UL 1740

STANDARD FOR SAFETY

Robots and Robotic Equipment

UL Standard for Safety for Robots and Robotic Equipment, UL 1740

Fourth Edition, Dated January 26, 2018

Summay of Topics

This revision of ANSI/UL 1740 dated November 17, 2020 includes changes regarding illuminated e-stop; 40.2.2.2.

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

The revised requirements are substantially in accordance with Proposal(s) on this subject dated May 1, 2020 and September 18, 2020.

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Standard for Robots and Robotic Equipment

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The most recent designation of ANSI/UL 1740 as an American National Standard (ANSI) occurred on October 20, 2020. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, and Title Page.

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

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INTRODUCTION

1 Scope

1.1 These requirements cover robots and robotic equipment rated 600 V or less and intended for installation in accordance with the National Electrical Code, NFPA 70. Equipment evaluated to these requirements is intended to meet the requirements of Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1, ISO 10218-1, and can be installed in accordance with ISO 10218-1, Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1 and ISO 10218-2, Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 2: Robot Systems and Integration.

1.2 These requirements cover robotic equipment and systems intended for indoor and outdoor use in applications such as parts assembly, parts transfer, automated material handling, inspection, loading, die-casting, deburring, welding, paint spraying, automated storage/retrieval systems, and the like.

1.3 Robots and robotic equipment that contain unique features or functions associated with the application or end-product equipment, and not specifically addressed in this standard or referenced standards, shall also be evaluated to the applicable requirements of standards for the application or end-product equipment.

1.4 In addition to the requirements in this standard, robots and robotic systems shall also comply with the applicable sections of the Electrical Standard for Industrial Machinery, NFPA 79.

1.5 Robots and robotic systems intended for use in hazardous locations, as defined by the National Electrical Code, NFPA 70, shall also comply with the applicable safety requirements based on the specific end-use application, including those contained in the following standards:

a) Intrinsically Safe Apparatus and Associated Apparatus for Use in Class I, II, and III, Division 1, Hazardous (Classified) Locations, UL 913;

b) Explosion-Proof and Dust-Ignition-Proof Electrical Equipment for Use in Hazardous (Classified) Locations, UL 1203;

c) Nonincendive Electrical Equipment for Use in Class I and II, Division 2 and Class III, Divisions 1 and 2 Hazardous (Classified) Locations, ISA 12.12.01;

d) Electric Motors and Generators for Use in Hazardous (Classified) Locations, UL 674; and

e) Purged and Pressurized Enclosures for Electrical Equipment, NFPA 496.

1.6 In the following text, a requirement that applies to one type of equipment, such as a controller or pendant, will be identified by a specific reference. In the absence of a specific reference or if the term robot or robotic equipment is employed, it is to be understood that the requirement applies to all types of equipment covered by this standard.

2 Glossary

2.1 For the purpose of this standard the following definitions apply.

2.2 AUTOMATIC OPERATION – The time when a robot is performing its programmed tasks through continuous program execution.

2.3 AWARENESS SIGNAL – A device that warns a person of an approaching or present hazard by an audible or visible means. A visible means could include a text message or display on a pendant or user interface screen.

2.4 CATEGORY – Classification of the Safety-Related Parts of a Control System (SRP/CS) in respect of their resistance to faults and their subsequent behavior in the fault condition, and which is achieved by the structural arrangement of the parts, fault detection and/or by their reliability.

2.5 CLASS 2– A circuit, transformer, or power source having energy- and voltage-limiting characteristics as described in Standard for Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers, UL 5085-3.

2.6 COLLABORATIVE OPERATION – State in which a purposely designed robot system and an operator work within a collaborative workspace.

2.7 COLLABORATIVE WORKSPACE – Space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation.

2.8 DRIVE POWER – The source or means of supplying energy to the robot actuators to produce motion.

2.9 ELECTRICAL/ ELECTRONIC/ PROGRAAMMABLE ELECTRONIC E/E/PE – Based on Electrical (E) and/or Electronic (E) and/or Programmable Electronic (PE) technology.

NOTE – The term is intended to cover any and all devices or systems operating on electrical principles.

EXAMPLE: Electrical/electronic/programmable electronic devices include:

– Electro-mechanical devices (electrical);

– Solid-state non-programmable electronic devices (electronic);

– Electronic devices based on computer technology (programmable electronic).

2.10 EMERGENCY STOP (FUNCTION) – Function which is intended to:

a) Avert arising or reduce existing hazards to persons, damage to machinery or to work in progress; and

b) Be initiated by a single human action.

2.11 ENABLING DEVICE – A manually operated device which, when continuously activated, permits motion.

2.12 END-EFFECTOR – An accessory device or tool specifically designed for attachment to the robot wrist or tool mounting plate to enable the robot to perform its intended task. (Examples may include gripper, spot weld gun, arc weld gun, spray paint gun, or any other application tools.)

2.13 FIELD-WIRING TERMINAL – A wiring terminal on permanently connected equipment to which connections are made when the equipment is installed in the field.

2.14 FUNCTIONAL SAFETY (FS) – Part of the overall safety relating to the Equipment Under Control (EUC) and the EUC control system that depends on the correct functioning of the E/E/PE safety-related systems and other risk reduction measures.

2.15 INTERLOCK – An arrangement which allows the operation of one control or mechanism, or prevents the operation of another.

2.16 ISOLATED LIMITED-ENERGY SECONDARY CIRCUIT – A circuit derived from an isolated secondary winding of a transformer having a maximum capacity of 100 Volt-Amperes and an open-circuit secondary-voltage rating not exceeding 1000 V.

2.17 ISOLATED LOW-VOLTAGE LIMITED-ENERGY – A circuit involving a potential of not more than 42.4 V (60 V dc) peak supplied by one of the following:

a) An energy-limiting Class 2 transformer;

b) A nonenergy-limiting Class 2 transformer and an overcurrent protective device. The protective device is:

1) Not to be of the automatic reclosing type;

2) To be trip-free from the reclosing mechanism; and

3) Not to be readily interchangeable with a device of a different rating.

c) A combination of an isolated transformer secondary winding and a fixed impedance that complies with all the performance requirements for an energy-limiting Class 2 transformer or a non-isolated low-voltage limited-energy power source;

d) A dry-cell battery having output characteristics not greater than those of an energy-limiting Class 2 transformer or a non-isolated low-voltage limited-energy power source; or

e) A combination of a rechargeable battery and a fixed impedance that complies with all of the performance requirements for an energy-limiting Class 2 transformer or a non-isolated low-voltage limited-energy power source.

2.18 MANUAL MODE – Control state that allows for the direct control by an operator.

2.19 NON-ISOLATED LOW-VOLTAGE LIMITED-ENERGY POWER SOURCE – A circuit derived from a source of supply classified as line voltage by connecting impedance in series with the supply circuit as a means of limiting the voltage and power to comply with Class 2 characteristics.

2.20 OPEN TYPE (PRODUCT) – (Product) Intended for incorporation within enclosure or assembly which will provide access protection.

2.21 OPERATOR – The person designated to start, monitor and stop the intended productive operation of a robot or robot system. An operator may also interface with a robot for productive purposes.

2.22 OPPOSITE POLARITY – A difference of potential between two points, where shorting of these two points would result in a condition involving overload, rupturing of printed-wiring board foil pattern, components, or fuses, and the like.

2.23 PAYLOAD – The rated mass of the end-effector and material, that can be handled by a robot in a normal and continuous operation. Other mechanical characteristics may also affect payload rating, such as center of mass, etc.

2.24 PENDANT – Hand held unit linked to the control system with which a robot can be programmed or moved.

2.25 PERFORMANCE LEVEL (PL) – Discrete level used to specify the ability of safety-related parts of control systems to perform a safety function under foreseeable conditions.

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

2.27 POLLUTION DEGREE – The level of pollution present at the location on or in a product where the clearance and creepage distance measurement is made, and can be controlled by design of the product. For example, enclosures can be used to achieve Pollution Degree 3, heaters within enclosures can help achieve Pollution Degree 2, and encapsulation can be used to achieve Pollution Degree 1.

2.28 PRIMARY CIRCUIT – The wiring and components that are conductively connected to the supply circuit.

2.29 PROGRAM –

a) A sequence of instructions to be executed by the computer or robot controller to control a robot/robot system;

b) To furnish (a computer) with a code of instructions;

c) To teach a robot system a specific set of movements and instructions to accomplish a task.

2.30 PROTECTIVE DEVICE– A device designed, constructed and installed to create a sensing field or area to detect an intrusion into that field or area by personnel, robot(s), or other objects.

2.31 PROTECTIVE STOP – Type of interruption of operation that allows a cessation of motion and related hazards for safeguarding purposes and which retains the program logic to facilitate a restart.

2.32 QUALIFIED PERSON – One familiar with the construction and operation of the equipment and the hazard(s) involved.

2.33 REDUNDANCY – The application of more than one device or system, or part of a device or a system, such that if one fails to perform its function, another is available to perform that function.

2.34 RISK OF ELECTRIC SHOCK – Under normal conditions a risk of electric shock exists between any two conductive parts or between a conductive part and earth ground if the continuous current flow between the two points exceeds the leakage current limits determined by the Leakage Current Test, Section 47, and if the open circuit voltage exceeds the limits in Table 2.1. Under fault or abnormal conditions: a risk of electric shock is considered to exist at any part at the potentials in Table 2.1 and when the continuous current flow through a 500 ohm resistor connected across the potential exceeds 5.0 mA.

Table 2.1
Risk of electric shock threshold

Waveform type [a]	Maximum voltage	
	Dry and damp locations	Wet locations
Sinusoidal ac	30 V rms	15 V rms
Non-sinusoidal ac	42.4 V peak	21.2 V peak
dc [b, c]	60 V	30 V

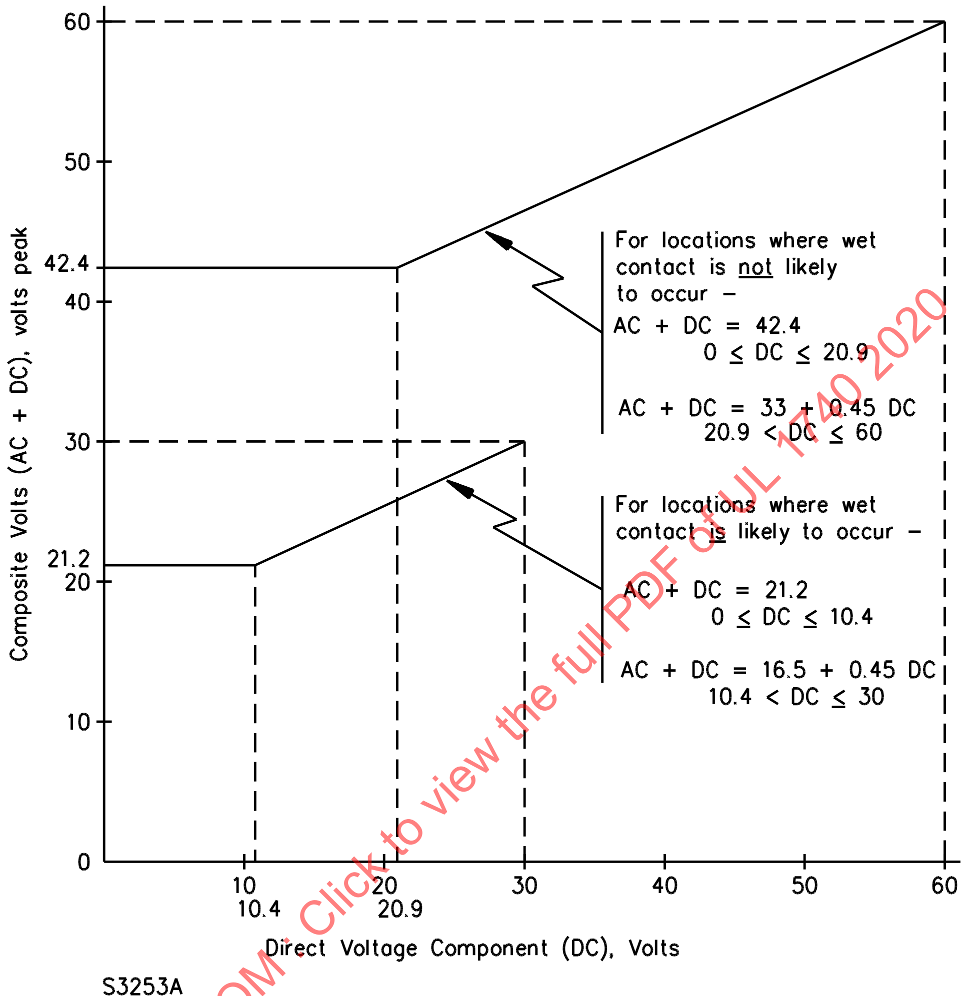
[a] The voltage limits for a composite AC + DC waveform (V peak) shall be per Figure 2.1 based on the Direct Voltage component (V DC) of the waveform. The graph line for locations where wet contact is not likely to occur refers to Dry and Damp locations. The graph line for locations where wet contact is likely to occur refers to wet locations.

[b] If the peak-to-peak ripple voltage on a dc waveform exceeds 10 percent of the dc voltage, the waveform shall be considered a composite waveform per footnote a above.

[c] DC waveforms interrupted at frequencies between 10 – 200 Hz shall be limited to 24.8 V in dry and damp locations, and 12.4 V in wet locations.

Figure 2.1

Voltage limits



2.35 RISK OF FIRE – A risk of fire is considered to exist at any two points in a circuit where the open circuit voltage is more than 42.4 V peak and the energy available to the circuit under any condition of load including short circuit, results in a current of 8 A or more after 1 minute of operation.

2.36 ROBOT – Actuated mechanism programmable in two or more axes with a degree of autonomy, moving within its environment, to perform intended tasks.

1 A robot includes the control system and interface of the control system.

2 The classification of robot into industrial robot or service robot is done according to its intended application.

2.37 ROBOTIC SYSTEM – A system that includes the robot (hardware and software) consisting of the robot, the end-effector(s), any equipment, devices, or sensors required for the robot to perform its tasks; and any communication interface that is operating and monitoring the robot, equipment, or sensors, as far as these peripheral devices are supervised by the robot control system.

2.38 SAFEGUARD – Guard or protective device.

2.39 SAFETY CIRCUIT – A primary or secondary circuit containing a control that is relied upon to reduce a risk of fire, electric shock, or injury to persons at the controlled equipment.

2.40 SAFETY CONTROL – An automatic control and interlock (including relays, switches, and other auxiliary equipment used to form a system) that is intended to reduce the risk of fire, electric shock, or injury to persons.

2.41 SAFETY INTEGRITY LEVEL (SIL) – Discrete level (one out of a possible four), corresponding to a range of safety integrity values, where SIL 4 has the highest level of safety integrity and SIL 1 has the lowest.

2.42 SAFETY-RELATED PART OF A CONTROL SYSTEM (SRP/CS) – Part of a control system that responds to safety-related input signals and generates safety-related output signals.

NOTE 1: The combined safety-related parts of a control system start at the point where the safety-related input signals are initiated (including, for example, the actuating cam and the roller of the position switch) and end at the output of the power control elements (including, for example, the main contacts of a contactor).

NOTE 2: If monitoring systems are used for diagnostics, they are also considered as SRP/CS.

2.43 SECONDARY CIRCUIT – A circuit supplied from a secondary winding of an isolating transformer.

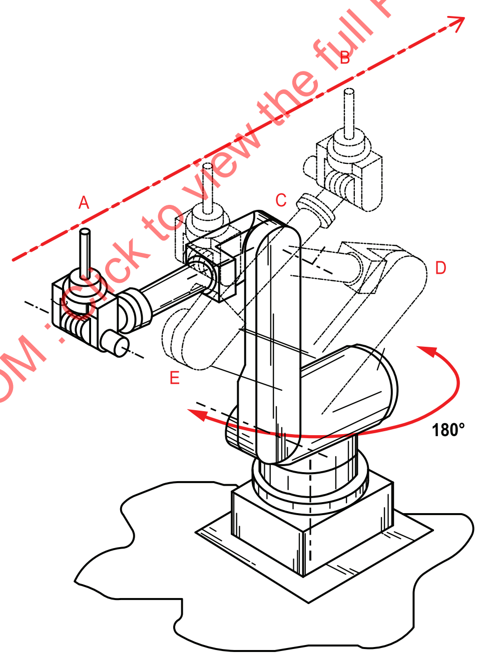
2.44 SENSOR – A device that responds to physical stimuli (such as heat, light, sound, pressure, magnetism, motion) and transmits the resulting signal or data providing a measurement, operating a control, or both.

2.45 SINGLE POINT OF CONTROL – The ability to operate the robot such that initiation of robot motion from one source of control is only possible from that source and cannot be overridden from another source.

2.46 SINGULARITY – Condition where the motion of a set of robot joints produces no net Cartesian motion (translational or rotational) of either the robot flange or the Tool Center Point (TCP). Cartesian motions that pass near this condition can produce unexpected high joint speeds, which can be hazardous. A singularity can also be defined as an occurrence whenever the rank of the Jacobian matrix becomes less than full rank – Mathematically, in a singular configuration, the joint velocity in joint space can become infinite to maintain Cartesian velocity. In actual operation, motions defined in Cartesian space that pass near singularities can produce high joint speeds. These high speeds can be unexpected to an operator. Figure 2.2 below demonstrates the robot behavior as the wrist passes near the 'shoulder' singularity, as the robot moves the tool linearly from point A (with the elbow at point C) to point B (with the elbow at point E), Joint 1 rotates rapidly from a configuration where the elbow is at point D, finally ending at configuration with the elbow at point E.

Figure 2.2

Singularity diagram



This modified figure above is being used with Permission from FANUC America Corporation.

2.47 SPACE – Three dimensional volume.

2.48 SPACE, MAXIMUM – Space which can be swept by the moving parts of the robot as defined by the manufacturer plus the space which can be swept by the end-effector and the workpiece.

2.49 SPACE, OPERATING – Portion of the restricted space that is actually used while performing all motions commanded by the task program.

2.50 SPACE, RESTRICTED – Portion of the maximum space restricted by limiting devices that establish limits which will not be exceeded.

