components installed, is to withstand the impulse voltage corresponding to the rated insulation voltage and the assigned overvoltage category.

A-8.1.2.3 Sample and routine tests
Sample and routine tests are conducted using the same procedures and criteria as for type tests. See A-8.3.2.

A-8.2 Creepage distances

A-8.2.1 Design verification

A-8.2.1.1 Creepage distances require verification of their magnitude. Verification of the values in Table A-7-4 is by linear measurement.

A-8.2.1.2 For measurement principles, see A-7.3.4. For measurement examples, see Annex C.

A-8.3 Solid insulation

A-8.3.1 Performance verification

The voltage withstand characteristics of solid insulation are verified by a type test. See A-7.1.1 and A-7.1.2.

A-8.3.2 Pre-test conditioning

A-8.3.2.1 For type tests, the device or equipment is to be conditioned for 96 hours in an atmosphere of 85 ± 5 percent relative humidity at a temperature of 25 ± 2°C, prior to the application of the test voltage.

A-8.3.2.2 Routine and sample tests, and dielectric tests conducted after endurance or performance tests, are to be performed without conditioning.

A-8.3.3 Test selection factors

The voltage withstand characteristic of solid insulation is dependent upon many factors which should be considered for the selection of methods and values for testing. One of these factors is the voltage-time characteristic of the insulation. The one-minute dielectric test does not prove its ability to withstand an impulse withstand voltage associated with a clearance. Likewise, a one-minute power frequency test at the rated impulse withstand voltage of the clearance would be too severe. Therefore, the impulse voltage test is used for this purpose at the same level as that required for the clearance.

A-8.4 Dielectric tests

A-8.4.1 Conditions of test

A-8.4.1.1 Metal enclosure
If the equipment or the device is to be used in an enclosure, it is to be mounted in the smallest enclosure in which it is likely to be used. Where the equipment or the device is to be used without an

enclosure, it is to be mounted on a metal plate and all metal parts (frame, etc.) that are grounded in normal service are to be connected to the metal plate.

A-8.4.1.2 Nonmetallic actuator or enclosure

An actuator (handle) of insulating material, and the integral non-metallic enclosure of the device that is intended to be used without an additional enclosure, is to be covered by a metal foil and connected to the frame or the mounting plate.

A-8.4.1.3 Altitude

Breakdown voltage of a clearance in air, for a homogeneous field is, according to Paschen's Law, a function of the distance between electrodes and the atmospheric pressure. Therefore, testing at an altitude other than 2,000 meters requires the use of corrected test voltages given in Table A-8-1. This table also applies for an inhomogeneous field.

Table A-8-1
Test Voltages For Verifying Clearances
At Altitudes Less Than 2,000 M

Rated Impulse Withstand Voltage, kV	Corresponding Test Voltage, kV Altitude			
2,000 m (6562 Ft)	0 m (0 Ft)	200 m (650 Ft)	500 m (1641 Ft)	1,000 m (3281 Ft)
0.33	0.36	0.35	0.35	0.34
0.5	0.54	0.54	0.53	0.52
0.8	0.93	0.92	0.90	0.86
1.5	1.8	1.7	1.7	1.6
2.5	3.1	3.0	2.9	2.8
2.7	3.3	3.3	3.2	3.0
4.0	4.9	4.8	4.7	4.4
4.3	5.3	5.2	5.0	4.8
5.6	6.9	6.8	6.5	6.2
6.0	7.4	7.2	7.0	6.7
6.8	8.4	8.2	8.0	7.6
8.0	9.8	9.6	9.3	8.9
8.8	8.10	10.6	10.3	9.8
11.0	13.8	13.5	13.0	12.3
12.0	15.0	14.7	14.2	13.4
16.0	20.0	19.6	18.9	17.9
20.0	25.0	24.5	23.7	22.4

NOTE
At a given altitude, corrections for normal variations in barometric pressure are disregarded.
For the principles and formulas used to develop the values in Table A-8-1 see IEC 664.

A-8.4.2 *Types of dielectric tests*

A-8.4.2.1 Dielectric test voltages

The preferred dielectric test voltage is an impulse voltage. Other dielectric tests which provide equivalent voltage levels with greater levels of energy available when the voltage breakdown level of a clearance is reached are shown in Table A-8-2. Some of these tests, such as the half sine pulse, can also be used to limit the energy available when a clearance breaks down under test.

Table A-8-2
Dielectric Test Voltages
(2,000 Meters Altitude)

		Power Frequency			
Type of Test	**Impulse***	**AC**	**AC Peak or DC**,†**	**AC Peak ½ Sine**	**AC Peak Ramp**
Rate of Rise	**1.2/50 micro-second**	**rms**,† ...**	**... 50/60**	**Wave**,† ...**	**6,000 V/sec.**
Hertz	...	50/60	AC 3 Pos. &	50/60	50/60
Duration of Test	**3 Pos. & 3 Neg††**	**3 Pos. & 3 Neg**	**3 Neg.; DC Min. 10 ms**	**3 Pos. & 3 Neg††**	**4-5 ma** Detection †††**
	230	330	330	330	330
	500	350	500	500	500
	800	570	800	800	800
	1,500	1,060	1,500	1,500	1,500
	2,500	1,770	2,500	2,500	2,500
	4,000	2,830	4,000	4,000	4,000
	6,000	4,240	6,000	6,000	6,000
	8,000	5,660	8,000	8,000	8,000
	12,000	8,480	12,000	12,000	12,000

* The test voltage values are given in Table A1 of IEC Publication 664.

** Available current should be limited to 4-5 milliamperes. The test equipment can be power limited or designed to shut off by the detection of 4-5 milliamperes leakage current.

† The ½ sine wave pulse and AC voltages are slightly more severe than the impulse voltage values in time duration and have been found to be satisfactory in laboratory tests. These two test methods are relatively easy to achieve with less sophisticated test apparatus than the impulse test method.

†† The minimum interval between pulses is 1 second.

††† The voltage is to be increased until the ramp value is exceeded without detection of a leakage current of 4-5 milliamperes.

A-8.4.2.2 Impulse dielectric test

The purpose of this test is to verify that clearances will withstand specified transient over-voltages.

A test voltage of 1.2/50 microsecond wave shape is used to simulate overvoltage due to lightning or switching operations.

A-8.4.2.3 Power frequency dielectric test

The power frequency dielectric tests in this standard are an alternate to the impulse dielectric test.

Since the dielectric test voltage is greater than the rated voltage, care should be taken to not apply the test voltage in a manner which energizes a circuit.

A-8.4.2.4 DC dielectric test

A DC dielectric test voltage is considered to be equivalent to the peak value of the power frequency dielectric test voltage.

The DC test voltage may be used in place of an AC test voltage in those cases where an AC test voltage would result in undesirable AC current which might be sufficient to damage (overheat or

overvoltage, or both) components or which may appear to be a high leakage current. Care should be taken to discharge any stored energy left in the circuit after test.

A-8.4.3 Points of application of test voltages

The test voltages of A-8.4.2 are applied as follows:

A-8.4.3.1 Between the poles of the main circuit of the equipment and the metal parts that are grounded in normal service, including the enclosure, with the contacts in the opened and closed positions.

A-8.4.3.2 Between each pole of the main circuit and with the other poles connected to the frame, and with the contacts in the opened and closed positions.

A-8.4.3.3 Between each control and auxiliary circuit that is not normally connected to the main circuit in service and each of the main and other control and auxiliary circuits that have been connected to the frame for the purpose of the test.

A-8.4.3.4 For solid-state equipment being tested per A-8.4.3.1 or A-8.4.3.2 the test voltage is to be applied between the poles of the main circuit with the solid-state devices in their blocking condition, and also with a shorting wire across the devices simulating the closed condition.

A-8.4.3.5 For equipment intended for use in other than motor branch circuits, the test voltage is to be applied between poles rated for opposite polarity and between all poles and the metal parts that are grounded in normal service with contacts in the opened and closed positions.