2.51 SPACE, SAFEGUARDED – Space defined by the perimeter safeguarding.

2.52 STATIONARY EQUIPMENT – Hard wired or cord- and plug-connected equipment that is intended to be fastened in place, or located in a dedicated space.

2.53 TEACHER – A person who provides the robot with a specific set of instructions to perform a task.

2.54 TOOL CENTER POINT (TCP) – The origin of the tool coordinate system.

2.55 USER SERVICING – Any form of servicing that can be performed by personnel other than those who are trained to maintain the particular equipment is considered user servicing. Some examples of user servicing are:

a) The attachment of accessories by means of attachment plugs and receptacles or by means of other separable connectors;

b) The changing of magnetic, electronic (USB sticks, flash memory, etc.) or optical media and the like that do not involve complicated operations;

c) The replacement of disks, or programmable logic boards. Replacement of lamps and fuses and resetting of circuit breakers located in an operator-access area unless the lamps, fuses, or circuit breakers are marked to indicate replacement or resetting only by qualified service personnel;

d) The marking of routine operating adjustments necessary to adapt the unit for its different intended functions;

d) Routine cleaning of data-handling media.

2.56 WET LOCATION – Portions of an indoor installation where occasional or continuous exposure to water (for example: mist, spray, cutting jet) or other liquids is anticipated.

3 Components

3.1 Except as indicated in 3.2, a component of a product covered by this standard shall comply with the requirements for that component. See Appendix A for a list of standards covering components generally used in the products covered by this standard.

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

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

b) Is superseded by a requirement in this standard.

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

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

4 Units of Measurement

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

4.2 Unless indicated otherwise, all voltage and current values are nominal rms values.

5 Undated References

5.1 Any undated reference to a code or standard appearing in the requirements of this standard shall be interpreted as referring to the latest edition of that code or standard.

CONSTRUCTION

6 General

6.1 Robotic equipment shall employ materials that are acceptable for the application and shall be made and finished with the degree of uniformity and grade of workmanship practicable in a well-equipped factory.

7 Frame and Enclosure

7.1 General

7.1.1 Robotic equipment shall be constructed and assembled so that it will have the strength and rigidity necessary to resist the abuses and the environment to which it is likely or intended to be subjected, without increasing the risk of fire, electric shock, or injury to persons due to total or partial collapse resulting in a reduction of spacings, loosening or displacement of parts, or other serious defects. Examples of intended environment, in addition to normal use, may include water spray, water cutting, hosedown (cleaning), oil, noncorrosive liquids, corrosive liquids and gases, dust, and the like. See Robots Intended for Use in Water Environments, Section 48, Enclosure Test, Section 76, and Gasket Tests, Section 78 for selected tests.

7.2 Cast metal

7.2.1 A cast-metal enclosure shall be at least 3.2 mm (1/8 in) thick at every point, more than 3.2 mm (1/8 in) thick at reinforcing ribs and door edges, and at least 6.4 mm (1/4 in) thick at tapped holes for conduit.

Exception: Other than at plain or threaded conduit holes, malleable iron and die-cast or permanent mold cast aluminum, brass, bronze, or zinc shall be:

a) At least 2.4 mm (3/32 in) thick for an area greater than 155 cm² (24 in²) or having any dimension more than 152 mm (6 in); and

b) At least 1.6 mm (1/16 in) thick for an area of 155 cm² (24 in²) or less having no dimension more than 152 mm (6 in). The area considered may be bounded by reinforcing ribs subdividing a larger area.

7.3 Sheet metal

7.3.1 The thickness of a sheet-metal enclosure shall not be less than that specified in Table 7.1 and Table 7.2, except that at points to which a wiring system is to be connected, uncoated steel shall be at least 0.81 mm (0.032 in) thick, zinc-coated steel at least 0.86 mm (0.034 in) thick, and nonferrous metal at least 1.14 mm (0.045 in) thick.

Exception: Enclosure thickness at points other than where a wiring system is to be connected need not comply with these requirements if the enclosure complies with the requirements in the Compression Test and Deflection Test in the Standard for Enclosures for Electrical Equipment, Non-Environmental Considerations, UL 50.

Table 7.1
Thickness of sheet metal for enclosures – carbon steel or stainless steel

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness			
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length		Uncoated		Metal coated	
cm	(in)	cm	(in)	cm	(in)	cm	(in)	mm	(in)	mm	(in)
10.2	(4.0)	Not limited		15.9	(6.25)	Not limited		0.51	(0.020)[d]	0.58	(0.023)[d]
12.1	(4.75)	14.6	(5.75)	17.1	(6.75)	21.0	(8.25)				
15.2	(6.0)	Not limited		24.1	(9.5)	Not limited		0.66	(0.026)[d]	0.74	(0.029)[d]
17.8	(7.0)	22.2	(8.75)	25.4	(10.0)	31.8	(12.5)				
20.3	(8.0)	Not limited		30.5	(12.0)	Not limited		0.81	(0.032)	0.86	(0.034)
22.9	(9.0)	29.2	(11.5)	33.0	(13.0)	40.6	(16.0)				
31.8	(12.5)	Not limited		49.5	(19.5)	Not limited		1.07	(0.042)	1.14	(0.045)
35.6	(14.0)	45.7	(18.0)	53.3	(21.0)	63.5	(25.0)				
45.7	(18.0)	Not limited		68.6	(27.0)	Not limited		1.35	(0.053)	1.42	(0.056)
50.8	(20.0)	63.5	(25.0)	73.7	(29.0)	91.4	(36.0)				
55.9	(22.0)	Not limited		83.8	(33.0)	Not limited		1.52	(0.060)	1.60	(0.063)
63.5	(25.0)	78.7	(31.0)	88.9	(35.0)	109.2	(43.0)				
63.5	(25.0)	Not limited		99.1	(39.0)	Not limited		1.70	(0.067)	1.78	(0.070)
73.7	(29.0)	91.4	(36.0)	104.1	(41.0)	129.5	(51.0)				
83.8	(33.0)	Not limited		129.5	(51.0)	Not limited		2.03	(0.080)	2.13	(0.084)
96.5	(38.0)	119.4	(47.0)	137.2	(54.0)	167.6	(66.0)				
106.7	(42.0)	Not limited		162.6	(64.0)	Not limited		2.36	(0.093)	2.46	(0.097)
119.4	(47.0)	149.9	(59.0)	172.7	(68.0)	213.4	(84.0)				
132.1	(52.0)	Not limited		203.2	(80.0)	Not limited		2.74	(0.108)	2.82	(0.111)
152.4	(60.0)	188.0	(74.0)	213.4	(84.0)	261.6	(103.0)				
160.0	(63.0)	Not limited		246.4	(97.0)	Not limited		3.12	(0.123)	3.20	(0.126)

Table 7.1 Continued on Next Page

Table 7.1 Continued

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness			
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length		Uncoated		Metal coated	
cm	(in)	cm	(in)	cm	(in)	cm	(in)	mm	(in)	mm	(in)
185.4	(73.0)	228.6	(90.0)	261.6	(103.0)	322.6	(127.0)				

[a] See 7.3.3.

[b] The width is the smaller dimension of a rectangular piece of sheet metal that is part of an enclosure. Adjacent surfaces of an enclosure may have common supports and be made of a single sheet.

[c] Not limited applies only if the edge of the surface is flanged at least 12.7 mm (1/2 in) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet steel for an enclosure intended for outdoor use – raintight or rainproof – shall not be less than 0.86 mm (0.034 in) thick if zinc coated and not less than 0.81 mm (0.032 in) thick if uncoated.

Table 7.2
Thickness of sheet metal for enclosures – aluminum, copper, or brass

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]				Minimum thickness	
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length			
cm	(in)	cm	(in)	cm	(in)	cm	(in)	mm	(in)
7.6	(3.0)	Not limited		17.6	(7.0)	Not limited			
8.9	(3.5)	10.2	(4.0)	21.6	(8.5)	24.1	(9.5)	0.58	(0.023)[d]
10.2	(4.0)	Not limited		25.4	(10.0)	Not limited			
12.7	(5.0)	15.2	(6.0)	26.7	(10.5)	34.3	(13.5)	0.74	(0.029)
15.2	(6.0)	Not limited		35.6	(14.0)	Not limited			
16.5	(6.5)	20.3	(8.0)	38.1	(15.0)	45.7	(18.0)	0.91	(0.036)
20.3	(8.0)	Not limited		48.3	(19.0)	Not limited			
24.1	(9.5)	29.2	(11.5)	53.3	(21.0)	63.5	(25.0)	1.14	(0.045)
30.5	(12.0)	Not limited		71.1	(28.0)	Not limited			
35.6	(14.0)	40.6	(16.0)	76.2	(30.0)	94.0	(37.0)	1.47	(0.058)
45.7	(18.0)	Not limited		106.7	(42.0)	Not limited			
50.8	(20.0)	63.4	(25.0)	114.3	(45.0)	139.7	(55.0)	1.91	(0.075)
63.5	(25.0)	Not limited		152.4	(60.0)	Not limited			
73.7	(29.0)	91.4	(36.0)	162.6	(64.0)	198.1	(78.0)	2.41	(0.095)
94.0	(37.0)	Not limited		221.0	(87.0)	Not limited			
106.7	(42.0)	134.6	(53.0)	236.2	(93.0)	289.6	(114.0)	3.10	(0.122)
132.1	(52.0)	Not limited		312.4	(123.0)	Not limited			
152.4	(60.0)	188.0	(74.0)	330.2	(130.0)	406.4	(160.0)	3.89	(0.153)

[a] See 7.3.3.

[b] The width is the smaller dimension of a rectangular piece of sheet metal that is part of an enclosure. Adjacent surfaces of an enclosure may have common supports and be made of a single sheet.

[c] Not limited applies only if the edge of the surface is flanged at least 12.7 mm (1/2 in) or fastened to adjacent surfaces not normally removed in use.

[d] Sheet copper, brass, or aluminum for an enclosure intended for outdoor use – raintight or rainproof – shall not be less than 0.74 mm (0.029 in) thick.

7.3.2 Table 7.1 and Table 7.2 are based on a uniform deflection of the enclosure surface for any given load concentrated at the center of the surface regardless of metal thickness.

7.3.3 With reference to Table 7.1 and Table 7.2, a supporting frame is a structure of angle or channel or folded rigid section of sheet metal that is rigidly attached to and has essentially the same outside dimensions as the enclosure surface and that has sufficient torsional rigidity to resist the bending moments that may be applied by the enclosure surface when it is deflected. A structure that is as rigid as one built with a frame of angles or channels is considered to have equivalent reinforcing. Constructions considered to be without supporting frame include:

a) A single sheet with single formed flanges – formed edges;

b) A single sheet that is corrugated or ribbed;

c) An enclosure surface loosely attached to a frame – for example, with spring clips; and

d) An enclosure surface having an unsupported edge.

7.3.4 An enclosure shall be constructed to reduce the risk of unintentional contact with enclosed electrical devices, and to provide internal devices with protection from specified external conditions.

7.3.5 An air filter acting as an enclosure part shall comply with the requirements for Class 1 filters as specified in the Standard for Air Filter Units, UL 900. If abnormal tests show that no equivalent flame barrier exists, then an air filter is not considered to be an enclosure part and may be omitted from these requirements.

7.4 Doors and covers

7.4.1 A part of an enclosure, such as a door or a cover, shall be provided with a means – such as latches, locks, interlocks, or screws – for firmly securing it in place.

Exception: A snap-on cover that complies with the requirements in Securement of Snap-On Cover Test, Section 80, need not have additional securing means.

7.4.2 An enclosure cover shall be hinged if it gives access to a fuse or any other overload-protective device that requires renewal, or if it is necessary to open the cover in connection with the normal operation of the device.

Exception: A hinged cover is not required for an enclosure:

a) To which access is required only in the event of burnout of a current element or the like on short circuit;

b) In which the only fuse enclosed is a control-circuit fuse, if the fuse and control-circuit load – other than a fixed control-circuit load, such as a pilot lamp – are within the same enclosure; or

c) In which a means is provided for resetting all overload-protective devices from outside the enclosure, or kits are available to provide a means for resetting all overload-protective devices from outside the enclosure. (See Manufacturer's Documentation, Section 92.)

7.4.3 Other than as noted in 7.4.4, a hinged cover provided in accordance with the requirement in 7.4.2 shall be provided with a snap latch or a captive multi-turn or partial-turn fastener. Such securing means shall be located or used in multiple so as to hold the cover closed over its entire length. A captive fastener shall be operable by hand or by a simple hand tool such as a screwdriver.

7.4.4 A door more than 1.2 m (48 in) long on the hinged side shall be provided with one of the following:

a) A multipoint latch operated by a single knob or handle; or

b) Two or more snap latches or captive fasteners; or

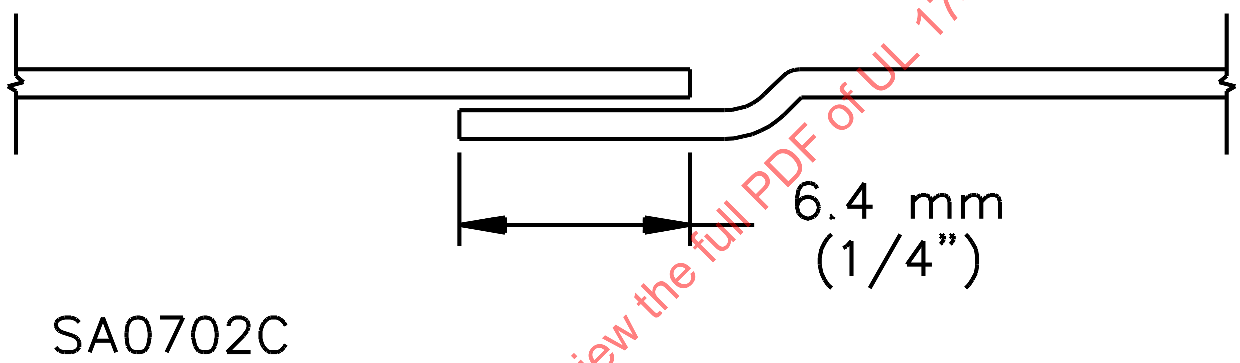
c) One knob-operated latch and one snap latch or captive fastener.

7.4.5 A hinged cover enclosure that is not required to comply with 7.4.2 may use noncaptive fasteners.

7.4.6 A door giving access to a fuse or any portion of a circuit breaker other than the operating handle shall shut closely against a 6.4 mm (1/4 in) rabbet as illustrated in Figure 7.1 or the equivalent.

Figure 7.1

Rabbet

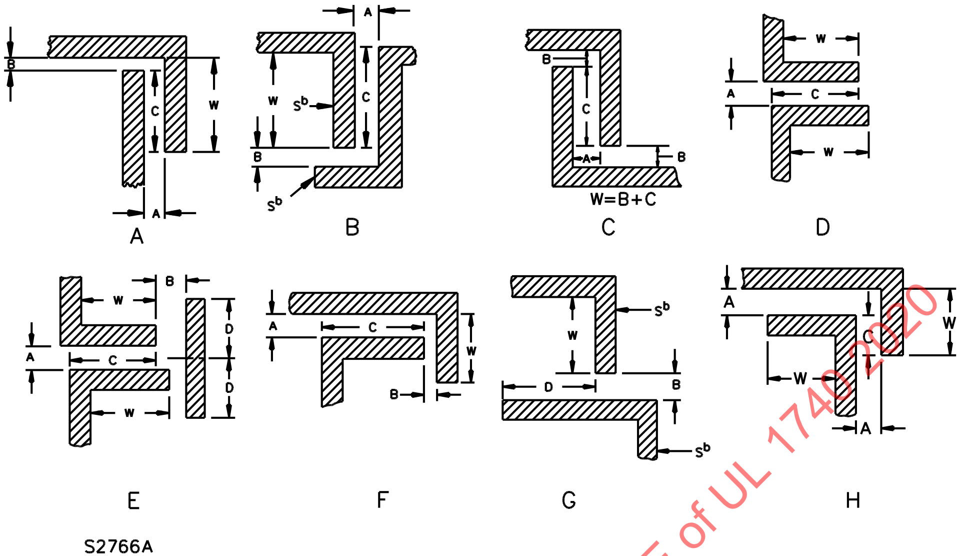


7.4.7 A cover giving access to a fuse or any portion of a circuit breaker other than the operating handle shall have flanges for the full length of the four edges. Flanges on a cover shall fit closely with the outside walls of the enclosure, and shall comply with Figure 7.2 and Table 7.3. An acceptable combination of flange and rabbet may be used.

Exception: The flange width may be less than that specified if the construction complies with the Deflection Test in the Standard for Enclosures for Electrical Equipment, Non-Environmental Considerations, UL 50.

Figure 7.2

Flanged cover constructions[a]



[a] See Table 7.3 for dimensions for sketches A – H.
[b] The surfaces "S" may be in line with one another – not as shown.

Table 7.3
Dimensions for flanged cover constructions

Sketch – see Figure 7.2	Dimensions									
	W Minimum flange width[a]		A Maximum space between parts		B Maximum gap		C Minimum overlap		D Minimum barrier extension	
	mm	(in)	mm	(in)	mm	(in)	mm	(in)	mm	(in)
A	12.7	(1/2)	3.2	(1/8)	3.2	(1/8)	11.1	(7/16)	–	–
A	19.1	(3/4)	4.8	(3/16)	4.8	(3/16)	15.9	(5/8)	–	–
A	25.4	(1)	6.4	(1/4)	6.4	(1/4)	22.2	(7/8)	–	–
B	12.7	(1/2)	3.2	(1/8)	3.2	(1/8)	11.1	(7/16)	–	–
B	19.1	(3/4)	4.8	(3/16)	4.8	(3/16)	15.9	(5/8)	–	–
B	25.4	(1)	6.4	(1/4)	6.4	(1/4)	22.2	(7/8)	–	–
C	12.7	(1/2)	4.8	(3/16)	4.8	(3/16)	6.4	(1/4)	–	–
C	19.1	(3/4)	6.4	(1/4)	6.4	(1/4)	11.1	(7/16)	–	–
D	12.7	(1/2)	2.4	(3/32)	–	–	11.1	(7/16)	–	–
E	12.7	(1/2)	3.2	(1/8)	3.2	(1/8)	11.1	(7/16)	6.4	(1/4)
F	12.7	(1/2)	3.2	(1/8)	6.4	(1/4)	11.1	(7/16)	–	–
G[b]	12.7	(1/2)	–	–	0.8	(1/32)	–	–	(12.7)	(1/2)
H	6.4	(1/4)	3.2	(1/8)	–	–	4.8	(3/16)	–	–

[a] Tolerance: minus 1.6 mm (1/16 in).

[b] Equipment within the enclosure must be located on the side of the barrier extension D that is opposite the gap B.

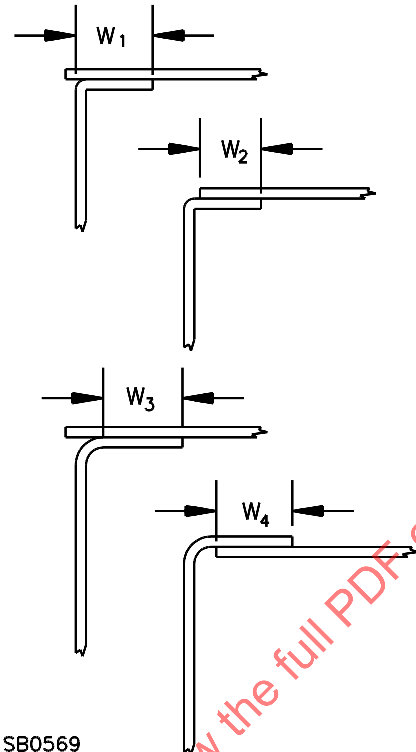
7.4.8 To determine whether a flanged cover complies with the requirement in 7.4.7 regarding width of flange, the distance between the flat portion of the cover – clear of forming radii, beads, draws, and the like – and a straight edge placed anywhere across any two flanges at any points is to be measured.

7.4.9 A gasket that is required for an electrical enclosure to maintain a tight fit or to comply with the enclosure performance requirements shall be secured with adhesive or by mechanical means. The gasket and its securing means shall not be damaged when the joint is opened. A construction involving a gasketed joint that provides the intended tight fit shall be investigated to determine whether it is acceptable for the application.

7.4.10 Figure 7.3 illustrates the method of determining the amount of overlap between a flat cover and a flanged box wall and the amount of overlap at a corner or box seam. If the radius of the flange bend is small, the flange width and overlap are considered to be W1 or W2, depending upon the actual construction, and shall be at least 12.7 mm (1/2 in). If the radius of the flange bend is excessive or if the flat sheet is on the inside of the flange, the overlap, W3 or W4, is to be measured over only that portion where the two pieces of metal are actually in contact with each other, and shall be at least 12.7 mm (1/2 in).

Figure 7.3

Overlap between flat cover and box flange and at corner or box seam



7.4.11 To determine the overlap of a telescoping cover, the enclosure is to be placed on its back on a bench, with the cover in its normally closed position, and a mark is to be scribed on all walls of the box along the edge of the flange. The overlap is the measured distance between the scribe marks and the edges of the box walls, noted as W4 in Figure 7.3. In scribing the marks, the cover is to be held in a fixed position with sufficient firmness to prevent displacement of the cover by the scribing tool, but without bending or distorting any portion of the box, cover, or other part of the enclosure.

7.4.12 A flat strip used to provide a rabbet, or an angle strip fastened to the edges of a door giving access to a fuse or any portion of a circuit breaker, other than the operating handle, shall be at least 60 percent of the required thickness of the metal box, but not less than 1.07 mm (0.042 in) if of uncoated steel, not less than 1.14 mm (0.045 in) if of zinc-coated steel, and not less than 1.47 mm (0.058 in) thick if of nonferrous metal. It shall be secured at no fewer than two points. There shall not be more than 38 mm (1-1/2 in) between an end of the strip and a point at which it is secured, and the distance between adjacent points at which the strip is secured shall not be more than 152 mm (6 in).

7.4.13 The continuity of a bonding means for a snap-on or fastener-attached cover shall comply with the requirements in Bonding of Internal Parts, Section 21.

7.5 Nonmetallic – General

7.5.1 The requirements in 7.5.2 – 7.5.5 cover polymeric enclosures.

7.5.2 A nonmetallic enclosure or enclosure part shall have mechanical strength and durability and be formed so that operating parts will be protected against damage and shall resist the abuses likely to be encountered during installation and normal use and service.

7.5.3 An enclosure or enclosure part shall protect persons against a risk of electric shock, and the material shall not create or contribute to a risk of fire, electric shock, or injury to persons.

7.5.4 Among the factors that are to be taken into consideration when judging the acceptability of a nonmetallic enclosure are:

a) Mechanical strength;

b) Resistance to impact;

c) Moisture absorption;

d) Resistance to combustion and to ignition from electrical sources;

e) Dielectric properties, insulation resistance, and resistance to arc tracking; and

f) Resistance to distortion and creeping at temperatures to which the material may be subjected under conditions of normal or abnormal use.

A material shall not display a loss of these properties beyond the minimum acceptable level as a result of aging. Tests on nonmetallic enclosures for portable equipment, stationary equipment and equipment intended to be permanently connected electrically shall be conducted in accordance with requirements in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

7.5.5 A polymeric enclosure intended for connection to a rigid metal conduit system shall comply with the Polymeric Enclosure Rigid Metallic Conduit Connection Test in the Standard for Enclosures for Electrical Equipment, Non-Environmental Considerations, UL 50.

7.6 Bonding

7.6.1 Nonmetallic robotic equipment shall be marked in accordance with 91.10 if a bonding means is not provided.

7.7 Parts of enclosures

7.7.1 A part, such as a dial or nameplate, that is a part of an enclosure shall be metal or other material as specified for the enclosure in 7.7.2 and 7.7.3.

7.7.2 A nonmetallic part, such as a reset knob, lever, or button not larger than an area of 6.45 cm^2 (1 in^2), that protrudes through a hole in the enclosure, shall be made of material rated V-2 or better in accordance with the requirements in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

7.7.3 A nonmetallic part that protrudes through an enclosure hole having an area larger than 6.45 cm^2 (1 in^2) shall be made of a material that complies with the requirements in 7.5.2 – 7.5.4, and material requirements of 7.7.2.

7.8 Windows

7.8.1 Glass covering an observation opening or the like shall be secured in place so that it cannot be readily displaced in service, and shall provide mechanical protection for the enclosed parts.

7.8.2 Glass for an opening not more than 101.6 mm (4 in) in any dimension shall not be less than 1.6 mm (1/16 in) thick, and glass for a larger opening, but not more than 929 cm^2 (144 in^2) in area and having no dimension greater than 304.8 mm (12 in), shall not be less than 3.2 mm (1/8 in) thick. Glass used to cover a larger area shall not be less than 3.2 mm (1/8 in) thick and shall conform to one of the following:

a) The glass shall be of a non-shattering or tempered type that, when broken, shall conform to the performance specifications in the Performance Specifications and Methods of Test for Safety Glazing Material Used in Buildings, ANSI Z97.1; or

b) The glass shall withstand the 3.39 J (2.5 lbf·ft) impact specified in Glass Window Impact Test, Section 79.

7.9 Openings in enclosures – Ventilating openings

7.9.1 A ventilating opening may be provided in an enclosure if the equipment requiring ventilation complies with 7.9.2 – 7.9.8 and is:

a) Housed in a separate ventilated portion of the enclosure or compartment; or

b) Housed in a separate ventilated enclosure or compartment.

7.9.2 A ventilating opening shall not be provided in a compartment or part of an enclosure that contains field-wiring splices in a line-voltage circuit.

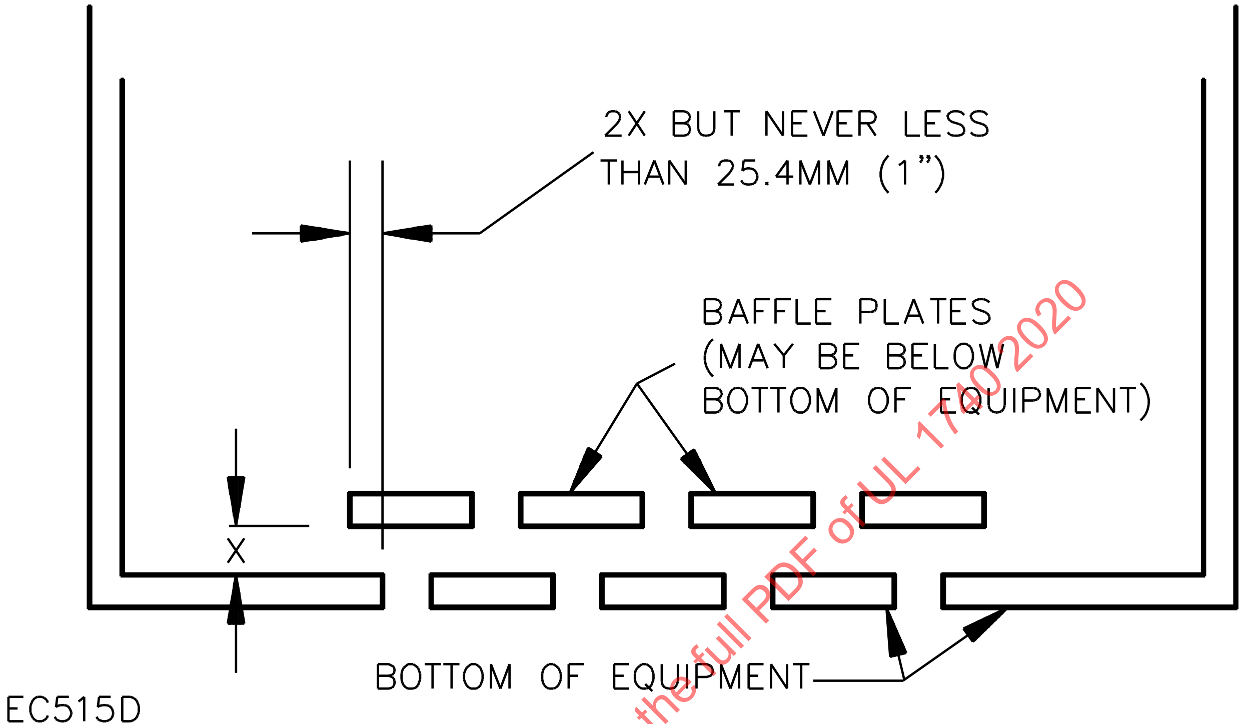
7.9.3 A ventilating opening shall not be located in a mounting surface of an enclosure.

7.9.4 The shortest distance between a ventilating opening and the bottom of an enclosure or a wall-mounting surface shall be at least one-quarter of the enclosure height or depth, respectively, or 25.4 mm (1 in) whichever is less.

7.9.5 A ventilating opening may be provided in the bottom surface of an enclosure if the opening does not permit materials to fall directly out from the interior of the unit. Figure 7.4 illustrates a construction that meets this requirement.

Figure 7.4

Bottom surface ventilating openings



7.9.6 There shall be no emission of flame or molten material through a ventilating opening, or other risk of fire, during normal tests or during abnormal tests, such as transformer burnout and burnout of a relay with blocked armature.

7.9.7 Unless the construction of robotic equipment provided with forced ventilation is such that there is no direct path between live parts and the outlet opening, Abnormal Tests in addition to those mentioned in 7.9.6 shall be conducted to determine that there is no emission of flame or molten material through that opening.

7.9.8 Air from a ventilating opening, either forced or otherwise shall not be directed:

a) Into a duct or into a concealed space in a building;

b) Against the mounting surface; and

c) So that a disturbance would be propagated to other equipment.

8 Mounting

8.1 Robotic equipment that is intended to be fastened in place shall have provision for mounting it securely in position. Bolts, screws, or other parts used for mounting the equipment shall be independent of those used to secure components of the equipment to the frame, base, or panel.

8.2 If the equipment is mounted in a manner that permits removal without the use of tools, a cord connected means for electrical termination may be employed. A means for hanging or storage may be provided.

8.3 Actuating and emergency stop controls subject to rotational movement, where loosening mounting means can result in a hazard or loss of safety function, shall be mechanically secured by a means other than friction fit, such as through the use of a "D" shape, keyway, or the like.

9 Clearance

9.1 Where the conditions of maintenance and supervision assure that only qualified persons will service the installation, the dimensions of the working space in the direction of access to live parts operating at not over 150 volts – or areas of high temperature, high pressure, or moving parts which could result in the risk of injury to persons – that are likely to require examination, adjustment, servicing, or maintenance while energized shall be a minimum of 915 mm (3.0 ft). Where controls are enclosed in cabinets, the door(s) shall open at least 90 degrees or be removable.

10 Operating Mechanism

10.1 The robotic equipment shall be investigated under conditions of actual service to determine if it complies with all applicable requirements and is otherwise acceptable for its application.

10.2 The position of an operating handle shall be marked, if necessary, as a guide for proper operation.

10.3 A control that has or is intended to have a marked off position or an implied off position shall:

a) Open all ungrounded conductors of the circuit with an air gap when the actuator is in the off position; and

b) Be prevented from functioning automatically when in the off position either by a positive mechanical means or the equivalent.

10.4 When used for isolation or as a disconnect, with reference to the requirements in 10.3, the off state of a solid-state switch is not considered to be an open circuit.

10.5 A component – such as a resistor, capacitor, diode, and the like – shall not be connected across the contacts of a safety control or a protective or limiting device.

Exception: A component may be connected across the contacts of a safety control if investigated and found to be acceptable in the end product.

11 Accessibility of Uninsulated Live Parts, Film-Coated Wire, and Moving Parts

11.1 To reduce the likelihood of unintentional contact that may involve a risk of electric shock from an uninsulated live part or film-coated wire or injury to persons from a moving part, an opening in an enclosure shall comply with either (a) or (b).

a) For an opening that has a minor dimension (see 11.5) less than 25.4 mm (1 in), such a part or wire shall not be contacted by the probe illustrated in Figure 11.1.

b) For an opening that has a minor dimension of 25.4 mm (1 in) or more, such a part or wire shall be spaced from the opening as specified in Table 11.1.

Exception No. 1: A motor need not comply with these requirements if it complies with the requirements in 11.2.

Exception No. 2: Robotic equipment that has certain openings, such as openings for mechanical part movement in the enclosure need not comply with these requirements.

Figure 11.1

Articulated probe with web stop

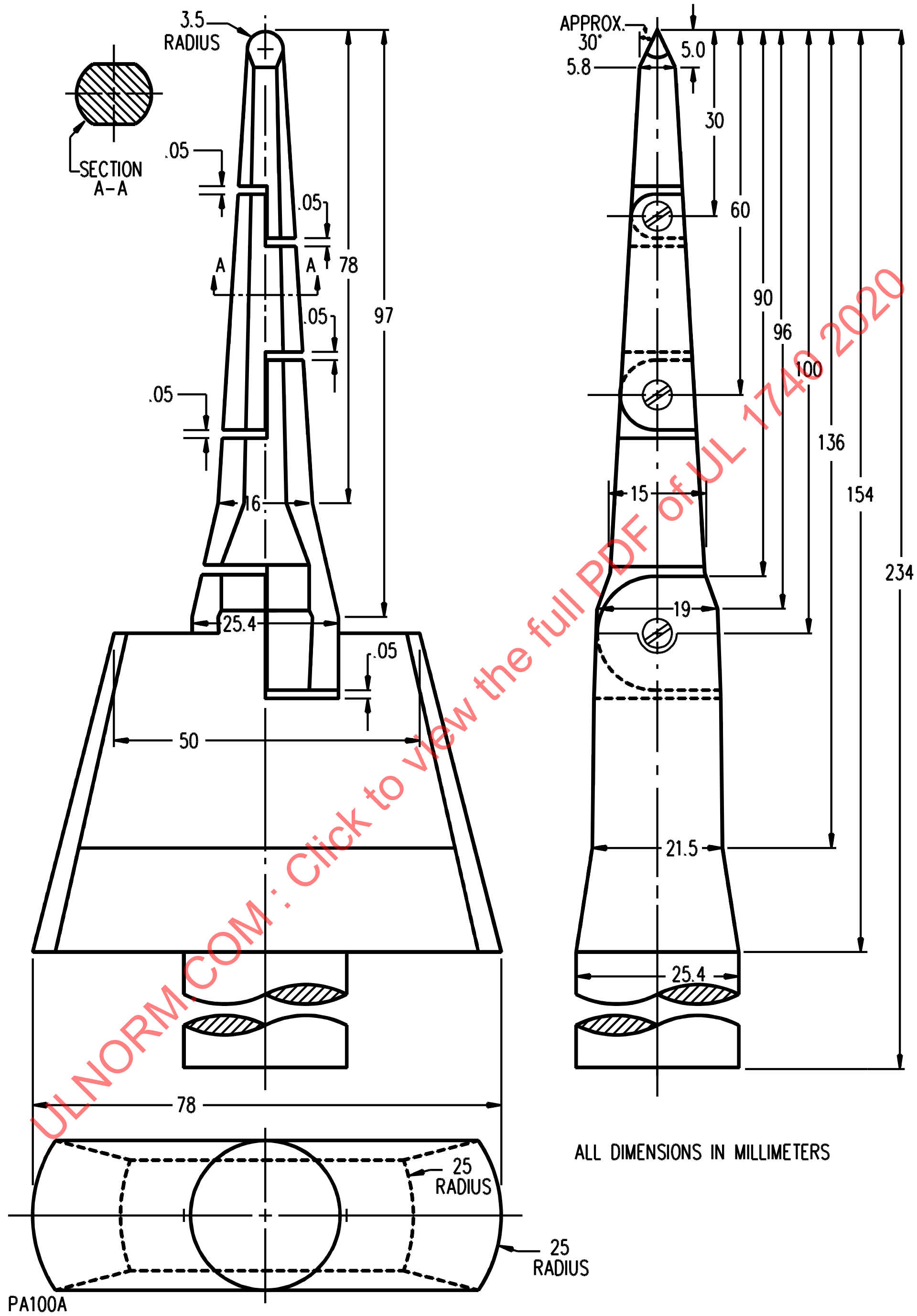


Table 11.1
Minimum acceptable distance from an opening to a part that may involve a risk of electric shock or injury to persons

Minor dimension[a] of opening		Minimum distance from opening to part,	
mm[b]	(in)[b]	mm[b]	(in)[b]
19.1	(3/4)[c]	114.0	(4-1/2)
25.4	(1)	165.0	(6-1/2)
31.8	(1-1/4)	190.0	(7-1/2)
38.1	(1-1/2)	318.0	(12-1/2)
47.6	(1-7/8)	394.0	(15-1/2)
54.0	(2-1/8)	444.0	(17-1/2)
	(d)	762.0	(30)

[a] See 11.5.