A-8.4.4 Test results

There should be no unintentional flashover or disruptive discharge or puncture (disruptive discharge through solid insulation) during the test. The operation of a specific overvoltage protective function incorporated in the equipment for that purpose is permitted.

A-8.5 Overvoltages generated by the equipment or device

A-8.5.1 Performance verification

Equipment intended for use in a system where transient voltages are controlled by transient limiting means is to be type tested to verify compliance with 7.1.2.4.

A-8.5.2 Procedure

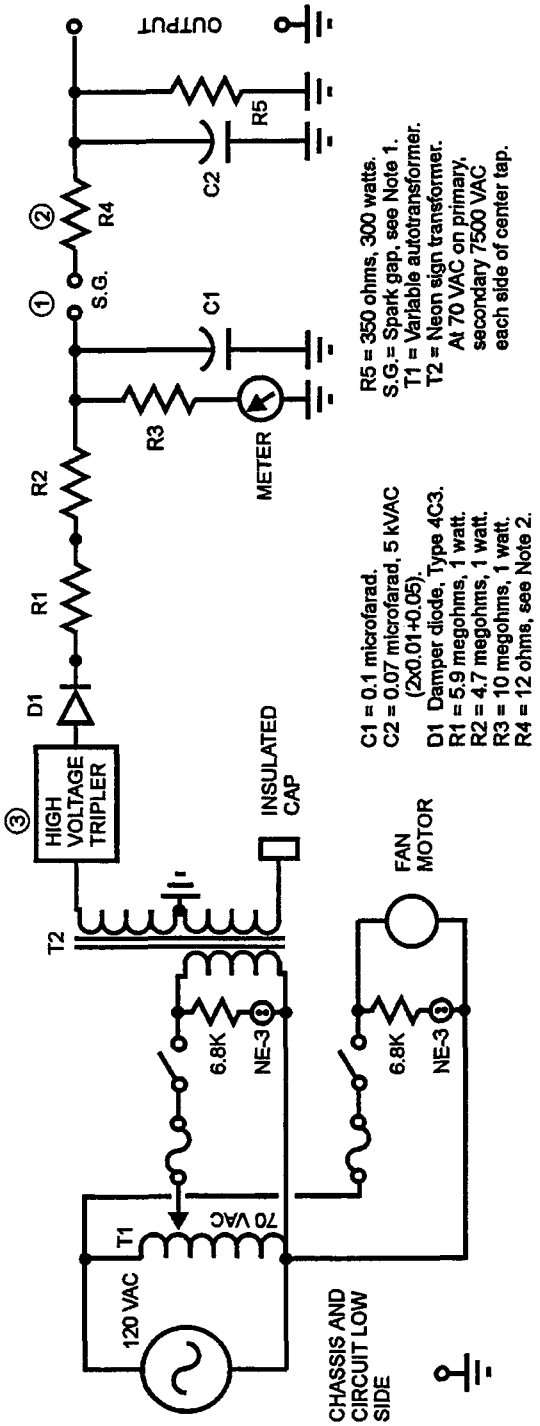
All line and load terminals of the component, device, or equipment are to be monitored for overvoltages during operation at rated operational voltage under load and no-load conditions, and while being energized and deenergized.

A-8.5.3 Test results

See A-7.1.2.4.

Annex B
TYPICAL IMPULSE TEST CIRCUIT
(Informative)

See 7.2.1 and A-8.1.2.1.



Notes:

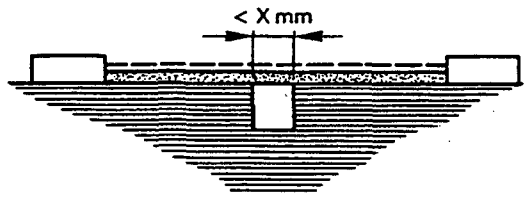
1. Spark gap employing boiler electrodes.
2. R4 is 12 ohm surge resistor, No.22 AWG (0.32 mm^2) nichrome wire wound on flat mount to reduce reactance.
3. High voltage tripler. Murata No. MSR 2513-RRET002ICE22.

Annex C
EXAMPLES OF CLEARANCE AND CREEPAGE MEASUREMENT

(Informative)

For values of X (minimum width of grooves), see Table A-7-5.

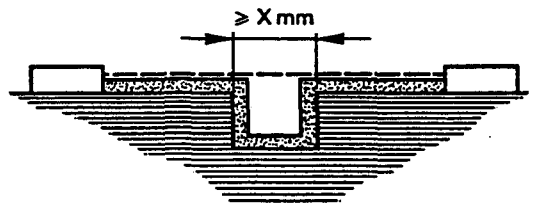
Example 1



Condition: This creepage distance path includes a parallel- or converging-sided groove of any depth with a width less than X mm.

Rule: Creepage distance and clearance are measured directly across the groove as shown.

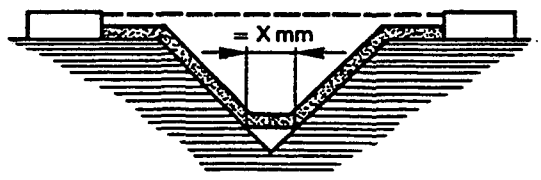
Example 2



Condition: This creepage distance path includes a parallel-sided groove of any depth and equal to or more than X mm.

Rule: Clearance is the "line-of-sight" distance. Creepage distance path follows the contour of the groove.

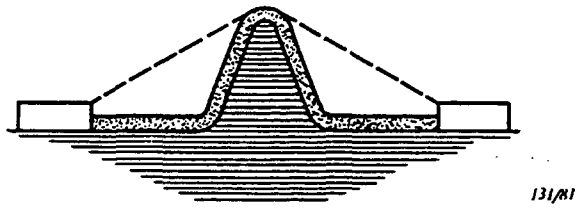
Example 3



Condition: This creepage distance path includes a V-shaped groove with a width greater than X mm.

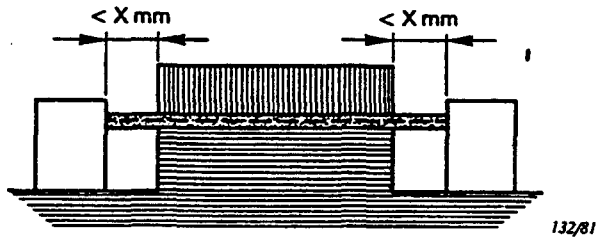
Rule: Clearance is the "line-of-sight" distance. Creepage distance path follows the contour of the groove but "short-circuits" the bottom of the groove by X mm link.

Example 4



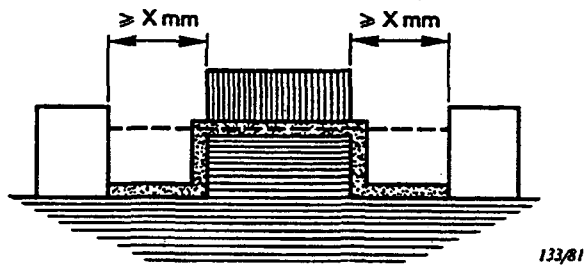
Condition: This creepage distance path includes a rib. Rule: Clearance is the shortest air path over the top of the rib. Creepage path follows the contour of the rib.

Example 5



Condition: This creepage distance path includes an uncemented joint with grooves less than X mm wide on each side. Rule: Creepage distance and clearance path is the "line-of-sight" distance shown.

Example 6

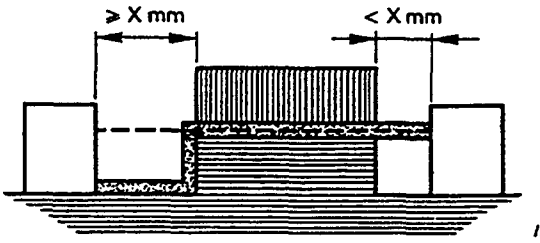


Condition: This creepage distance path includes an uncemented joint with grooves equal to or more than X mm wide on each side. Rule: Clearance is the "line-of-sight" distance. Creepage distance path follows the contour of the grooves.