[b] Between 19.1 mm (3/4 in) and 54 mm (2-1/8 in), interpolation is to be used to determine a value between values specified in the table.

[c] Any dimension less than 25.4 mm (1 in) applies to a motor only.

[d] More than 54 mm (2-1/8 in), but not more than 152.0 mm (6 in).

11.2 With reference to a part or wire in an integral enclosure of a motor as mentioned in Exception No. 1 to 11.1:

a) An opening that has a minor dimension (see 11.5) less than 19.1 mm (3/4 in) is acceptable if:

1) A moving part cannot be contacted by the probe illustrated in Figure 11.2;

2) Film-coated wire cannot be contacted by the probe illustrated in Figure 11.3;

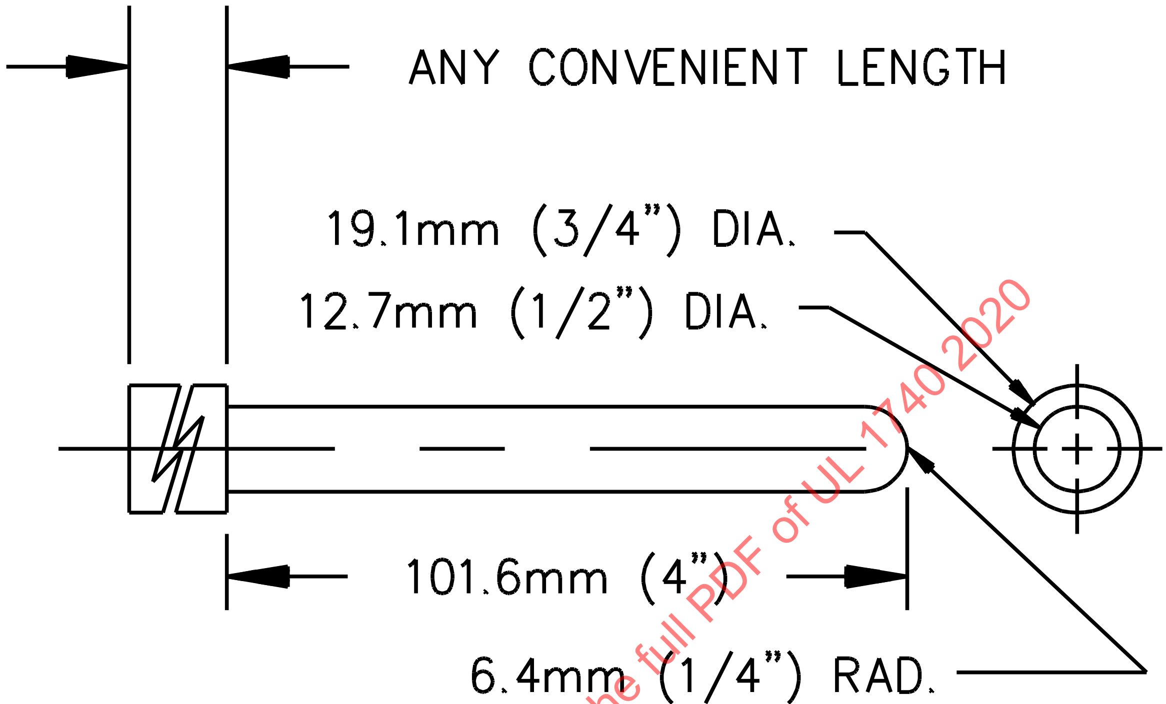
3) In a directly accessible motor (see 11.6), an uninsulated live part cannot be contacted by the probe illustrated in Figure 11.4; and

4) In an indirectly accessible motor (see 11.6), an uninsulated live part cannot be contacted by the probe illustrated in Figure 11.2.

b) An opening that has a minor dimension of 19.1 mm (3/4 in) or more is acceptable if a part or wire is spaced from the opening as specified in Table 11.1.

Figure 11.2

Probe for moving parts and uninsulated live parts



PA140C

Figure 11.3

Probe for film-coated wire

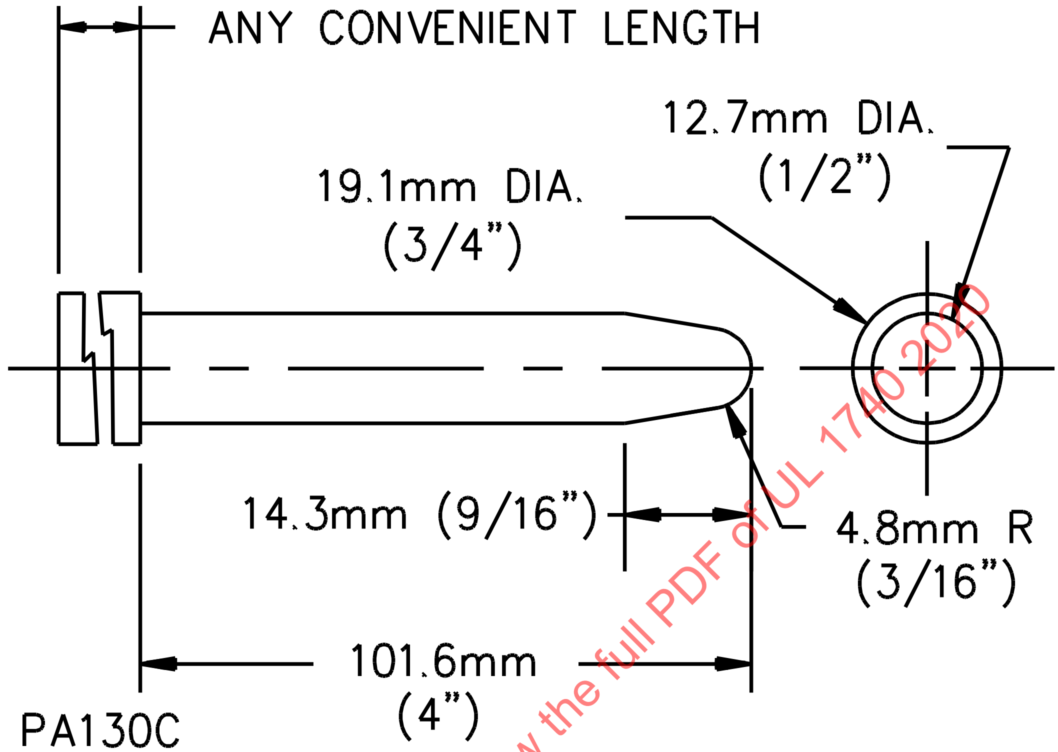
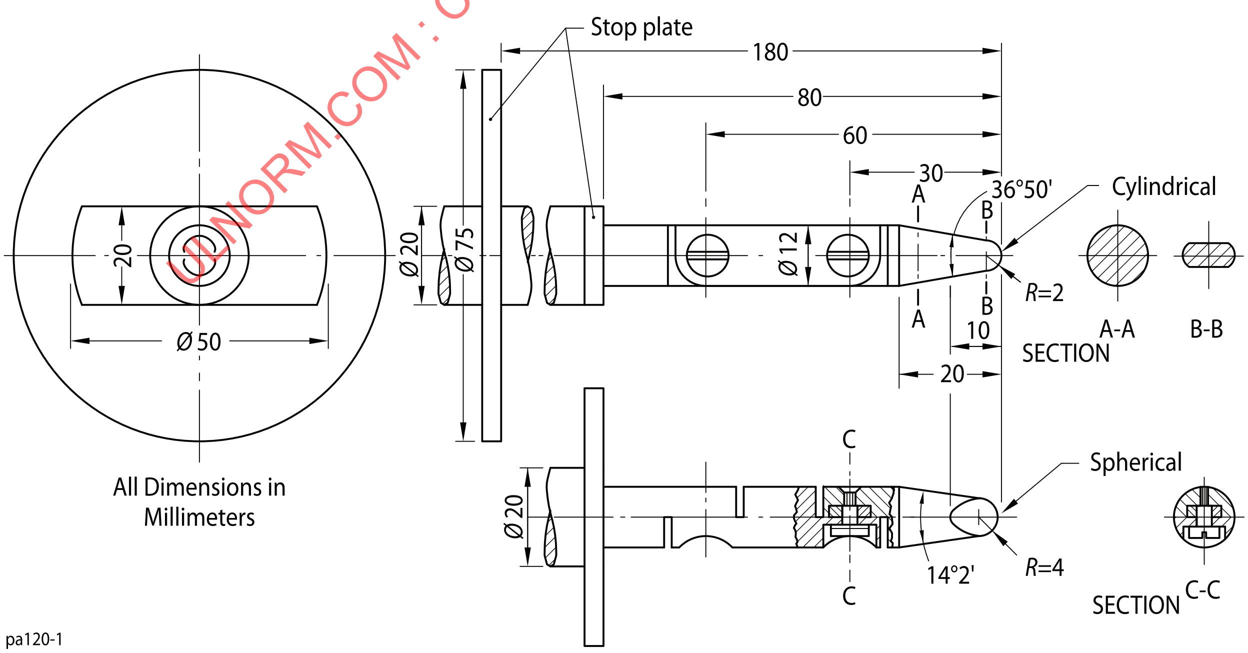


Figure 11.4

Articulated probe



11.3 The probes mentioned in 11.1 and 11.2 and illustrated in Figure 11.1 – Figure 11.4 are to be applied to any depth that the opening will permit; and are to be rotated or angled before, during, and after insertion through the opening to any position that is necessary to examine the enclosure. The probes illustrated in Figure 11.1 and Figure 11.4 are to be applied in any possible configuration; and, if necessary, the configuration is to be changed after insertion through the opening.

11.4 The probes mentioned in 11.1 and 11.2 shall be used as measuring instruments to judge the accessibility provided by an opening, and not as instruments to judge the strength of a material; they shall be applied with the minimum force necessary to determine accessibility.

11.5 With reference to the requirements in 11.1 and 11.2, the minor dimension of an opening is the diameter of the largest cylindrical probe having a hemispherical tip that can be inserted through the opening.

11.6 With reference to the requirements in 11.2:

a) An indirectly accessible motor is a motor:

1) That is accessible only by opening or removing a part of the outer enclosure, such as a guard or panel, that can be opened or removed without using a tool; or

2) That is located at such a height or is otherwise guarded or enclosed so that it is unlikely to be contacted.

b) A directly accessible motor is a motor:

1) That can be contacted without opening or removing any part; or

2) That is located so as to be accessible to contact.

11.7 During the examination of a product to determine whether it complies with the requirements in 11.1 or 11.2, a part of the enclosure that may be opened or removed by the user without using a tool (to attach an accessory, to make an operating adjustment, or for other reasons) is to be opened or removed.

11.8 With reference to the requirements in 11.1 and 11.2, insulated brush caps are not required to be additionally enclosed.

12 Protection Against Corrosion

12.1 Iron and steel parts shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means.

Exception No. 1: Bearings, thermal elements, or the like, if such protection is impractical, need not be protected.

Exception No. 2: Small minor parts of iron and steel – such as washers, screws, bolts, and the like – that do not carry current if corrosion of such unprotected parts would not be likely to result in a risk of fire, electric shock, or injury to persons need not be protected.

Exception No. 3: Parts made of stainless steel (properly polished or treated if necessary), aluminum, magnesium, and nickel need not be protected.

12.2 The requirement in 12.1 applies to all enclosing cases whether of sheet steel or cast iron, and to all springs and other parts upon which proper mechanical operation may depend.

12.3 Enclosures exposed to corrosive elements such as salt spray shall comply with the enclosure performance requirements outlined in the Standard for Enclosures for Electrical Equipment, Environmental Considerations, UL 50E.

13 Polymeric Materials

13.1 General

13.1.1 A barrier or integral part, such as an insulating washer or bushing, and a base or a support for mounting live parts, shall be moisture-resistant material that will not be adversely affected by the temperature and stresses to which it will be subjected under conditions of use.

13.1.2 Polymeric material is to be judged with respect to its acceptability for the application. If an investigation is necessary to determine whether a material is acceptable, the investigation is to be conducted in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C. Consideration is to be given to:

a) The material's mechanical strength, resistance to hot wire ignition, resistance to high-current-arc ignition, resistance to high-voltage-arc ignition, dielectric strength, insulation resistance, and heat-resistant qualities, in both the aged and unaged conditions;

b) The degree to which the material is enclosed; and

c) Any other feature affecting the risk of fire, electric shock, or injury to persons. All factors are to be considered with respect to conditions of actual service.

13.1.3 Polymeric materials used for parts involved in risk of electric shock, fire, or injury to persons, shall be rated V-2 minimum as determined in accordance with requirements in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94.

13.1.4 Polymeric materials used for parts not involved in risk of electric shock, fire, or injury to persons shall be rated HB minimum.

Exception: Internal belts, pulleys, bumpers (such as end of travel mechanical hard stops), impact padding (such as exterior cushioning), and the like, can be exempted from the polymeric material requirements. A determination of exemption shall be made based on the intended application.

13.2 Small parts

13.2.1 The flammability and other requirements in 13.1.3 and 13.1.4 do not apply to small/segregated parts. For the purposes of these requirements, a small/segregated part is defined as one that complies with each of the following items:

a) Its volume does not exceed 2 cm^3 (0.122 in^3);

b) Its maximum dimensions do not exceed 3 cm (1.18 in); and

c) Its location is such that it cannot propagate flame from one area to another or act as a bridge between a possible source of ignition and other ignitable parts.

13.3 Insulating material

13.3.1 When not specified otherwise in this standard, insulating materials shall meet the requirements of Standard for Industrial Control Equipment, UL 508.

14 Field Connections

14.1 General

14.1.1 Compartments, raceways, and the like – for routing and stowage of conductors connected in the field – shall not contain rough, sharp, or moving parts that may damage conductor insulation.

14.1.2 For power-circuit connections, permanently connected robotic equipment shall have provision for the connection of a grounding-type wiring system.

14.1.3 Wiring terminals or leads shall be provided and shall be acceptable for the connection of conductors having an ampacity not less than 125 percent of the maximum current under full load conditions with all motors and loads in operation at the same time.

14.1.4 With reference to 14.1.3, it is assumed that minimum 75°C (167°F) conductors will be employed for currents of more than 100 A.

14.1.5 For equipment marked to indicate that it is acceptable for use with copper, copper-clad aluminum, or aluminum conductors, the field-wiring terminals shall comply with the requirements for such devices and with the requirement in 14.1.3 for a wire of each metal for which it is marked. See 89.10 and 89.11.

14.1.6 A terminal box or compartment on equipment permanently connected electrically shall be located so that wire connections therein will be accessible for inspection, without disturbing either factory or field connected wiring, after the equipment is installed in the intended manner.

Exception No. 1: Wire connections to equipment intended to be mounted on an outlet box may be accessible upon removal of the equipment from the outlet box.

Exception No. 2: Factory-provided isolated low-voltage limited-energy, non-safety-circuit wire connected to a hinged panel or cover may be flexed.

14.1.7 A field-wiring lead shall not be more than two standard wire sizes smaller than the copper conductor to which it will be connected, and shall not be smaller than 0.82 mm^2 (18 AWG) for example, a 5.3 mm^2 (10 AWG) or larger field-wiring lead is required for connection to a 13.3 mm (6 AWG) field-provided conductor. A field-wiring lead shall not be less than 152.4 mm (6 in) long. Insulation on such a lead shall be:

a) At least 0.8 mm (1/32 in) thick thermoplastic or equivalent;

b) At least 0.4 mm (1/64 in) thick rubber plus a braid cover for 300 V or less applications; or

c) At least 0.8 mm (1/32 in) thick rubber plus a braid cover for applications between 301 and 600 V.

Exception No. 1: A 0.82 mm^2 (18 AWG) size field-wiring lead may be provided for connection to a 3.3 mm^2 (12 AWG) size branch circuit conductor.

Exception No. 2: A lead may be more than two wire sizes smaller than the field-provided copper conductor to which it will be connected, but not smaller than 0.82 mm^2 (18 AWG), if more than one factory-

provided copper lead is intended for connection to the same field-provided load, and the construction complies with the following conditions:

a) A wire connector for connection of the field-provided wire is provided as part of the unit of remote-control assembly, and the wire connector is acceptable for the combination of wires that will be spliced;

b) The factory-provided leads are bunched or otherwise arranged so that stress does not result on an individual lead; and

c) The equipment is marked in accordance with 89.12.

14.1.8 A pigtail lead intended for field-wiring connection shall be suitable for the application.

14.1.9 A lead provided for connection to an external line-voltage circuit shall not be connected to a wire-binding screw or pressure terminal connector located in the same compartment as the splice unless the screw or connector is rendered unusable for field-wiring connection or:

a) The lead is insulated at the unconnected end; and

b) A marking on the equipment clearly indicates the intended use of the lead.

14.1.10 The surface of an insulated lead intended solely for the connection of an equipment-grounding conductor shall be green with or without one or more yellow stripes, and no other lead in a field-wiring compartment shall be so identified.

14.1.11 The free end of a field-wiring lead that will not be used on every installation – such as a tap for a multivoltage transformer or one free lead for a single-pole, double-throw switch – shall be insulated.

14.1.12 The free end of an equipment-grounding conductor shall be insulated – for example, it shall have the end folded back and taped to the lead – unless the conductor is located so that it cannot contact live parts in the event that the conductor is not used in the field.

14.1.13 Robotic equipment that is acceptable for use with a fitting for only one type of wiring system shall be supplied with such a fitting.

14.1.14 An opening in a conductive enclosure for the entry of a conductor or conductors of an isolated limited-energy secondary circuit shall be provided with an insulating bushing. The bushing may be mounted in place in the opening or may be within the enclosure so that it may be properly mounted when the equipment is installed.

Exception: An insulating bushing may not be required if the conductor or conductors are provided with suitable protection against abrasion.

14.1.15 The opening mentioned in 14.1.14 may be acceptable for accommodating armored cable or conduit.

14.1.16 A bushing of rubber or rubber-like material provided in accordance with 14.1.14 shall be 3.2 mm (1/8 in) or more thick, except that it may be not less than 1.2 mm (3/64 in) thick if the metal around the hole is eyeletted or similarly treated to provide smooth edges. A bushing shall be located so that it will not be exposed to oil, grease, oily vapors, or other substances having a deleterious effect on the material of the bushing. A hole in which such a bushing is mounted shall be free from sharp edges, burrs, projections, or the like, that might damage the bushing.

14.2 Terminals

14.2.1 Terminal parts by which supply connections are made shall comply with the requirements in 14.2.2 – 14.2.9 so as to provide good connections even under hard usage.

14.2.2 A wiring terminal shall acceptably hold the next larger size conductor than that required in 14.1.3 if the terminal receives the larger size conductor, unless the equipment is marked in accordance with 89.13.

14.2.3 Soldering lugs or solderless (pressure) wire connectors shall be used.

Exception: For a 5.3 mm^2 (10 AWG) or smaller wire, the parts to which wiring connections are made may consist of clamps or binding screws with terminal plates having upturned lugs or the equivalent to hold the wires in position.

14.2.4 A nominal 2.8-, 3.2-, 4.8-, 5.2-, or 6.4-mm (0.110-, 0.125-, 0.187-, 0.205-, or 0.250-in) wide quick-connect terminal shall comply with the requirements in the Standard for Electrical Quick-Connect Terminals, UL 310. Other sizes of quick-connect terminals shall be investigated with respect to crimp pull-out, engagement-disengagement forces of the connector and tab, and temperature rises; all tests are to be conducted in accordance with the requirements of Standard for Electrical Quick-Connect Terminals, UL 310.

14.2.5 A wire-binding screw employed at a wiring terminal shall not be smaller than 4.0 mm diameter (No. 8).

Exception: A 3.5 mm diameter (No. 6) screw may be used for the connection of a 2.1 mm^2 (14 AWG) conductor.

14.2.6 A terminal plate tapped for a wire-binding screw shall be of metal not less than 0.76 mm (0.030 in) thick for a 2.1 mm^2 (14 AWG) or smaller wire, and not less than 1.27 mm (0.050 in) thick for a wire larger than 2.1 mm^2 (14 AWG). There shall not be less than two full threads in the metal.

Exception: An isolated low-voltage limited-energy transformer may have terminal plates 0.76 mm (0.030 in) thick for either primary or secondary connections.

14.2.7 A terminal plate formed from stock having the required thickness specified in 14.2.6 may have the metal extruded at a tapped hole for a binding screw so as to provide two full threads.

Exception: Two full threads are not required if fewer threads make a connection in which the threads do not strip when it is subjected to a 2.3-N·m (20-in-pound) tightening torque.

14.2.8 A wire-binding screw shall thread into metal.

14.2.9 To polarize the wiring of robotic equipment intended to be connected to more than one wire of a supply circuit rated at 125 or 125 / 250 V or less and employing an Edison screwshell lampholder or a single-pole switch or overcurrent-protective device other than an automatic control, one terminal or lead shall be identified for connection to the grounded conductor of the supply circuit. A terminal or lead identified for connection to the grounded supply conductor shall be electrically connected to screw shells of lampholders and shall not be connected to a single-pole switch or a single-pole overcurrent-protective device.

15 Cord Connected Robotic Equipment

15.1 In determining the acceptability of a cord and plug connection for stationary robotic equipment, the decision should include consideration of whether:

a) The cord connection of the equipment facilitates frequent interchange;

b) Reduction of the transmission of noise or vibration is accomplished;

c) The fastening means or mechanical connections are intended to permit removal for maintenance and repair; or

d) All external connections to the equipment are by means of cord and attachment plug.

15.2 The cord shall be: Type S, ST, SJ, SJT, SO, STO, SJO, SJTO or suitable for the application including a grounding conductor or an equivalent hard-usage cord directly connected to the equipment and terminated in a grounding attachment plug. The rating of the plug and the ampacity of the cord shall comply with 14.1.3.

16 Strain Relief

16.1 Strain relief shall be provided so that mechanical stress on a supply cord will not be transmitted to terminals, splices, or interior wiring.

16.2 A strain-relief device shall be subjected to the test described in 69.1.

16.3 Surfaces against which a knot in a flexible cord that serves as strain relief may bear or which it may contact shall be free from projections, sharp edges, burrs, fins, and the like, that may abrade the insulation on conductors.

17 Bushings

17.1 Where a flexible cord passes or is intended to pass through an opening in a wall, barrier, or enclosing case, there shall be a substantial bushing or the equivalent that is reliably secured in place, and has a smoothly rounded surface against which the cord may bear.

17.2 A cord hole with a smoothly rounded surface through wood, porcelain, phenolic composition, or other acceptable nonconductive material, is considered to be the equivalent of a bushing.

17.3 A bushing exposed to humidity, water, liquids, oil, grease, oily vapor, or other substance shall be acceptable for the intended application(s).

18 Current-Carrying Parts

18.1 A current-carrying part shall have the necessary mechanical strength and ampacity for the intended use and shall be of metal, or other material, that is acceptable for the application.

18.2 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it is prevented from turning or shifting in position if such motion may result in reduction of spacings to less than those required by this standard. The security of a contact assembly shall provide for the continued alignment of contacts.

Exception: A pressure terminal connector need not be prevented from turning provided spacings not less than those required result when the terminals are turned 30 degrees toward each other, toward other uninsulated parts of opposite polarity, or toward grounded metal parts.

19 Conductors

19.1 General

19.1.1 Power and control:

a) Conductors – other than those permitted in 19.1.2 – shall conform to one of the following:

1) Type MTW complying with the requirements in the Standard for Machine-Tool Wires and Cables, UL 1063;

Exception No. 1: Conductors with insulation characteristics equivalent to Type MTW, or suitable for the application, shall be permitted on individual devices supplied completely wired (such as motor starters, and the like).

Exception No. 2: If subject to temperatures, environment, voltages, or flexibility exceeding the limits for Type MTW, conductors having suitable characteristics shall be used.

2) Multiconductor flexible cords, Type SO, ST, SJ, or SJTO, or equivalent;

3) Multiconductor control cables having individual conductors and a jacket suitable for the purpose;

4) Mineral-insulated metal-sheathed cable, Type MI.

b) Conductors shall not be smaller than:

1) Power circuits – 2.08 mm^2 (14 AWG);

Exception: If it is demonstrated by a temperature test that the insulation temperature rating is not exceeded during operation, smaller conductors may be used.

2) Lighting and control circuits on the robotic equipment and in raceways – 1.31 mm^2 (16 AWG).

Exception: 0.82 mm^2 (18 AWG) shall be permitted in a jacketed, multiconductor cable assembly.

3) Control circuits on panels – 0.82 mm^2 (18 AWG);

4) Electronic, precision, and static control – see 19.1.2.

c) The continuous current carried by conductors shall not exceed the values given in Table 19.1.

Exception: The ampacity values specified in Table 19.1 may be exceeded if it is demonstrated by a temperature test that the insulation temperature rating is not exceeded.

d) Motor circuit conductors shall have an ampacity not less than 125 percent of the maximum current under full load conditions with all motors and loads in operation at the same time.

Table 19.1
Conductor ampacity

Conductor size		Ampacity in		Conductor		Ampacity in	
mm^2	(AWG)	Cable or raceway	Control enclosure	mm^2	(AWG or MCM)	Cable or raceway	Control enclosure
0.05	(30)		0.5	67.43	(00)	145	225
0.08	(28)		0.8	85.1	(000)	165	260
0.13	(26)		1	107.2	(0000)	195	300
0.21	(24)	2	2	127	(250)	215	340
0.32	(22)	3	3	152	(300)	240	375
0.52	(20)	5	5	177	(350)	260	420
0.82	(18)	6	7	203	(400)	280	455
1.31	(16)	10	10	253	(500)	320	515
2.08	(14)	15	20	304	(600)	355	575
3.31	(12)	20	25	355	(700)	385	630
5.26	(10)	30	40	380	(750)	400	655
8.37	(8)	40	60	405	(800)	410	680
13.30	(6)	55	80	456	(900)	435	730
21.15	(4)	70	105	507	(1000)	455	780
26.67	(3)	85	110				
33.62	(2)	95	140				
42.41	(1)	110	165				
53.49	(0)	125	195				

19.1.2 Electronic, precision, and static control:

a) Conductors used to connect electronic, precision, static control, or similar devices or panels shall be rated VW-1, or have a suitable flame rating for the application and shall conform to the following:

1) Conductor insulation shall be suitable for the purpose and voltage on that conductor. If the conductors are run with, or adjacent to, other conductors, all conductors shall be insulated for the maximum voltage involved;

2) Conductors shall be of annealed stranded copper;

Exception: Solid conductors 0.205 – 0.0507 mm^2 (24 – 30 AWG) are acceptable within the control enclosure if not subject to flexing.

3) Printed-wiring boards with a minimum rating of V-2 are acceptable in place of conventional conductor assemblies.

b) Size of conductors:

1) Conductors in raceways shall not be smaller than 0.823 mm^2 (18 AWG);

Exception: 0.0507 mm^2 (30 AWG) or smaller conductors are acceptable in a jacketed, multiconductor cable assembly.

2) Conductors within the control enclosures shall not be smaller than 0.128 mm^2 (26 AWG).

Exception: Conductors not smaller than 0.0507 mm^2 (30 AWG) are acceptable for short jumpers and special-wiring applications. For example, solderless wrapped or wire-clip type connections or shielded conductors.

c) The continuous current carried by conductors shall not exceed the values given in Table 19.1.

Exception: The ampacity values specified in Table 19.1 may be exceeded if it is demonstrated by a temperature test that the insulation provided is acceptable.

19.1.3 The effects of vibration, impact, and exposure are to be considered for the risks of fire, electric shock and personal injury – under normal and abnormal conditions – for wires smaller than 0.205 mm^2 (24 AWG).

19.1.4 Wiring that extends between moving parts of a robot that is subject to movement in use other than installation and servicing, shall be stranded and the arrangement shall preclude twisting or stressing of terminations as a result of the movement. The wiring shall be routed or protected to reduce the likelihood of damage to the insulation. The conductors shall be of a jacketed type – such as Type SJ, SJO, SJT or other conductors suitable for the application – and shall be provided with strain relief so that stress will not be transmitted to terminals or splices.

Exception: Wiring in Class 2 circuitry – where damage of the wire does not result in a risk of injury to persons, an unintended motion, dropping payload or the like – need not be jacketed.

19.1.5 Wiring that is subject to motion, and any supplementary insulation provided on the wire, may be subjected to a flexing test to determine the acceptability for the application. See 70.1.

19.1.6 Impregnated or unimpregnated cotton- or asbestos-insulated wire shall not be employed.

19.1.7 Metal clamps and guides used for routing stationary internal wiring shall be smooth or provided with rounded edges.

19.1.8 Auxiliary mechanical protection that is not electrically conductive shall be provided:

a) Under a clamp at which pressure is exerted on a conductor having thermoplastic insulation less than 0.76 mm (0.030 in) thick and no overall braid; and

b) On any wire or wires that are subject to motion, as defined in 19.1.4.

19.1.9 Tubing shall not be subjected to sharp bends, tension, compression, or repeated flexing, and shall not contact sharp edges, projections, or corners. Tubing may be used in dry or damp locations but is not acceptable in wet locations.

19.1.10 Rubber-insulated conductors shall not be exposed to oil, grease, oily vapor, or other substance having a deleterious effect on rubber, unless the insulation has been investigated and found to be acceptable for the application.

19.1.11 A wireway shall be smooth and free from sharp edges, burrs, fins, moving parts, and the like that can abrade insulation on conductors.

19.1.12 Mounting screws and nuts shall be constructed or located so that sharp edges will not damage wiring. A screw shall have a flat or blunt end. The end of a screw shall have no burrs, fins, or sharp edges that might abrade wire insulation, and shall not project more than 4.8 mm (3/16 in) into a wireway.

19.1.13 A hole in a sheet-metal wall through which insulated wires pass and on which they may bear shall be provided with a smoothly rounded bushing or shall have smooth, rounded surfaces upon which the wires may bear, to avoid abrasion of insulation.

19.1.14 A soldered connection shall be made mechanically secure before being soldered.

Exception No. 1: A connection for which a soldering or brazing material having a softening or melting point greater than 454°C (849°F) is used.

Exception No. 2: A hand-soldered lead passed through a hole in a printed-wiring board and bent 90 degrees to the board to make contact with the conductor before soldering. If soldering on a printed-wiring board is performed by a machine process in which the soldering time and solder temperature are automatically controlled – bending over of leads is not required.

Exception No. 3: The lead wire is strapped in place, or the equivalent, adjacent to the soldered connection to hold the lead end in place.

19.2 Interconnecting cords and cables

19.2.1 Cable assemblies and flexible cords used for external interconnection between sections of a unit or between units of a system shall be of a type as specified in 19.2.2 – 19.2.4 and shall be provided with acceptable strain relief and bushings in accordance with Strain Relief, Section 16, and Bushings, Section 17.

Exception: Cable assemblies used in nonsafety Class 2 circuits need not comply.

19.2.2 Insertion of a male connector in a female connector other than the one intended to receive it, misalignment of male and female connectors, and other manipulations of parts that are accessible to the operator shall not result in a risk of fire, electric shock, or injury to persons. Accessibility shall be judged by the probes of Figure 11.1 and Figure 11.2.

19.2.3 If either or each end of an external interconnecting cable terminates in a connector with one or more exposed contacts, a risk of electric shock shall not exist between earth ground and any contact that is exposed on either the connector or its receptacle while the connector is out of its receptacle.

19.2.4 An interlock circuit in the cable to de-energize the exposed contacts whenever an end of the cable is disconnected may be provided to comply with the requirement in 19.2.3. If an interlock is not provided, compliance is to be determined by means of the procedure in Interconnecting Cords and Cables Test, Section 53.

19.2.5 Electrical connectors that could cause hazard if they are separated, or if they break away, shall be designed and constructed to guard against such unintended separation. Connectors that must be mated during robot installation and could cause a hazard if mismated shall be provided with a means to prevent mismating. See 53.1.

19.3 Interconnection of units

19.3.1 Unless acceptable cable assemblies are employed, each unit in a system shall be provided with acceptable field-wiring terminals (see 14.2.1 – 14.2.9) to facilitate interconnection by means of permanently installed wiring.

19.3.2 If interconnection of units of a system involves Class 2 circuits, the Class 2 circuits may be terminated in field-wiring connections other than specified in 14.2.1 – 14.2.9, such as wire-wrap or crimp-on types, if:

a) The Class 2 circuits are permanently separated from all other circuits; and

b) The mating parts and constrictions for their method of attachment are provided.

20 Grounding

20.1 General

20.1.1 There shall be provision for grounding the robotic equipment and all dead metal parts that are exposed or that are likely to be touched by a person during a normal operation or adjustment and that are likely to become energized through electrical malfunction. (See 68.1.)

Exception: Robotic equipment supplied solely by an isolated, low voltage limited energy source are not required to be grounded.

20.1.2 To determine whether a part is likely to become energized, such factors as construction, the proximity of wiring, and a dielectric voltage-withstand test conducted after appropriate overload, endurance, and burnout tests are to be evaluated.

20.2 Grounding means

20.2.1 An equipment-grounding terminal or lead-grounding point shall be connected to the frame or enclosure by a positive means, such as by a bolted or screwed connection.

20.2.2 Nonconductive coatings – such as paint, lacquer, and enamel – shall be removed from the grounding surface area to assure electrical continuity; or the grounding connection shall reliably penetrate the nonconductive coating.

20.2.3 A grounding point shall be located so that it is unlikely that the grounding means will be removed during normal servicing.

20.2.4 The following are acceptable means for electrically grounding permanently connected equipment:

a) An equipment-grounding terminal or lead intended to be connected to a nonmetal-enclosed wiring system, for example, a nonmetallic-sheathed cable;

b) A knockout or equivalent opening in a metal enclosure intended to be connected to a metal-enclosed wiring system.

20.3 Terminals and leads

20.3.1 A wire-binding screw intended for connection of an equipment-grounding conductor shall have a green-colored head that is hexagonal, slotted, or both.

20.3.2 A wire-binding screw or pressure wire connector intended for connection of an equipment-grounding conductor shall be located so that it is unlikely to be removed during servicing.

20.3.3 A terminal for connection of an equipment-grounding conductor shall be capable of securing a conductor of the required size and shall be constructed as specified in 14.2.1 – 14.2.9.

20.3.4 A grounding terminal for a 5.3 mm^2 (10 AWG) or smaller wire may be a threaded stud welded to the enclosure or equivalent. Such a terminal shall be of acceptable material, for example, it shall be plated if of steel; and shall also comply with 20.3.1 – 20.3.3, and 14.2.1 – 14.2.9.

20.3.5 A soldering lug, a push-in (screwless) connector, or a quick-connect or similar friction-fit connector shall not be used for a grounding terminal.

20.3.6 A lead intended for connection to an equipment-grounding conductor shall be of the size specified in 21.2.8, and shall have a free length of 152 mm (6 in) or more.

20.3.7 The surface of an insulated lead intended solely for connection of an equipment-grounding conductor shall be green with or without one or more yellow stripes, and no other lead visible in a field wiring compartment to the installer shall be so identified.

20.3.8 The color coding requirement in 20.3.7 does not apply to an isolated low-voltage limited-energy non-safety circuit under the following conditions:

a) Leads or wiring to isolated low-voltage limited-energy terminals are remote from the location where the line-voltage connections are made and connectors and live parts are segregated in accordance with 30.5 and 30.6; or

b) Leads or isolated low-voltage limited-energy terminals are specifically marked with the intended use so that reference to a wiring diagram is not necessary.