– – – – – Clearance

Creepage distance

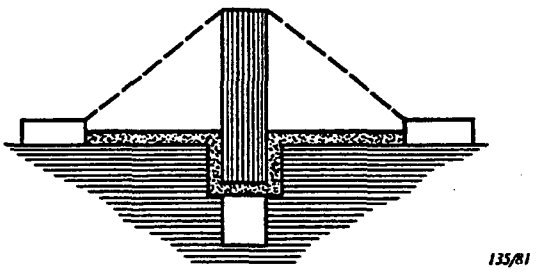
Example 7



Condition: This creepage distance path includes an uncemented joint with a groove on one side less than X mm wide and the groove on the other side equal to or more than X mm wide.

Rule: Clearance and creepage distance paths are as shown.

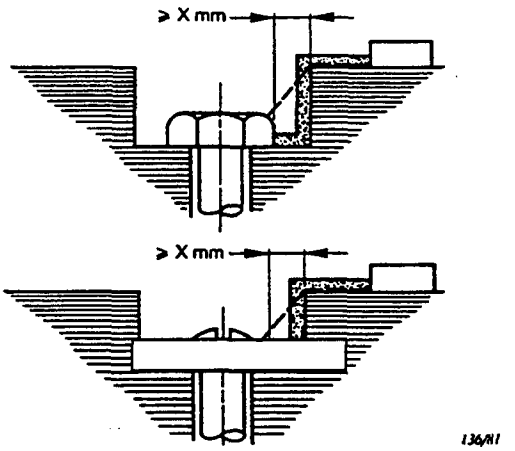
Example 8



Condition: Creepage distance through uncemented joint is less than creepage distance over barrier.

Rule: Clearance is the shortest direct air path over the top of the barrier.

Example 9



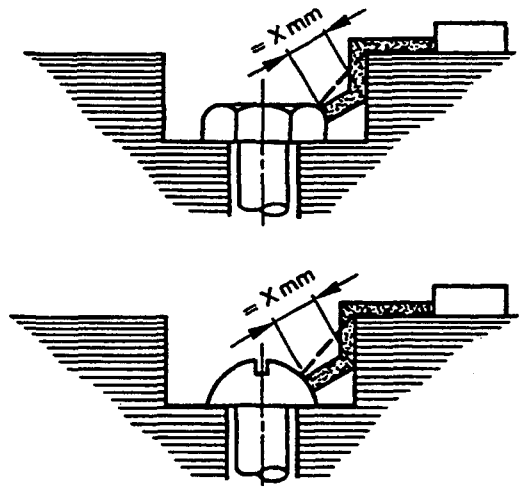
Condition: Gap between head of screw and wall of recess wide enough to be taken into account.

Rule: Clearance and creepage distance paths are as shown.

– – – – – Clearance

Creepage distance

Example 10

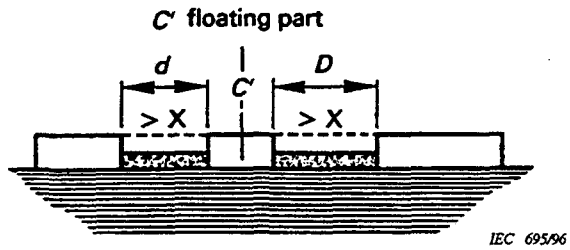


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Condition: Gap between head of screw and wall of recess too narrow to be taken into account.

Rule: Measurement of creepage distance is from screw to wall when the distance is equal to X mm.

Example 11



IEC 695/96

Clearance is the distance $d + D$

Creepage distance is also $d + D$

– – – – – Clearance

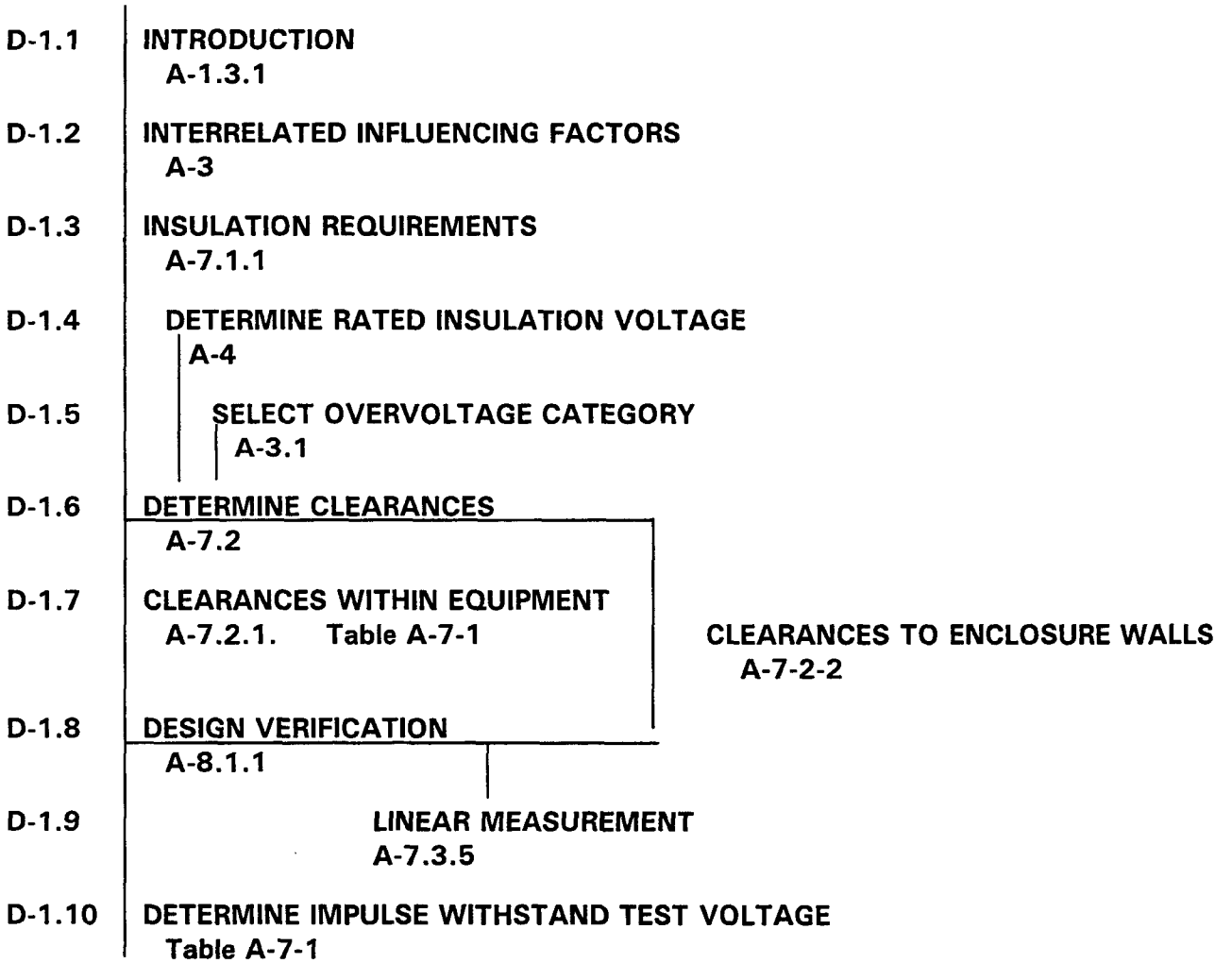
Creepage distance

Annex D
FLOWCHARTS FOR DETERMINING CLEARANCE AND CREEPAGE DISTANCES ACCORDING TO THE CONCEPT OF ANNEX A

(Informative)

References are to clauses and tables in Annex A.