20.3.9 The surface of an insulated grounding conductor of a flexible cord shall be green with or without one or more yellow stripes and no other lead shall be so identified.

20.3.10 The grounding conductor of a power-supply cord shall be attached to the grounding blade of an attachment plug and shall be connected within the frame or enclosure by a means not likely to be removed during ordinary servicing not involving the power-supply cord. A grounding conductor shall be arranged so that an external pull on a power-supply cord will not transmit stress to the grounding connection on a frame or enclosure before line-voltage connections are broken.

20.3.11 Circuitry shall be arranged so that an equipment-grounding connection or conductor, an enclosure, a frame, a component mounting panel, and earth ground do not carry current except in the event of an electrical fault.

Exception: A single-point reference ground may be employed in an isolated low-voltage limited-energy or isolated low-voltage limited-energy secondary circuit. An enclosure, frame, or panel, including bolted joints, may carry the current of an isolated low-voltage limited-energy circuit. Such current shall not be carried by a field-equipment grounding means, a metallic raceway or other power-supply grounding means, or earth ground in either case.

21 Bonding of Internal Parts

21.1 General

21.1.1 On robotic equipment that is grounded, an exposed noncurrent-carrying metal part likely to become energized through electrical fault – see 20.1.1 and 20.1.2 – shall be reliably bonded to the point of connection of the field-equipment grounding means.

Exception No. 1: A metal part, such as an adhesive-attached metal-foil marking, a screw, or a handle that is:

a) Located on the outside of an enclosure or cabinet and isolated from an electrical components and wiring by grounded metal parts so that it is not likely to become energized; or

b) Separated from wiring and spaced from uninsulated live parts as if it were a grounded part.

Exception No. 2: A small internal assembly screw, or other small fastener, such as a rivet, a handle for a pull-out disconnect switch, or a magnet or armature of a relay of contactor.

Exception No. 3: A metal panel or cover, that:

a) Is insulated from electrical components and wiring by an insulating barrier of vulcanized fiber, varnished cloth, phenolic composition, or other moisture-resistant material not less than 0.71 mm (0.028 in) thick and reliably secured in place;

b) Does not enclose uninsulated live parts, and wiring is positively separated from the panel or cover so that it is not likely to become energized; or

c) Is isolated from live parts and wiring by grounded or bonded interposing metal so that the interposing metal would be subject to an electrical fault before the isolated metal panel or cover.

Exception No. 4: Robotic equipment supplied solely by a battery, batteries, or a battery pack.

21.1.2 A guard, baffle, or cover that can be removed without a tool is to be removed when determining whether a part is exposed to contact by the user. A part that can be contacted by a 9.5 mm (3/8 in) diameter rod having a hemispherical end inserted through an opening in a permanently attached guard of baffle for a distance of 102 mm (4 in) is considered exposed for the purposes of grounding.

21.1.3 Uninsulated metal parts – such as cabinets, electrical enclosures and covers, motor frames and mounting brackets, controller mounting frames, brackets, capacitors, other electrical components, interconnecting tubing and piping, valves, and pneumatic accessories – shall be electrically bonded together if they may be contacted by a user or service person. See 21.1.5 and Exceptions to 21.1.1 for parts to which this requirement does not apply.

21.1.4 Operations and adjustments that subject parts to contact by a user include actions taken at the time of installation and during normal use – such as seasonal adjustments, relamping, replacing fuses, resetting overload devices, and oiling motors. These procedures and those specified in Protection of Users and Service Personnel, Section 40, subject parts to contact by a service person.

21.1.5 A part on the back side of a component mounting panel and a part located so as to require major disassembly by using tools are not considered to be exposed to the user; such parts are not considered to be exposed to a service person unless it is likely that servicing will be performed while the equipment is energized after disassembly.

21.1.6 Uninsulated live parts and wiring shall be held away from moving parts – such as relay and contactor magnets and armatures – by clamping, routing, or equivalent means that provide permanent separation.

21.1.7 If a component is likely to be separated from its grounding means after installation for the purposes of testing or adjustment while the equipment is energized, it shall be provided with a bonding terminal or with a bonding conductor so that it is not necessary to remove it from the component for such service.

21.2 Construction and connection

21.2.1 Parts shall be bonded by metal-to-metal contact or by a separate bonding jumper in accordance with 21.2.2 – 21.2.9.

21.2.2 A separate bonding conductor shall be copper, a copper alloy, or other material acceptable for use as an electrical conductor.

21.2.3 A ferrous metal part in a grounding path shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means.

21.2.4 A separate bonding conductor or strap:

a) Shall be protected from mechanical damage or shall be located within an outer enclosure or frame; and

b) Shall not be secured by a removable fastener used for any purpose other than bonding unless the bonding conductor is unlikely to be omitted after removal and replacement of the fastener.

21.2.5 The ends of a bonding conductor shall be in metal-to-metal contact with the parts to be bonded.

21.2.6 A splice shall not be employed in a wire used for bonding purposes.

21.2.7 An internal connection for bonding internal parts to an enclosure for grounding, but not for a field-installed grounding conductor or for the grounding wire in a supply cord, may employ a quick-connect terminal provided:

a) The connector is not likely to be displaced;

b) The terminal has the dimensions specified in Table 21.1; and

c) The component is limited to use on a circuit having a branch-circuit protective device as specified in Table 21.1.

Table 21.1
Quick-connect terminals for grounding internal parts

Nominal size of terminal, mm (in)			Rating of branch-circuit protective device, amperes
Width	Thickness	Length	
4.7 (0.187)	0.5 (0.020)	6.35(1/4)	20 or less
4.7 (0.187)	0.8 (0.032)	6.35 (1/4)	20 or less
5.2 (0.205)	0.8 (0.032)	6.35 (1/4)	20 or less
6.4 (0.250)	0.8 (0.032)	8.0 (5/16)	60 or less

21.2.8 A separate component-bonding conductor shall not be smaller than;

a) That specified in Table 21.2; or

b) The conductor supplying a motor or component, whichever is the smaller.

Table 21.2
Bonding conductor size

Rating or setting of automatic over current device in circuit ahead of equipment, conduit, etc., not exceeding, amperes	Size of bonding conductor[a]							
	Copper wire		Aluminum wire		Rigid conduit or pipe		Electrical metallic tubing	
	mm²	(AWG)	mm²	(AWG)	mm	(in)	mm	(in)
20[b]	3.3	(12)	5.3	(10)	12.7	(1/2)	12.7	(1/2)
30	5.3	(10)	8.4	(8)	12.7	(1/2)	12.7	(1/2)
40	5.3	(10)	8.4	(8)	12.7	(1/2)	12.7	(1/2)
60	5.3	(10)	8.4	(8)	12.7	(1/2)	12.7	(1/2)
100	8.4	(8)	13.3	(6)	12.7	(1/2)	12.7	(1/2)
200	13.3	(6)	21.2	(4)	12.7	(1/2)	25.4	(1)
400	26.7	(3)	42.4	(1)	19.05	(3/4)	31.75	(1-1/4)
600	42.4	(1)	67.4	(00)	19.05	(3/4)	31.75	(1-1/4)
800	53.5	(1/0)	85.0	(000)	25.4	(1)	50.8	(2)
1000	67.4	(2/0)	107.2	(0000)	25.4	(1)	50.8	(2)
1200	85.0	(3/0)	127.0	(250 kcmil)	25.4	(1)	50.8	(2)

[a] Or equivalent cross-sectional area.

[b] For a cord-connected device, the grounding wire in the cord may be the same size as the current carrying conductors.

21.2.9 If more than one size of branch-circuit overcurrent device is involved, the size of the bonding conductor is to be based on the rating of the overcurrent device intended to provide ground-fault protection for the component bonded by the conductor. For example, if a motor is individually protected by a branch-circuit overcurrent device smaller than other overcurrent devices used with the equipment, a bonding conductor for that motor is to be sized on the basis of the overcurrent device intended for ground-fault protection of the motor.

22 Motors

22.1 A motor shall be suitable for the application and shall be capable of delivering its maximum normal load without introducing a risk of fire, electric shock, or injury to persons.

22.2 A motor shall incorporate overload protection and short-circuit protection (locked-rotor protection).

Exception: A motor intended to move air only by means of an air-moving fan that is integrally attached, keyed, or otherwise fixed to the motor shaft is not required to have overload protection.

22.3 The overload protection required by 22.2 shall consist of one of the following:

a) Impedance protection complying with the requirements in the Standard for Impedance Protected Motors, UL 1004-2 and the Standard for Rotating Electrical Machines – General Requirements, UL 1004-1; or

b) Thermal protection complying with the applicable requirements in the Standard for Thermally Protected Motors, UL 1004-3 and Standard for Rotating Electrical Machines – General Requirements, UL 1004-1;

c) Other protection, such as electronic based components, overload relays and the like, that tests show is equivalent to the protection mentioned in (a) or (b).

23 Printed-Wiring Boards

23.1 A printed-wiring board shall comply with the Standard for Printed-Wiring Boards, UL 796.

23.2 A printed-wiring board containing circuits involving a risk of fire or electric shock shall be rated at least V-2 as specified in requirements in the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94. Printed-wiring boards not involving a risk of fire or electric shock may be rated HB.

23.3 The laminate material in a printed-wiring board used in a circuit that involves a risk of fire or electric shock shall:

a) Comply with the Direct Support of current-carrying parts (DSR) performance level requirements specified in the Standard for Printed-Wiring Boards, UL 796; and

b) Be marked with:

1) "▲" ; or

2) Have a unique type designation that is limited to such printed-wiring boards to indicate compliance with the Standard for Printed-Wiring Boards, UL 796 requirements.

23.4 A conformal coating employed on the surface of a printed-wiring board, intended to be used for the acceptance of reduced spacings, may be acceptable if it complies with the Standard for Printed Wiring Boards, UL 796.

24 Transformers

24.1 A transformer that supplies a low-voltage limited-energy circuit of 42.4 V peak (60 V dc) shall be an isolating type.

24.2 A transformer shall comply with the performance requirements outlined in this standard, including the temperature and dielectric voltage-withstand tests.

25 Capacitors, Capristors and Varistors

25.1 Isolating components

25.1.1 A component – such as a capacitor, a combination capacitor and resistor, or a suppressor used for line-by-pass, or metal-cabinet isolation; or between supply-circuit (line) connected parts and exposed metal parts (where the component is continually stressed) – shall comply with the requirements in the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14.

25.2 Across-the-line components

25.2.1 A component – such as a capacitor, a combination capacitor and resistor, a varistor, or a suppressor connected across the supply circuit – shall comply with the Standard for Fixed Capacitors for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, UL 60384-14.

25.2.2 A component as described in 25.2.1 is also considered to be across-the-line if it is used for line-by-pass isolation in a product provided with a terminal or connection intended to be grounded.

25.3 General

25.3.1 A component – such as a capacitor, a combination capacitor and resistor, varistor or a suppressor – shall employ materials and shall be constructed so that it will not constitute a risk of fire. It shall not be adversely affected by the temperature it reaches under the most severe conditions of use.

25.3.2 Under both normal and abnormal conditions of use, a component as described in 25.3.1, employing a liquid dielectric medium more combustible than askarel shall not result in a risk of fire or electric shock; and shall be constructed to reduce the risk of expelling the dielectric medium.

25.3.3 A capacitor complying with the requirements for protected oil-filled capacitors in the Standard for Capacitors, UL 810, is considered to be protected against the expulsion of the dielectric medium.

26 Supply-Circuit Disconnecting Means

26.1 General

26.1.1 A disconnecting means shall be provided for each incoming supply circuit. This means shall be located outside the safeguarded space.

26.1.2 The disconnecting means shall be:

a) Manually operable and shall be a fusible or nonfusible motor circuit switch or a circuit breaker; or

b) An attachment plug in accordance with 26.9.1.

26.1.3 Rating:

a) The ampacity of the disconnecting means shall not be less than 125 percent of the sum of the full-load currents required for all equipment that may be in operation at the same time under normal conditions of use. For an attachment plug, see 26.9.1;

b) The interrupting capacity of the disconnecting means shall not be less than the sum of the locked-rotor current of the largest motor plus the full-load current of all other connected operating equipment;

c) Fusible motor-circuit switches or circuit breakers shall be applied in accordance with the Electrical Standard for Industrial Machinery, NFPA 79.

26.2 Position indication

26.2.1 The disconnecting means shall plainly indicate whether it is in the open or closed position.

26.3 Supply conductors to be disconnected

26.3.1 Each disconnecting means shall disconnect all ungrounded conductors of a single supply circuit simultaneously. Where there is more than one source, additional individual disconnecting means shall be provided for each supply circuit, so that all supply to the robot may be interrupted.

26.4 Connections to supply lines

26.4.1 Incoming supply-line conductors shall terminate at the disconnecting means with no connection to terminal blocks or other devices ahead of the disconnecting means.

26.5 Exposed live parts

26.5.1 With the disconnecting means open, there shall be no exposed live parts.

26.6 Mounting

26.6.1 The disconnecting means shall be mounted within or adjacent to the control enclosure. If mounted within the control enclosure, the disconnecting means shall be mounted at the top of the control panel with no other equipment mounted directly above it.

26.6.2 If two or more disconnecting means are provided within the control enclosure for multiple supply circuits, they shall be grouped in one location.

26.7 Electrical cabinet interlocks (Not intended for Functional Safety of a Workcell)

26.7.1 Any door(s) that permit(s) access to live parts operating at a risk of electric shock or more shall be interlocked in accordance with Electrical Standard for Industrial Machinery, NFPA 79.

26.8 Operating handle

26.8.1 The operating handle shall include the following characteristics:

a) The operating handle of the disconnecting means shall be readily accessible;

b) The center of the grip of the operating handle of the disconnecting means, when in its highest position, shall not be more than 1.98 m (6-1/2 ft) above the floor. A permanent operating platform, readily accessible by means of a permanent stair or ladder, shall be considered as the floor for the purpose of this requirement;

c) The operating handle shall be capable of being locked only in the "off" position;

d) When the control enclosure door is closed, the operating handle shall positively indicate whether the disconnecting means is in the open or closed position.

26.9 Attachment plug and receptacle

26.9.1 An attachment plug and receptacle are acceptable as a disconnecting means if there is compliance with all of the following conditions:

a) The motor or motors on the machine total two horsepower or less;

b) The supply voltage does not exceed 150 Volts to ground;

c) DC is not used;

d) The ampacity of the attachment plug is not less than 125 percent of the sum of the full-load currents required for all equipment that may be in operation at the same time under normal conditions of use;

e) The attachment plug is single-voltage rated;

f) The attachment plug is provided with a grounding pole and so constructed that the grounding pole is made before any current-carrying poles are made and is not broken until all current-carrying poles of the attachment plug have been disconnected. A grounding pole shall not be used as a current-carrying part;

g) The attachment plug is readily accessible.

27 Overcurrent Protection, Control-Circuit Conductors

27.1 A conductor of a control circuit that is connected to the load side of the branch-circuit protective device – common control – shall be protected against overcurrent in accordance with Table 27.1 by a protective device located within the controller. See 27.2 and 27.4.

Exception No. 1: If the rating or setting of the intended branch-circuit protective device is not more than the applicable value specified in Table 27.2, and the equipment is marked in accordance with 88.10 and 88.11, additional protection is not required.

Exception No. 2: A low-voltage limited-energy circuit of 42.4 V peak (60 V dc) control circuit, such as Class 2 need not be so protected.

Exception No. 3: A control-circuit conductor that is the same as or larger than the main circuit conductors need not be protected.

Table 27.1
Protective devices

Control-circuit wire size		Maximum acceptable rating of protective device, amperes
mm^2	(AWG)	
0.32	(22)	3
0.52	(20)	5
0.82	(18)	7
1.3	(16)	10
2.1	(14)	20
3.3	(12)	25

Table 27.2
Branch-circuit protective devices

Control-circuit wire size		Maximum acceptable rating of branch-circuit protective device, amperes	
mm^2	(AWG)	Conductors within enclosure	Conductors outside enclosure
0.32	(22)	12	3
0.52	(20)	20	5
0.82	(18)	25	7
1.3	(16)	40	10
2.1	(14)	100	45
3.3	(12)	120	60

27.2 The protective device specified in 27.1 shall be either a supplementary or a branch-circuit overcurrent-protective device. A fuse shall be factory installed in a supplementary fuseholder but may be omitted if a branch-circuit-type fuseholder is provided. The equipment shall be marked in accordance with 88.11.

27.3 Internal conductors of control circuits that are connected to a remote source of supply – not a common control – shall be provided with overcurrent protection in accordance with Table 27.2 or the device shall be marked in accordance with 88.12. The internal conductors shall not be smaller than 0.52 mm^2 (20 AWG).

27.4 With reference to 27.1 and 27.3:

a) A short, direct lead – generally 305 mm (12 in) long, such as transformer leads or a printed-wiring assembly having no connection external to the controller – need not be so protected.

b) Short, direct leads from contacts of a switching device, or the like for connection within the enclosure to field wiring need not be protected in addition to the remote protective device that will be provided for the field wiring. See 14.1.7.

27.5 A control-circuit transformer shall be protected by an overcurrent device in each secondary circuit. The device shall be rated or set at not more than 200 percent of the rated secondary current of the transformer.

Exception No. 1: A transformer protected by other means in accordance with the National Electrical Code, NFPA 70 need not be so protected.

Exception No. 2: A low-voltage limited-energy circuit of 42.4 V peak (60 V dc) transformer, such as Class 2, need not be so protected.

28 Spacings

28.1 General

28.1.1 Spacings in primary circuits shall not be less than the applicable values specified in Standard for Industrial Control Equipment, UL 508, or Standard for Low-Voltage Switchgear and Controlgear – Part 1: General Rules, IEC 60947-1, 5th Edition.

28.1.2 For the Voltage Surge Test in Section 65, the measured peak voltage for the test circuit, where transient voltages are known and controlled, shall not exceed 300 percent of the instantaneous peak working voltage for that circuit, or 300 Volts, whichever is greater.

Exception: Voltages do not need to be measured for robotic equipment where transient voltages are known and controlled by a Surge Protective Device (SPD), installed at the input side of the circuit, with a suitable surge handling capability and VPR (Voltage Protection Rating) or Measured Limiting Voltage (MLV) of the SPD ≤ 300 percent of the instantaneous peak working voltage for that circuit, or 300 Volts, whichever is greater. The Surge Protective Device (SPD) shall be a Type 1, 2, 3, 1CA, 2CA or 3CA. If the Surge Protective Device (SPD) is a Type 4CA or Type 5, the Nominal Current Discharge Rating (In) shall be equal or greater to the available current in Table 65.1 or voltages do need to be measured.

28.2 Clearance and creepage distances

28.2.1 As an alternative approach to the spacing requirements specified in 28.1, and other than as noted in 28.1, clearances and creepage distances are able to be evaluated in accordance with the requirements in the Standard for Insulation Coordination Including Clearance and Creepage Distances for Electrical Equipment, UL 840, as described in 28.2.4.

28.2.2 Clearances between an uninsulated live part and the walls of a metal enclosure, including fittings for conduit or armored cable, shall be as noted in the Standard for Industrial Control Equipment, UL 508, or Standard for Low-Voltage Switchgear and Controlgear, Part 1: General Rules, IEC 60947-1. The clearances shall be determined by physical measurement.

28.2.3 The clearance and creepage distance at field-wiring terminals shall be in accordance with the requirements in Spacings in the Standard for Industrial Control Equipment, UL 508 or Standard for Low-Voltage Switchgear and Controlgear, Part 1: General Rules, IEC 60947-1.

Exception: If the design of the field-wiring terminals is such that it will preclude the possibility of reduced spacing due to stray strands or improper wiring installation, clearances and creepage distances at the field-wiring terminal may be evaluated in accordance with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840.

28.2.4 In conducting evaluations in accordance with the requirements in the Standard for Insulation Coordination Including Clearance and Creepage Distances for Electrical Equipment, UL 840, the following guidelines shall be used:

a) Unless specified elsewhere in this standard, the Pollution Degree for robotic equipment, based on the presence of contaminants and possibility of condensation or moisture, shall be Pollution Degree 2 – Normal;

b) Robotic equipment intended for specific macro- environments, attainable by the use of specific conditions or housings may alternatively be tested to one of the following macro environments:

1) Pollution Degree 1 – No pollution or only dry, nonconductive pollution. The pollution has no influence;

2) Pollution Degree 2 – Normal nonconductive pollution. However, a temporary conductivity caused by condensation may be expected;

3) Pollution Degree 3 – Conductive pollution, or dry, nonconductive pollution that becomes conductive due to condensation that is expected;

4) Pollution Degree 4 – Pollution that generates persistent conductivity through conductive dust or rain and snow.

c) The macro-environment where the robotic equipment may be installed to achieve the required Pollution Degree, shall be identified by the installation instructions provided with the robotic equipment. Means to obtain such an environment if not inherent to the robotic equipment itself shall be provided;

d) Pollution Degree 2 exists on a printed wiring board between adjacent conductive material which is covered by any coating which provides an uninterrupted covering over at least one side and the complete distance up to the other side of conductive material;

e) Any printed wiring board which complies with the requirements in the Standard for Printed-Wiring Boards, UL 796, shall be considered to provide a Comparative Tracking Index (CTI) of 100, and if it further complies with the requirements for Direct Support in UL 796 then it provides a CTI of 175;

f) For the purposes of compliance with the requirements for coatings of printed wiring boards used to achieve Pollution Degree 1 in accordance with the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840, a coating which complies with the requirements for Conformal Coatings in the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C, complies with the requirements;

g) Pollution Degree 1 is also achievable at a specific printed wiring board location by application of at least a 0.79 mm (1/32 in) thick layer of silicone rubber or for a group of printed wiring boards through potting, without air bubbles, in epoxy or potting material;

h) Evaluation of clearances, only, to determine equivalence with current through air spacings requirements are able to be conducted in accordance with the requirements for Clearance A (Equivalency) of the Standard for Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment, UL 840. An impulse test potential having a value as determined in UL 840 is to be applied across the same points of the device as would be required for the Dielectric Voltage-Withstand Test;

i) For permanently connected robotic equipment the overvoltage category shall be OVC III except for on the secondary of a transformer or power supply, in which case the overvoltage category shall be OVC II.

29 Field Wiring Space

29.1 Except as noted in 29.2 and 29.3, the field wiring space within an enclosure shall provide ample room for the distribution of wires and cables as specified in Table 29.1.

Table 29.1
Field wiring space

Conductor size		Minimum usable volume per conductor	
mm^2	(AWG)	cm^3	(in^3)
2.1 and smaller	(14 and smaller)	33	(2)
3.3	(12)	37	(2.25)
5.3	(10)	41	(2.5)
8.4	(8)	49	(3)
13.3	(6)	82	(5)

29.2 As an alternative to the volume specified in Table 29.1, a trial installation may be made to determine that ample room is provided for the distribution of wires and cables required for the proper wiring of the robotic equipment. However, wire-bending space shall be provided in accordance with 29.4 and 29.5.

29.3 To determine if the robotic equipment complies with 29.2, it is to be wired as it would be in service, and in doing so, a reasonable amount of slack is to be left in each conductor. No more than average care is to be exercised in stowing this slack into the wiring compartment. The wiring shall not bear against sharp projections or edges that may damage the insulation.

29.4 The wire-bending space within the enclosure of a controller shall be in accordance with Table 29.2. Bending space is to be measured in a straight line from the end of the lug, connector, or terminal to the wall or barrier, in the direction the wire leaves the terminal.

Table 29.2
Minimum wire-bending space at terminals of enclosed controllers

Conductors size		Bending space, mm (in) wires per terminal		
mm^2	(AWG or MCM)	1		2
2.1 – 5.3	(14 – 10)	Not specified		–
8.4 – 13.3	(8 – 6)	38	(1-1/2)	–
21.2 – 26.7	(4 – 3)	51	(2)	–
33.6	(2)	64	(2-1/2)	–
42.4	(1)	76	(3)	–
53.5	(1/0)	127	(5)	127 (5)
67.4	(2/0)	152	(6)	152 (6)
85.0 – 107.2	(3/0 – 4/0)	178	(7)	178 (7)
127	(250)	203	(8)	203 (8)
152	(300)	254	(10)	254 (10)
177 – 253	(350 – 500)	305	(12)	305 (12)
304 – 355	(600 – 700)	356	(14)	406 (16)
380 – 456	(750 – 900)	457	(18)	483 (19)
NOTE – If provision for three or more wires per terminal exists, the minimum wire-bending space shall be in accordance with the National Electric Code, NFPA 70.				

29.5 Any supplementary terminal supplied with the controller shall be of a type identified by the manufacturer for use with the product, and shall not reduce the minimum wire-bending space.

30 Separation of Circuits

30.1 Insulated conductors shall be segregated or separated by barriers from:

a) Each other if used in different internal wiring circuits; and

Exception: Conductors provided with insulation acceptable for the highest voltage involved need not be separated or segregated.

b) Uninsulated live parts connected to different circuits.

30.2 Segregation of insulated conductors may be accomplished by clamping, routing, or equivalent means if permanent separation from insulated or uninsulated live parts of a different circuit is provided.

30.3 Field-installed conductors of any circuit shall be segregated or separated by barriers from:

a) Field-installed and factory-installed conductors connected to any other circuit, unless the conductors of both circuits are insulated for the maximum voltage of either circuit.

b) Uninsulated live parts of any other circuit of the equipment, and from any uninsulated live parts the short-circuiting of which may result in a risk of fire or electric shock.

30.4 In accordance with 30.3(a), if the intended uses of the equipment are such that in some applications a barrier is required while in some other applications no barrier is required, a removable barrier or one having openings for the passage of conductors may be employed. Instructions for the use of such a barrier shall be a permanent part of the equipment. Complete instructions in conjunction with a wiring diagram may be acceptable in place of a barrier if, upon investigation, the combination is found to be acceptable.

30.5 Field-installed conductors may be segregated from each other and from uninsulated live parts of the device connected to different circuits by arranging the location of openings in an enclosure for the various conductors – with respect to the terminals or other uninsulated live parts – so that there is no likelihood that intermingling of the conductors or parts of different circuits can occur.

30.6 With reference to 30.5, if the number of openings in the enclosure does not exceed the minimum required for the intended wiring of the robotic equipment, and if each opening is located opposite a set of terminals, it is to be assumed that a conductor entering an opening will be connected to the terminal opposite that opening. If more than the minimum number of openings are provided, the possibility of a conductor entering an opening other than the one opposite the terminal to which it is intended to be connected and the likelihood of it contacting insulated conductors or uninsulated current-carrying parts connected to a different circuit is to be investigated.

30.7 To determine if the robotic equipment complies with 30.3, it is to be wired as intended for service with a reasonable amount of slack left in each conductor within the enclosure and not more than average care is to be exercised in stowing the slack into the wiring compartment.

31 Use with lasers or X-Radiation

31.1 Equipment which employs laser or X-radiation (such as cathode-ray tube monitors or other x-radiation sources) shall be provided with documentation of compliance, as applicable, with the Federal requirements 21 CFR Part 1040 (Lasers) with or without the use of the Center for Devices and Radiological Health (CDRH) laser notice 50; or 21 CFR 1020 (Ionizing Radiation) of the Department of Health and Human Services (DHHS). In addition to these Federal requirements, it may be necessary to subject the end use equipment/system to supplemental evaluations to determine acceptability of risks in accordance with Functional Safety Analysis, Section 83.

PROTECTION AGAINST INJURY TO PERSONS

32 General

32.1 The requirements in Sections 33 – 39 apply to the normal operation of robotic equipment which may involve a risk of injury to persons.

32.2 There are risks of injury to persons inherent in some robotic equipment that, if completely eliminated, would defeat the utility of the equipment. The requirements in this section are intended to reduce such risks, while retaining the intended function of the equipment.

33 Sharp Corners and Edges

33.1 An enclosure, a frame, a guard, a handle, or the like, shall not be sufficiently sharp to constitute a risk of injury to persons in normal maintenance and use.

Exception: A part or portion of a part needed to perform a working function need not comply if a warning statement is located in proximity to the affected part.

34 Moving Parts – Other Than the Robot

34.1 A hinged or pivoted panel or cover shall be positioned or arranged such that it is not subject to falling or swinging due to gravity or normal vibration that can cause injury to persons by the panel or cover, by other moving parts capable of causing injury to persons, or by uninsulated live parts.

34.2 The rotor of a motor, a pulley, a belt, gears, a chain, a fan, or other moving part that could cause injury to persons shall be enclosed or guarded to reduce the risk of unintentional contact with the moving part.

34.3 A moving part within an integral enclosure that may involve a risk of injury to persons shall comply with the requirements specified in Table 11.1, and shall be considered with respect to the:

a) Degree of exposure;

b) Sharpness of the moving part;

c) Likelihood of unintentional contact with it;

d) Speed of the moving part; and

e) Likelihood that fingers, arms, or clothing would be endangered by the moving part.

35 Moving Parts – Drive Power Indicator

35.1 General

35.1.1 A robot shall be provided with the capability for a Drive Power Indicator, as well as instructions for implementing this capability. Optionally, the robot may be provided with a visual indicator indicating that drive power is available. When such a visual indicator is provided, it shall comply with the following requirements:

a) The visual indicator color shall follow the guidance of the Electrical Standard for Industrial Machinery, NFPA 79. *Yellow (Amber) is considered the default color for this indicator;*

b) The visual indicator may be mounted to the robot arm or it may be integrated into a workcell where it would be visible from various likely approaches or entry points to the system workcell;

c) If the visual indicator is mounted to the robot arm, or a structural part subject to the effects of vibration (that may adversely affect the life of the visual indicator):

1) It shall not be a screw-in type, which may loosen as a result of the effects of vibration; and

2) It shall not be a filament-type due to the likely effects of vibration that may cause premature filament failure.

d) When a robot is intended to be used in areas that are subject to high levels of process contaminants that could substantially reduce the visibility of the visual indicator, or if a supplemental covering is applied to protect the visual indicator against process contaminants, the visual indicator may be mounted outside the workcell.

35.2 Limiting robot motion

35.2.1 A means, such as mechanical, electrical, or the like, shall be provided to limit the motion of the robot arm in accordance with the Standard for Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots, ISO 10218-1. When mechanical stops are provided, they shall be capable of stopping the motion of the robot under rated load, maximum speed conditions and at maximum extension. See End of Travel Hardstop Test, Section 58, and Functional Safety Analysis, Section 86, for the evaluation of electronic components.

35.3 Robot control system

35.3.1 Where required by the risk assessment the robot control system shall be provided with user-connected inputs, outputs, or both, that reliably function to automatically stop the robot when safety gates, guards or the like are activated during robot operation.

35.3.2 The robot control system shall be provided with a reliable means to prevent hazards associated with dropping payloads, unintended movement and the like caused by:

a) Activation of the emergency stop;

b) Loss of drive power (hydraulic, electrical, pneumatic, and the like). Unless it can be demonstrated that a risk of fire, electric shock and injury to persons is unlikely, the control system shall also be provided with a means not to restart (automatically) the robot when power is restored; or

c) Failure to complete an intended motion.

35.3.3 Compliance with 35.3.2 shall be verified by the tests specified in Power Loss and Power Restoration Test, Section 59, and Emergency Stop Operation Test and Maximum Stopping Time and Distance or Angle Verification, Section 60, and Abnormal Operation Test – General, Section 54.

35.4 Emergency movement without drive power and brake release

35.4.1 The robot shall be designed and constructed so that each axis is capable of being moved without using drive power. See Emergency Movement of Robot Without Drive Power Test, Section 62, and Manufacturer's Documentation, Section 92. Manual release of power actuated brakes, solenoids, and the like, without drive power for emergency movement of robot axes, may be employed where weight counter-balancing, mechanical stops (such as blocks, chocks, securement pins, supports), or equivalent means exist.

35.4.2 A brake release shall be protected against unintentional actuation. The brake release means shall be readily accessible without the use of a key or special tools. Symbols shall identify each axis and warnings shall be provided concerning hazards of dropping the robot arm.

35.4.3 Robot arms with rated payloads and end-effectors (if provided) which exert a force of greater than 156 N (35 lbf) during emergency movement without drive power, shall be provided with weight counter-balancing, mechanical stops or equivalent means. The risk of injury to persons associated with the payload and end-effectors (if provided) due to sharp edges, crush points, puncture points, and the like, are to be considered.

36 Temperature

36.1 During the normal Temperature Test, Section 45, the maximum temperature of an enclosure surface, handle, lever, button, or knob that is contacted by a user during normal operation shall not exceed the temperatures specified in Table 45.1.

37 Mounting Devices

37.1 Equipment having a mass of more than 2.3 kg (5 lb.) and relying on a mounting means other than its own enclosure, if malfunction of the mounting means will result in a risk of injury to persons, shall be subjected to the test described in Mounting Devices Test, Section 73.

38 Parts Subject to Pressure

38.1 A pressure vessel having an inside diameter more than 152 mm (6 in), subjected to a pressure more than 102 kPa (15 psig), and eligible to be covered by the National Board of Boiler and Pressure Vessel Inspectors shall be marked in accordance with the appropriate boiler and pressure vessel code symbol of the American Society of Mechanical Engineers (ASME) for a working pressure not less than the pressure determined in accordance with 38.3.

38.2 A pressure vessel, because of its application, not covered by the scope of the inspection procedure of the ASME code shall be constructed so that it complies with requirements in 38.3.

38.3 A part or an assembly that is subject to air or vapor pressure, including the vapor pressure in a vessel containing only a superheated fluid, during normal or abnormal operation, shall be tested as applicable, per Parts Subject to Pressure Tests, Section 74.

38.4 A vessel having an inside diameter of more than 76 mm (3 in) and subject to air or steam pressure generated or stored within the robotic equipment shall be protected by a pressure-relief device.

39 Pressure-Relief Devices

39.1 A means for safely relieving pressure shall be provided for a part in which pressure might be generated by an external source of heat.

39.2 A pressure-relief device, a fusible plug, a soldered joint, nonmetallic tubing, or other equivalent pressure-relief means may be employed to comply with the requirements in 39.1.

39.3 A pressure-relief device is considered to be a pressure-actuated valve or rupture member designed to relieve excessive pressure automatically.

39.4 There shall be no shut-off valve between the pressure-relief means and the parts that it is intended to protect.

39.5 The start-to-discharge pressure setting of a pressure-relief device shall not be higher than the working pressure marked on the vessel. The discharge rate of the device shall be adequate to relieve the pressure.

39.6 A pressure relief device shall:

a) Be connected as close as possible to the pressure vessel or part of the system that it is intended to protect;

b) Be installed so that it is readily accessible for inspection and repair, and cannot be readily rendered inoperative so that it will not perform its intended function; and

c) Have its discharge opening located and directed so that:

1) Operation of the device will not deposit moisture on bare live parts or on insulation or components detrimentally affected by moisture; and

2) The likelihood of scalding persons is reduced.

39.7 A pressure-relief device having an adjustable setting is judged on the basis of the maximum setting unless the adjusting means is reliably sealed at a lower setting.

39.8 A control that limits the pressure in a vessel required to have a pressure-relief device shall be subjected to the test described in Pressure-Relief Devices Test, Section 75.

40 Protection of Users and Service Personnel

40.1 General

40.1.1 The requirements in this section do not apply to live parts in isolated low-voltage limited-energy circuits as defined in 2.17.

40.1.2 Live parts shall be arranged and covers located so that persons are not likely to be exposed to a risk of electric shock while removing and replacing a cover.

40.1.3 Live parts shall be:

a) Recessed at least 3.2 mm (1/8 in) from the plane of the front of the fixed portion of an enclosure;

b) Recessed at least 3.2 mm (1/8 in) from the front edge of a wiring compartment, in the case of equipment mounted to the face of a wiring compartment; or

c) Provided with equivalent protection by projections or guards.