D-1 Clearances, Transient Voltages Not Controlled



D-2 Clearances, Transient Voltages Controlled

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A-1.3.2, A-1.4

D-2.2 INTERRELATED INFLUENCING FACTORS
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D-2.3 INSULATION REQUIREMENTS
A-7.1.2

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A-4.0

D-2.5 SELECT OVERVOLTAGE CATEGORY
A-3.1

D-2.6 DETERMINE POLLUTION DEGREE
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D-2.7 DETERMINE CLEARANCES
A-7.2

D-2.8 CLEARANCES WITHIN EQUIPMENT
A-7.2.1 and Table A-7-2
A-7.4 and Tables A-7-7 and A-7-8

CLEARANCES TO ENCLOSURE WALLS
A-7.2.2

D-2.9 DESIGN VERIFICATION
A-8.1.1

D-2.10 LINEAR MEASUREMENT
A-7.3.5

D-2.11 PERFORMANCE VERIFICATION
A-8.1

D-2.12 DETERMINE IMPULSE WITHSTAND VOLTAGE
Table A-7-2

D-2.13 DIELECTRIC TEST
A-8.4

D-2.14 OVERVOLTAGES GENERATED BY EQUIPMENT DEVICE TEST
A-8.5

D-3 Creepage

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A-1.3, A-1.4

D-3.2 INTERRELATED INFLUENCING FACTORS
A-3

D-3.3 INSULATION REQUIREMENTS
A-7.1.1.4 or A-7.1.2.7

D-3.4 DETERMINE RATED INSULATION VOLTAGE
A-4

D-3.5 SELECT OVERVOLTAGE CATEGORY
A-3.1

D-3.6 SELECT MATERIAL GROUP
A-3.3

D-3.7 DETERMINE POLLUTION DEGREE
A-6.1, A-6.2, A-6.3

D-3.8 DETERMINE CREEPAGE
A-7.3

D-3.9 CONSIDER GROOVES AND RIBS ACROSS CREEPAGEPATH
A-7.3.2, A-7.3.3, A-7.3.4

D-3.10 CONSIDER MEASUREMENT RULES FOR CREEPAGE
A-7.3.5

D-3.11 DESIGN VERIFICATION
A-8.2.1

D-3.12 PERFORMANCE VERIFICATION
A-8.3

D-3.13 DIELECTRIC TESTS
A-8.4

Annex E
ELECTRICAL NOISE TESTS
(Informative)

E-1 General

Exposing solid-state devices to excessive electrical noise may damage the devices or cause malfunction of the equipment which they control.

The electrical noise tests described in E-6 are designed to test solid-state logic input and output modules and power supplies that interface with control power sources. The wiring associated with these devices is frequently subjected to the showering-arc type of electrical noise that the tests impose. The tests are intended to demonstrate that the equipment is immune to electrical noise when subjected to the specified noise signals under the specified test conditions.

The tests are not intended to be used with logic level signal wiring. Solid-state logic wiring that carries logic level signals should be kept physically separated from control wiring which carries the showering-arc type of electrical noise. Logic level signal wires to panel-mounted thumbwheel switches, potentiometers for remote adjustment of timers and photocells, or proximity input signal wiring and similar wiring should not be subjected to the tests specified in E-6.

The circuits formed by the connection to the logic elements shown in Figures E-1, E-2, and E-3 are intended to detect whether noise signals injected into the power supply and input and output wiring have penetrated the isolating means afforded by these devices to a degree that would cause malfunction of logic gates. Additional detection circuits may be formed by interconnecting other logic elements, such as flip-flops, counters, etc., to further evaluate the noise rejection of power supplies and input and output devices; however, these other logic elements are not included in the scope of the electrical noise test.

E-2 Noise suppression

Logic system components should be wired, enclosed and isolated from sources of potential noise so that any noise received by the logic components is less than that produced by the noise generator described in E-3 and E-4. This may require filters or surge suppressors applied to electromagnetic devices operating with logic system components to limit the magnitude and duration of transient voltages conducted or radiated into the logic system.

E-3 Noise generator

The characteristics of the electrical noise which is commonly produced by electrical contacts interrupting inductive loads are reproduced with controlled voltage amplitude by the test circuits shown in Figures E-4 and E-5.

The circuit in the Figure E-4 produces continuous single polarity transients.

The circuit in Figure E-5 is an alternate circuit to produce an output that oscillates between positive showering arc transients and negative showering arc transients. This circuit may be more appropriate for equipment sensitive to continuous single polarity transients, and may produce a slightly more severe test than the circuit of Figure E-4.

Adjustments of the sparkgap, G, from 0 to 1.25 millimeters will produce showering arc transients from a minimum of 350 volts to more than 2,000 volts. The voltage is measured by observing the oscilloscope display. Typical oscilloscope displays are shown in Figures E-6 and E-7.

DANGER - 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.

E-4 Coupling cable assembly

Electrical signals produced by the noise generator should be coupled into logic system circuits by simulating actual wiring conditions where multiple wires lie side by side in a common conduit or wire duct. The coupling cable assembly should be the means of providing repeatable conditions for injecting noise signals into logic system wiring. The assembly should be constructed in accordance with Figure E-8. The conductors in the cable should be arranged in accordance with Figure E-9. Connections between the noise generator and spark gap should be made with cable wires No. 1 and 6, which are diametrically opposite. Two other wires should be used to make the connections shown in Figures E-1, E-2 and E-3. These two wires should be selected using the calibration procedure described in Clause E-5.

E-5 Calibration procedure for noise generator and coupling cable assembly

In order to have a reproducible test, it is necessary to calibrate the output of the coupling cable assembly. This is done by selecting the proper pairs of wires to be used as the input and output of the cable assembly in accordance with the following:

a. Connect the test circuit to the terminals as shown in Figure E-10.

b. Adjust the noise generator by means of the sparkgap, C, to produce 1,500 volt transients similar to the display shown in Figure E-6 or Figure E-7.

c. After setting the noise generator, make an oscilloscope measurement of the output of the cable assembly as shown in Figure E-11. 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.

d. Where the measurements are not within the tolerances shown in Figure E-11 select a pair of wires other than 2-2A and 7-7A (for example, 10-10A and 5-5A, or 2-2A and 5-5A, or 10-10A and 7-7A). Where none of these combinations produces the desired result, it is recommended that a pair of wires other than 1-1A and 6-6A be used for the input and that the above test procedure be repeated with other pairs of wires being used for the output to determine which pairs of wires give an output within the calibration shown in Figure E-11.

The test apparatus is then ready for use in the test specified in Clause E-6.

The output of the cable assembly is connected to the device under test with a twisted pair of wires not more than 3 meters long.

E-6 Verification test for electrical noise

The modules which are combined to create a solid-state logic system should be significantly immune to electrical noise. Logic system components, including a power supply, OR logic element, AND logic

element, input signal converter, and 115-volt AC output amplifier, should be mounted and interwired as shown in Figures E-1, E-2 and E-3 using the manufacturer's standard assembly practices. While the logic system is operating, the output of a noise generator and coupling cable assembly constructed in accordance with Clauses E-3 and E-4 and calibrated in accordance with Clause E-5 should be applied to the system terminals for external wiring, using the test procedure described in Clause E-6.

Wired connections between the noise generator, coupling cable assembly, logic system and control relay load (CR) should be in accordance with Figure E-3.

For the initial test condition, use the connection diagram shown in Figure E-3 where the coupling cable assembly is connected to input contact 1CR.

E-6.1 Noise injected on input wiring

Connections should be made in accordance with Figure E-3 and the test sequences should be in accordance with the following:

a. Case I—OR logic element:

   1. Close line switch SW1 to energize the logic power supply.

   2. Preset the output of the OR logic element to a logic zero. Relay will not pick up.

   3. Close line switch SW2 to energize the noise generator.

   4. Relay CR should not pick up or chatter during a 1-minute noise test.

   5. Open all line switches to terminate the test.

b. Case II — AND logic element:

   1. Close line switch SW1 to energize the logic power supply.

   2. Preset the output of the AND logic element. Relay CR will pick up and remain in the picked-up position.

   3. Close line switch SW 2 to energize the noise generator.

   4. Relay CR should not drop out or chatter during a 1-minute noise test. A drop out of relay CR indicates a failure.

   5. Open all line switches to terminate the test.

E-6.2 Noise injected on output wiring

Connections should be made in accordance with Figure E-2 and the steps described in E-6.1 (a) or (b) should be repeated.

E-6.3 Noise injected on power supply line wiring

Connections should be made in accordance with Figure E-1 and the steps described in E-6.1 (a) or (b) should be repeated.

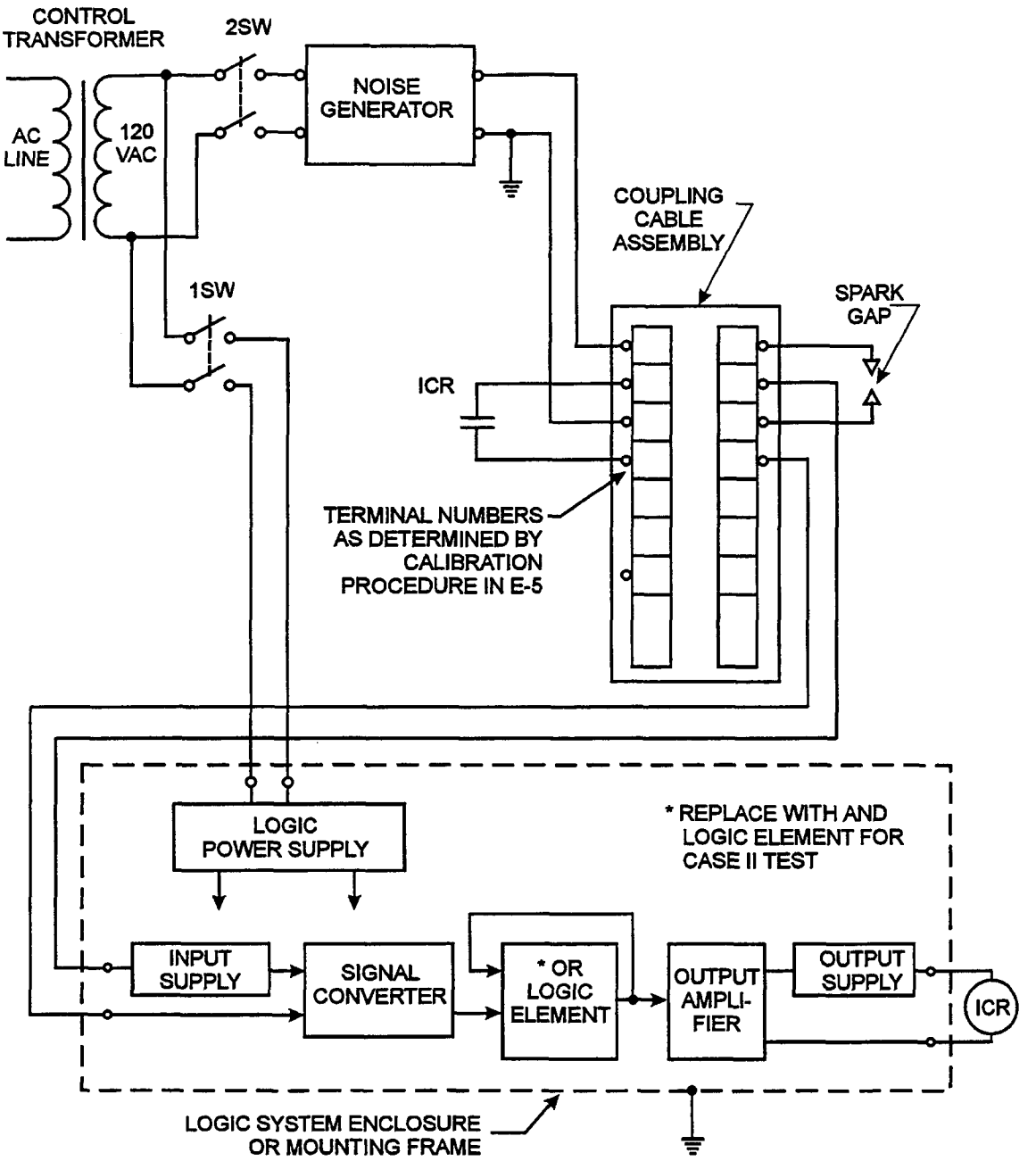


Figure E-1
Connection Diagram for Noise Test of Input Circuit

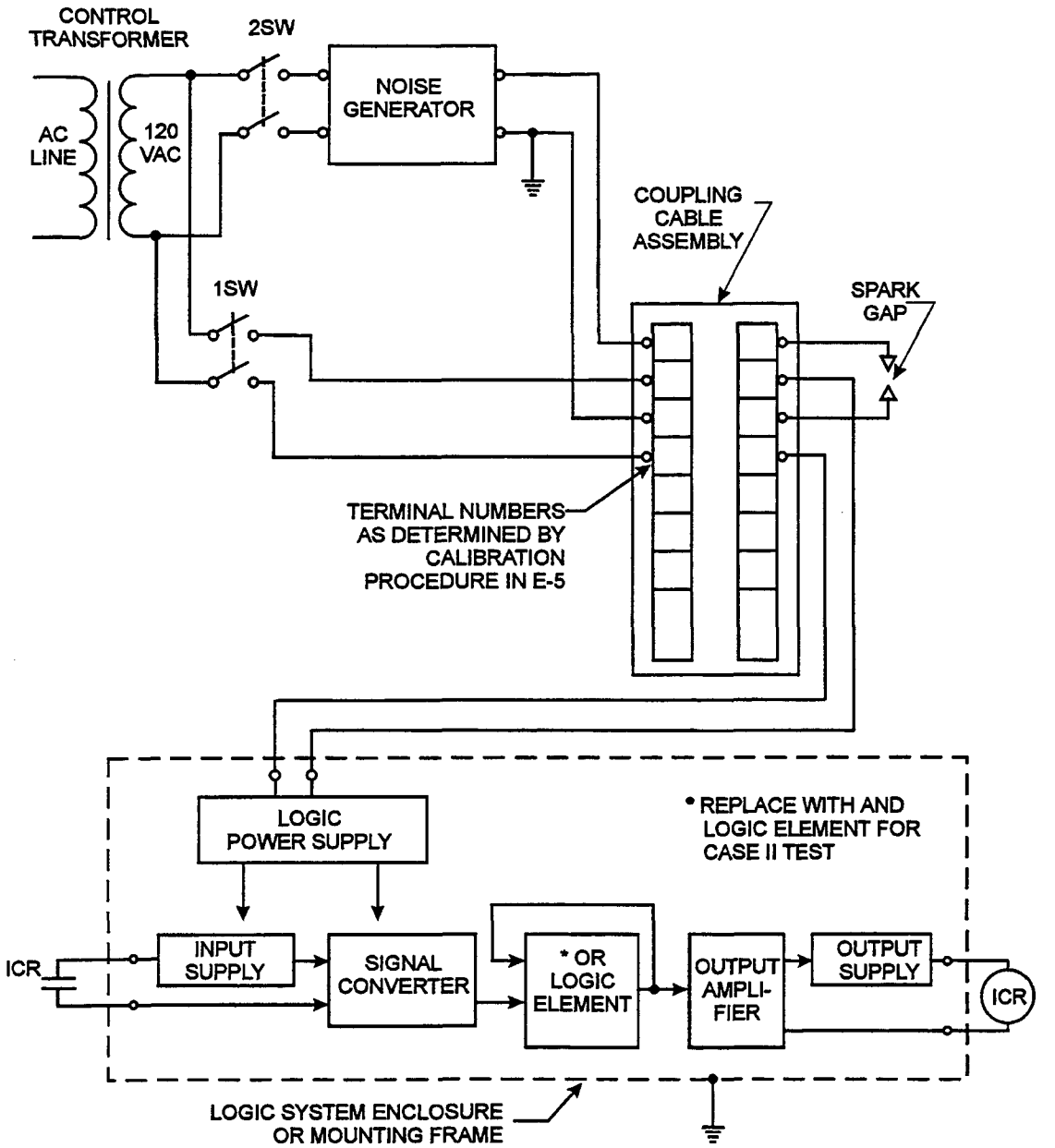


Figure E-2
Connection Diagram for Noise Test of Logic Power Supply Circuit

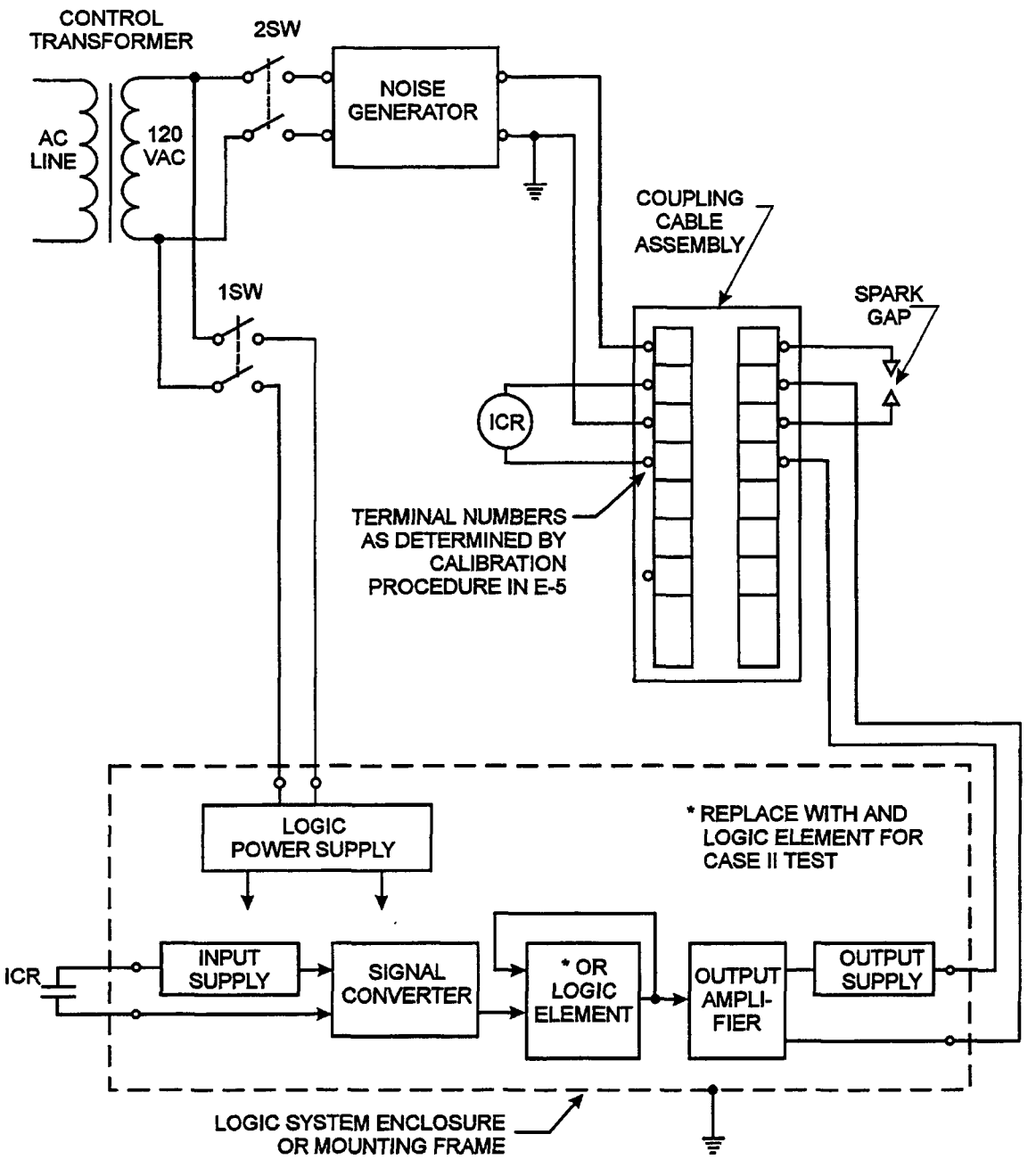
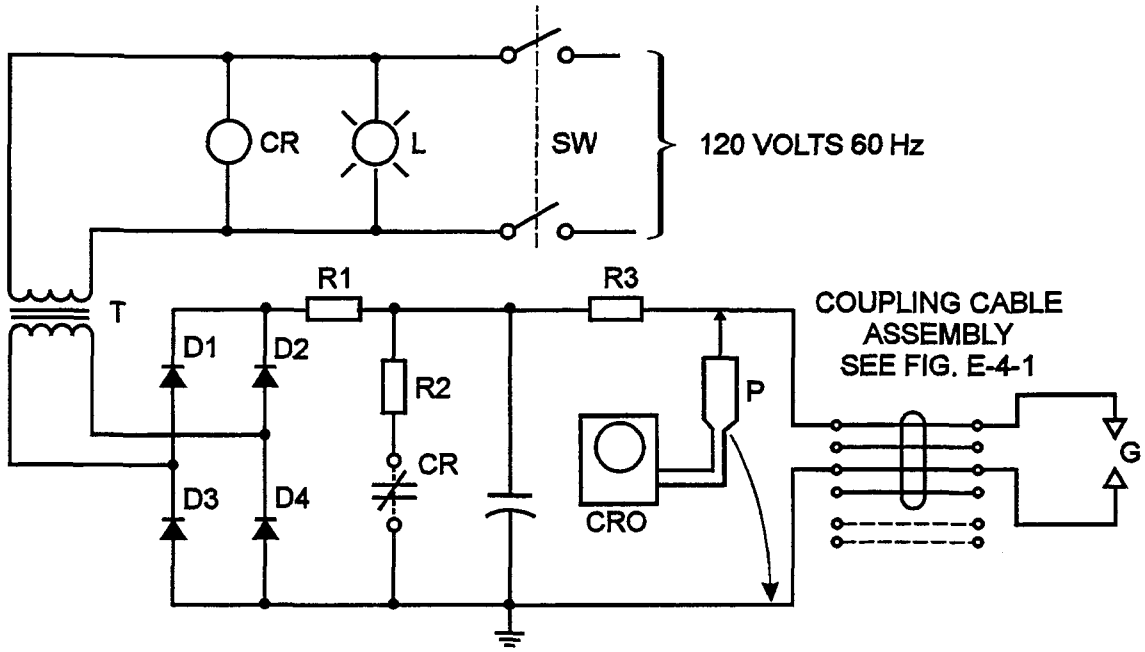


Figure E-3
Connection Diagram for Noise Test of Output Circuit

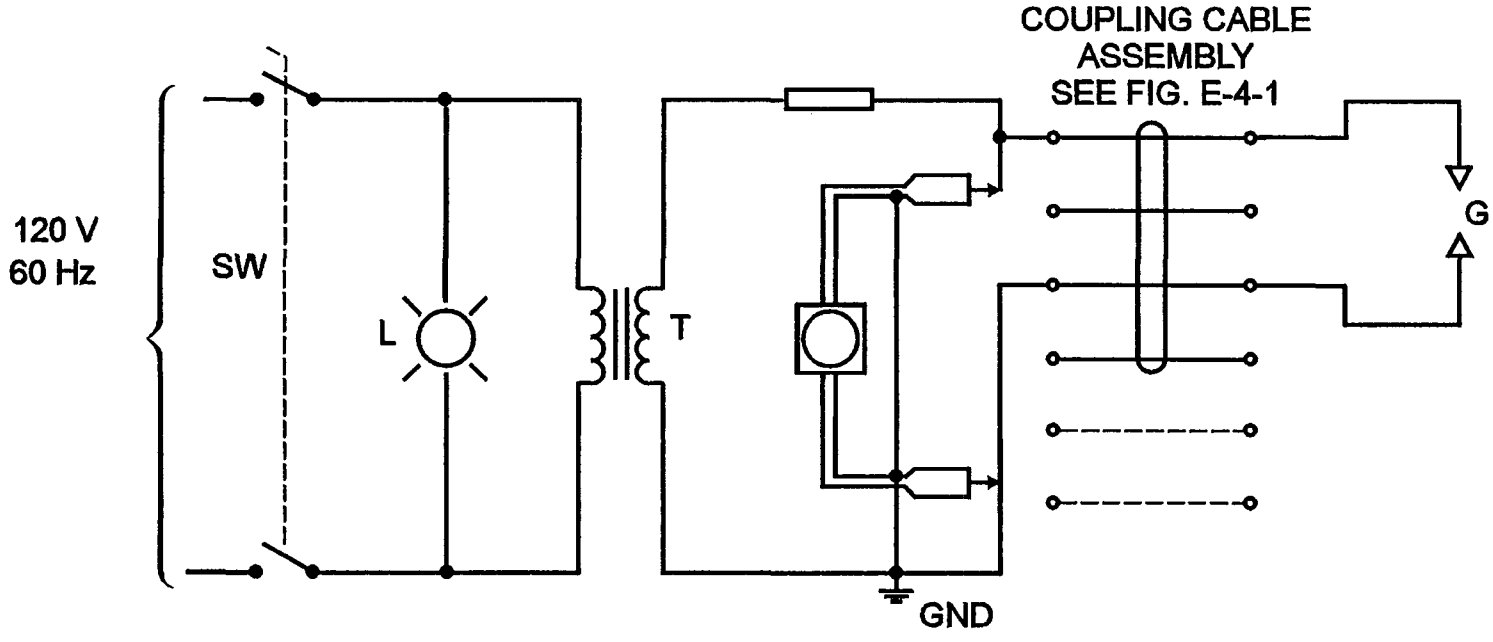


CR .....120 V, 60 Hz relay with normally closed contacts

T..... luminous sign transformer 110 VA, 120 V primary, 3 kV secondary
R1, R2..... 50 k Ω, 20 W wire-wound resistor
R3 .....300 k Ω, 30 W resistor
SW ..... ."ON"-"OFF" switch.
L ..... red warning lamp.
D1, D2, D3, D4 ... 10kV, 25mA silicon diodes.
C .....1.0 µF, 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 micrometer screw results in gap adjustment from 0 to 1.25 mm.)

CAUTION - THE VOLTAGE 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 OPEN

Figure E-4
Test Equipment, Single Polarity



SW - 120 V, 60 Hz relay with normally closed contacts
L - 120 V pilot light.
T - Luminous sign transformer
110 VA, 120 volt primary, 3 kV secondary
R - 300 k Ω, 30 watt resistor
CRO - cathode ray oscilloscope (100 kHz or greater upper band width) with differential input amplifier.
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 micrometer screw results in gap adjustment from 9 to 1.25 mm.)

SW - 120 V, 60 Hz relay with normally closed contacts
L - 120 V pilot light.
T - Luminous sign transformer
110 VA, 120 volt primary, 3 kV secondary
R - 300 k Ω, 30 watt resistor
CRO - cathode ray oscilloscope (100 kHz or greater upper band width) with differential input amplifier.
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 micrometer screw results in gap adjustment from 9 to 1.25 mm.)

Figure E-5
Test Equipment, Oscillating Polarity

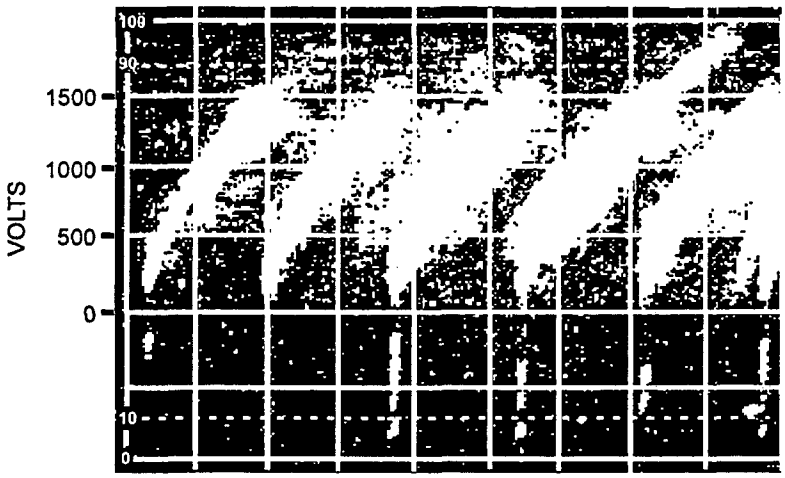


Figure E-6
Typical Oscillogram of Continuous Single Polarity Transient Produced by Showering Arc Electrical Noise Generator

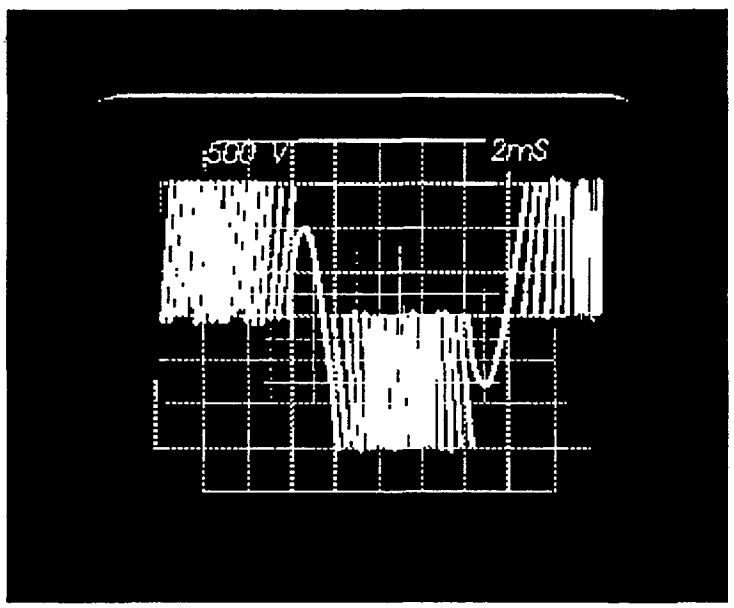


Figure E-7
Typical Oscillogram of Continuous Oscillating Polarity Transient Produced by Showering Arc Electrical Noise Generator

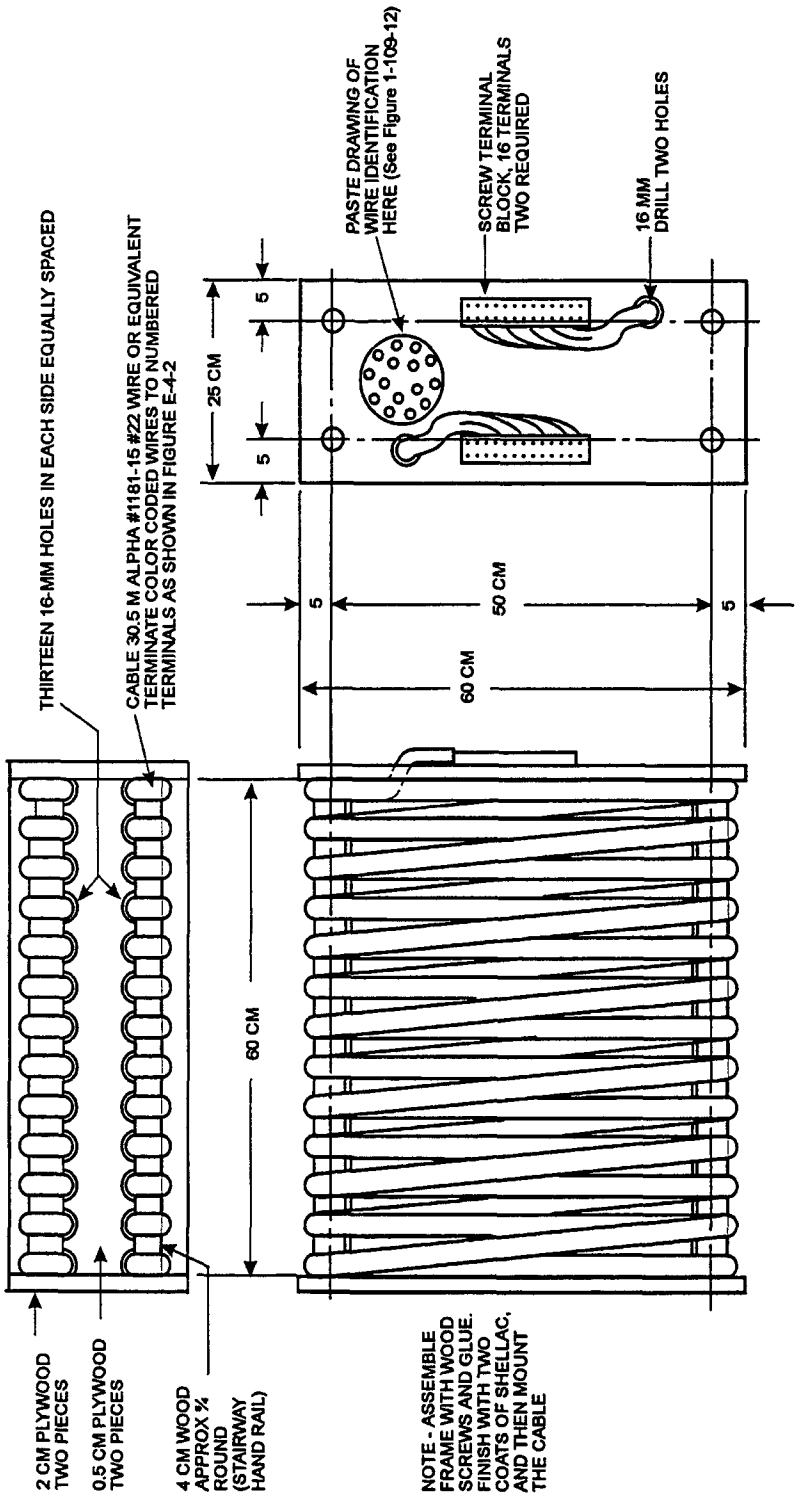
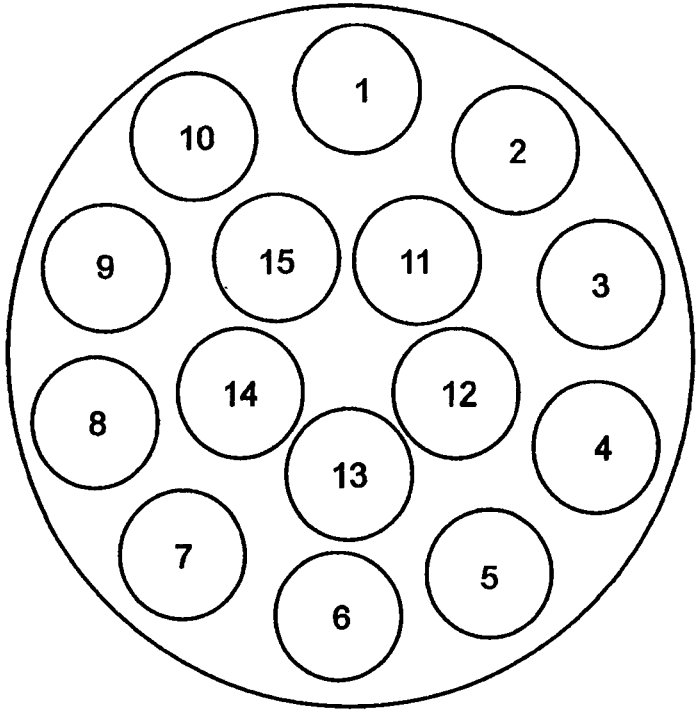


Figure E-8
Cable Assembly for Coupling Noise into Signal and Power Lines



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

1	1A
2	2A
3	3A
4	4A
5	5A
6	6A
7	7A
8	8A
9	9A
10	10A
11	11A
12	12A
13	13A
14	14A
15	15A

Figure E-9
Conductor Arrangement

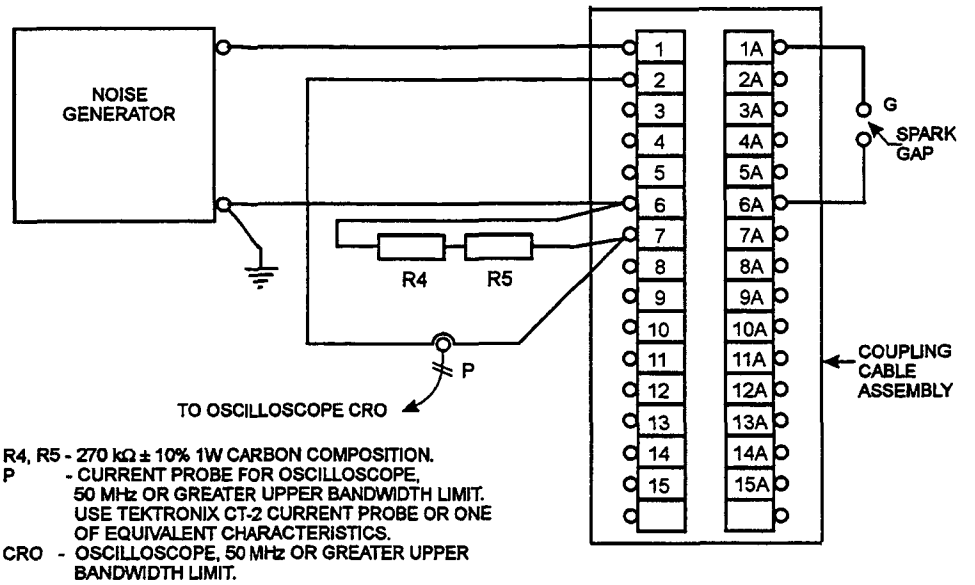
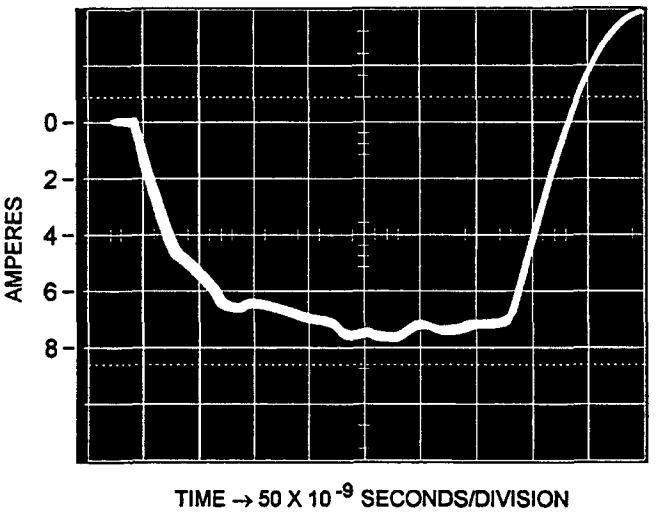


Figure E-10
Connection Diagram and Parts List for Coupling Cable Assembly Standardization



Peak current = 6.0 amperes minimum
Leading edge rise time from 1 to 3 amperes = $25 \cdot 10^{-9}$ seconds maximum

Figure E-11
Current Pulse Oscillogram for Standardization Coupling Cable Assembly



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