40.1.4 To determine whether live parts that are recessed or protected in accordance with 40.1.3 comply with the requirement in 40.1.2, the cover is to be removed and replaced to determine if live parts can be contacted.

40.1.5 Unless a cover complies with the requirements for hinged covers in 7.4.2 – 7.4.5, and unless all live parts are protected as specified in 40.1.6, a handle, knob, or other manual operating means shall be arranged so that it can be operated from outside the enclosure. The position of such an operating means shall be marked, if necessary, as a guide for proper operation. See 88.13.

Exception: Robotic equipment that involves manual operations that may be performed by a user only at the time of installation, during a servicing procedure, or seasonally, need not comply if it complies with the requirements in 40.1.6, 40.2.2, 40.4.4, and 40.5.4. The requirements in Current-Carrying Parts, Section 18, apply in any case.

40.1.6 An uninsulated live part or a moving part capable of causing injury to persons shall be located, guarded, or enclosed so as to reduce the likelihood of contact with such part by a person while changing a lamp or fuse, lubricating a motor, adjusting a control, or during other normal operations, including those performed only at the time of installation, during a servicing procedure, or seasonally.

40.1.7 A live heat sink for a solid-state component, a live relay frame, and the like, shall comply with 40.1.6 and unless the robotic equipment is marked in accordance with 88.9, shall also be guarded to reduce the likelihood of contact by persons, regardless of the location of the parts.

Exception: As provided in 40.1.9 and 40.1.10.

40.1.8 With reference to the requirement in 40.1.7, the size, shape, material, and color give a heat sink or relay frame the appearance of a dead metal part. Other live parts that can be mistaken as being dead parts are to be judged similarly.

40.1.9 A guard, baffle, or cover that can be removed without a tool is to be removed when determining whether a part is exposed to contact by a user. A part that can be contacted by a 9.5 mm (3/8 in) diameter rod having a hemispherical end inserted through an opening in a permanently attached guard or baffle for a distance of 102 mm (4 in) is considered to be accessible for the purpose of protecting persons. Also see Exception No. 2 to 11.1.

40.1.10 A part on the back side of a component mounting panel or located so that major disassembly by using a tool is necessary to expose it is not considered to be exposed to a service person unless it is likely that servicing will be performed while the part is energized after disassembly.

40.1.11 If a marking or an operating instruction refers a user to a hole or opening in an enclosure through which a tool is to be inserted for adjustment or a similar purpose, it shall not be possible to contact an uninsulated live part through the hole or opening with a 1.6 mm (1/16 in) diameter rod.

40.2 Robot control

40.2.1 General

40.2.1.1 Controls that can initiate robot motion shall be located or guarded so that unintentional robot arm movement is unlikely.

40.2.2 Emergency stop

40.2.2.1 An emergency stop function shall be provided and be readily visible and accessible. For robots incorporating a control panel, the emergency stop function shall be provided on the control panel and proper space shall be provided around the control panel so that the operator can easily activate the emergency stop function.

40.2.2.2 The emergency stop button shall be red in color with a yellow background; palm or mushroom head type; unguarded; and of the latched type or equivalent so that it is not possible to restart the robot until the emergency stop function is manually reset. Restarting of the robot shall only be possible by operating the start control after the emergency stop function has been reset. When emergency stop devices are installed on detachable or cableless operator control stations (e. g. pluggable or wireless portable teaching pendants) refer to the Clause on Emergency Stop Device in ISO 13850.

40.2.2.3 Every robot shall have an emergency stop function using hardware-based components. The emergency stop shall:

a) Avert arising or reduce existing hazards to persons, damage to machinery or to work in progress; and

b) Be initiated by a single human action.

Exception: Emergency stop circuits using electronic based components (Functional Safety) may be used if their performance has been evaluated to have sufficient safety performance as required by the risk assessment.

40.2.2.4 Maximum stopping distance and time of the robot operating with highest rated payload at maximum speed shall be identified in the manufacturer's instructions under normal conditions after the emergency stop has been actuated.

40.2.2.5 Each operator control station, including pendants, capable of initiating robot motion, shall have an emergency stop function.

40.2.2.6 When the results of a risk assessment determines that additional emergency stop capability shall be provided, provisions shall be made within the emergency stop circuit to include additional emergency stop devices.

40.2.2.7 When the results of the risk assessment requires an emergency output signal, the connection specifications (such as voltage, AC, DC, NC, etc.) shall be marked where they are readily visible. If the terminals can be reconfigured, this information is to be provided in the manual. The functional safety specification (such as B10d, PL, SIL, etc.) of the safety output signals shall be described in the manual.

40.2.2.8 The emergency stop function is not considered a safeguard.

40.3 Actuating controls

40.3.1 Actuating controls shall include an indication of the operating status.

40.3.2 A robot that can be controlled from a remote location shall have means that, when used, shall prevent the initiation of robot motion from a remote location.

40.4 Robot manual mode

40.4.1 Switching from automatic mode shall result in a stop.

40.4.2 Based on the results of a risk assessment, the stop may need to be a protective stop or a non-safety related stop.

40.4.3 When in the manual mode, it may be necessary for an operator to approach the robot. The maximum speed of the robot in manual mode shall be automatically and reliably restricted to 250 mm/second (10 in/second) at the end of arm tooling point (mounting flange surface) or end-effector, if provided. See 64.1.

Exception: Manual high-speed mode (formerly known as T2 or High Speed Attended Program Verification [APV]) is permitted in accordance with the Standard for Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots, ISO 10218-1.

40.4.4 When in manual mode, a robotic system shall be designed and constructed so that in the event of any single reasonably foreseeable malfunction, robot speed shall not exceed the manual mode speed limits. See Manual Mode Reduced Speed Measurement, Section 64.

40.4.5 The manual mode shall be functionally interlocked so that other modes of operation, such as automatic operation, cannot be activated.

40.4.6 When in manual mode, the robot controller shall detect a singularity during coordinated motion initiated from the pendant and shall either:

a) Stop robot motion and alert the teacher prior to motion of any part of the robot that exceeds 250 mm/second (10 in/second); or

b) Further reduce (or correct) the speed of the robot motion during the singularity so that no part of the robot exceeds a speed of 250 mm/second (10 in/second).

40.4.7 Manual High-Speed (High Speed APV or T2) shall meet the requirements of the Standard for Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots, ISO 10218-1.

40.5 Pendant

40.5.1 It shall not be possible to place the robot into automatic mode using the pendant exclusively.

40.5.2 An emergency stop function shall be provided on the pendant as described in 40.2.2.

40.5.3 When in manual mode, each control button on the pendant that initiates robot motion shall stop robot motion when the operator releases the control button.

40.5.4 An enabling device shall be provided on the pendant. During manual motion control, including manual mode, robot motion shall stop when the operator releases or compresses the enabling device from its normal operating position.

Exception: In accordance with ISO/TS 15066 for Collaborative Operation where a risk assessment, based on end use application, determines that an enabling device is not required.

40.5.5 Corded pendants shall be provided with a length of flexible cord that permits teaching outside the operating space.

40.5.6 Wireless/cableless pendants shall comply with the requirements found in the Standard for Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots, ISO 10218-1.

40.5.7 Single point of control – The robot control system shall be designed and constructed so that when the robot is placed into manual mode under local pendant control or other teaching device control, initiation of robot motion or change of local control selection from any other source is prevented. Stopping (such as an e-stop or protective stop) of robot motion and any associated workcell hazards, shall be permitted from multiple sources.

Exception: Robot controllers implementing remote control in manual mode shall comply with the requirements for the Standard for Robots and Robotic Devices - Safety Requirements for Industrial Robots – Part 2: Robot Systems and Integration, ISO 10218-2, Remote access for manual intervention.

40.6 Robot system workcell protection

40.6.1 General

40.6.1.1 The robot or robotic system shall be provided with safeguards. The means and degree of safeguarding, including the reliability of the safeguarding shall correspond directly to the assessed risk, consistent with the robot application. Safeguarding may include, but not be limited to protective devices, barriers, awareness barriers, awareness signals, designated procedures and training.

40.6.1.2 Robots or robotic systems shall be installed and provide workcell protection in accordance with Standard for Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 2: Robot Systems and Integration, ISO 10218-2.

40.7 Safeguarding requirements for maintenance – General

40.7.1 Robots or robotic systems shall include safeguards necessary for maintenance and mechanical servicing in accordance with Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 2: Robot Systems and Integration, ISO 10218-2.

40.8 Electrical servicing

40.8.1 Clearance, Section 9 and 40.1.6 require that certain electrical components within an overall assembly be so located that adequate space is provided for working on the components while the equipment is energized.

40.8.2 An electrical component that may need to be examined, adjusted, serviced, or maintained while the equipment is energized shall be located and mounted with respect to other components and with respect to grounded metal parts so that it is accessible for electrical servicing without subjecting a service person to a risk of electric shock or to a risk of injury to persons by adjacent moving parts. Access to a component shall not be impeded by other components or by wiring.

40.8.3 Compliance with 40.8.2 may be obtained by mounting control components in an assembly so that unimpeded access to each component is provided through an access cover or panel in the outer cabinet, if provided, and the cover of the control assembly enclosure.

40.8.4 Electrical components to which 40.8.2 and 40.8.3 apply include fuses, adjustable or resettable overload relays, manual or magnetic motor controllers, magnetically operated relays, adjustable or resettable pressure or temperature controllers, manual switching devices and clock timers. Such components in a low-voltage limited-energy circuit of 42.4 V peak (60 V dc) or less shall comply with the requirements in 40.8.2 in their relation to bare live parts in a circuit of greater energy level and to moving parts capable of causing injury to persons.

40.8.5 The following are not considered to be uninsulated live parts:

a) Coils of controllers, relays and solenoids, and transformer windings, if the coils and windings are provided with acceptable insulating overwraps at least 0.8 mm (1/32 in) thick, or the equivalent;

b) Enclosed motor windings;

c) Terminals and splices with acceptable insulation; and

d) Insulated wire.

41 Batteries and Battery Circuits

41.1 General

41.1.1 A battery, batteries and battery packs, shall comply with the requirements in this section, and Energy Storage and Energy Storage Circuit Tests – Electrical, Section 51.

41.2 Battery and fuel cell terminals

41.2.1 The terminals of a battery or a fuel cell shall be protected or located so they cannot be inadvertently short circuited during installation, replacement, or while in service.

41.3 Lithium batteries

41.3.1 A lithium ion and other lithium battery circuit, a primary or secondary circuit that obtains power from lithium batteries, shall have cells that comply with:

a) The Standard for Lithium Batteries, UL 1642;

b) The requirements in the Standard for Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes – Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made From Them, for Use in Portable Applications, UL 62133;

c) The requirements for secondary lithium cells in the Standard for Batteries for Use in Electric Vehicles, UL 2580; or

d) The requirements for secondary lithium cells in the Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications, UL 1973.

41.3.2 Lithium ion and other lithium cells that are configured into battery modules or battery packs shall comply with:

a) The Standard for Household and Commercial Batteries, UL 2054;

b) The Standard for Batteries for Use in Electric Vehicles, UL 2580;

c) The Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications, UL 1973; or

d) The Standard for Batteries for Use in Light Electric Vehicle (LEV) Applications, UL 2271.

41.4 Non-lithium battery circuits

41.4.1 A non-lithium battery circuit (a primary or secondary circuit that obtains power from rechargeable or non-rechargeable) non-lithium batteries, shall comply with the:

a) Primary non-rechargeable or secondary rechargeable/non-rechargeable requirements in Energy Storage and Energy Storage Circuit Tests – Electrical, Section 51; and

b) Primary circuit requirements in this standard or with the secondary circuit requirements in this standard.

41.5 Fuel cells

41.5.1 Fuel cells shall comply with the requirements in:

a) Standard for Fuel Cell Power Systems for Installation in Industrial Electric Trucks, UL 2267; or

b) Stationary Fuel Cell Power Systems, ANSI/FC 1; or

c) Portable Fuel Cell Power Systems, ANSI/FC 1.

42 Accessories and Attachments

42.1 Operation of the robot with an accessory or an attachment recommended by the manufacturer shall not increase the risk of injury to persons, fire or electrical shock.

PERFORMANCE

43 General

43.1 The performance of a robot and/or robotic equipment shall be investigated by subjecting a representative sample or samples to the tests described in Sections 44 – 83, as applicable. Consideration shall be given to the working environment, rated payloads, electrical and mechanical ratings, acceleration, heat-sink construction, solid-state-device ratings, and other construction criteria in selecting samples for testing that are representative of a line of similarly constructed equipment.

43.2 Unless otherwise noted, tests shall be conducted at rated voltage, current, and frequency.

44 Power Input and Maximum Ampacity Test

44.1 Power input

44.1.1 The power input to the robotic equipment shall not exceed the marked rating by more than 10 percent when it is operated under the conditions of normal use while connected to its rated supply voltage.

44.1.2 The robot is to be operated through the full operating space with its rated payload, and at its maximum speed and acceleration.

44.2 Maximum ampacity

44.2.1 The robot is to be operated at 125 percent of rated payload, with the conditions in 44.1.2, to determine ampacity of conductors [see 19.1.1 (d)], or be prevented from operation by overload protection means (see Overload Test, Section 56).

45 Temperature Test

45.1 When tested as described in this section, the robotic equipment shall not attain a temperature at any point sufficiently high to:

a) Constitute a risk of fire;

b) To damage any materials employed in the equipment; or

c) To exceed the temperatures specified in Table 45.1.

Table 45.1
Maximum temperature limits

Materials and components	°C	(°F)
A. INSULATION SYSTEMS		
a) Class A (105) insulation		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	105	(221)
Resistance method	115	(239)
In a totally enclosed motor:		
Thermocouple method	110	(212)
Resistance method	120	(248)
b) Class E (120) insulation system		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	115	(239)
Resistance method	125	(257)

Table 45.1 Continued on Next Page

Table 45.1 Continued

Materials and components	°C	(°F)
In a totally enclosed motor:		
Thermocouple method	120	(248)
Resistance method	130	(266)
c) Class B (130) insulation system		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	125	(257)
Resistance method	135	(275)
In a totally enclosed motor:		
Thermocouple method	130	(266)
Resistance method	140	(284)
d) Class F (155) insulation system		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	150	(302)
Resistance method	160	(320)
In a totally enclosed motor:		
Thermocouple method	155	(311)
Resistance method	165	(329)
e) Class H (180) insulation system		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	165	(329)
Resistance method	175	(347)
In a totally enclosed motor		
Thermocouple method	170	(338)
Resistance method	180	(356)
f) Class N (200) insulation system		
In an open motor or a transformer, windings of relays solenoids and other coils:		
Thermocouple method	180	(356)
Resistance method	190	(374)
In a totally enclosed motor:		
Thermocouple method	185	(365)
Resistance method	195	(383)
g) Class R (220) insulation system		
In an open motor or a transformer, windings of relays, solenoids and other coils:		
Thermocouple method	195	(383)
Resistance method	205	(401)
In a totally enclosed motor:		
Thermocouple method	200	(392)
Resistance method	210	(410)
B. COMPONENTS		
1. Capacitors:		

Table 45.1 Continued on Next Page

Table 45.1 Continued

Materials and components	°C	(°F)
a) Electrolytic[a]	65	(149)
b) Other types[a]	90	(194)
2. Field-wiring terminal[b]	75	(167)
3. Solid contacts, busses, and connecting bars[l]	90	(194)
4. Fuse clip	90	(194)
5. Printed-wiring board[c]	–	–
6. Power-switching semiconductor (triac, SCR, or the like)[d]	–	–
7. Rectifier:		
a) Selenium[e]	75	(167)
b) Silicon[e]	100	(212)
9. Sealing compound[f]	–	–
10. Epoxy[e]	90	(194)
12. Rubber- or thermoplastic-insulated wire and flexible cord[e,g]	60	(140)
C. ELECTRICAL INSULATION – GENERAL		
1. Fiber employed as electrical insulation	90	(194)
2. Phenolic composition employed as electrical insulation or as a part the deterioration of which could result in a risk of fire or electric shock:		
a) Laminated[e]	125	(257)
b) Molded[e]	150	(302)
3. Varnished-cloth insulation	85	(185)
4. Other insulating materials[h]	–	–
D. SURFACES		
1. A surface upon which a unit may be placed or mounted in service, and surfaces that may be adjacent to the unit when it is so placed or mounted	90	(194)
2. Any point on or within a terminal box or wiring compartment of permanently connected equipment in which power-supply conductors are to be connected, including such conductors themselves, unless the equipment is marked in accordance with 90.2	90	(194)
3. A handle, lever, button or knob that is contacted by the user during normal operation[j]:		
Metallic surface	60	(140)
Nonmetallic surface	85	(185)

[a] A capacitor that operates at a temperature limit of more than 65°C (149°F) for an electrolytic type and more than 90°C (194°F) for other types may be judged on the basis of its marked temperature limit. However, the measured temperature shall not exceed the temperature rating of the capacitor based on a 25°C (77°F) ambient temperature.

[b] The temperature on a wiring terminal or lug is measured at the point most likely to be contacted by the insulation of a conductor installed as in actual service.

[c] For a printed-wiring board, the maximum acceptable temperature limit is the specified limit of the board minus an assumed ambient of 25°C (77°F).

[d] For a power-switching semiconductor and the like, the maximum acceptable temperature limit on the case is the maximum case temperature recommended by the semiconductor manufacturer.

[e] These limitations do not apply to compounds and components that have been investigated and found acceptable for a higher temperature.

[f] The maximum sealing-compound temperature, when corrected to a 25°C (77°F) ambient temperature, shall be 15°C (27°F) less than the softening point of the compound as determined in accordance with the Test for Softening Point by the Ball-and Ring Apparatus, ASTM E28.

Table 45.1 Continued on Next Page

Table 45.1 Continued

Materials and components	°C	(°F)
[g] Rubber-insulated conductors within a motor having Class A (105) insulation, rubber-insulated motor leads, and a rubber-insulated flexible cord entering a motor may be subjected to a temperature limit of more than 60°C (140°F) if an acceptable braid is employed on each individual conductor. This does not apply to thermoplastic-insulated wires or cords.		
[h] The acceptability of insulating materials other than those covered in this table is to be determined with respect to properties, such as flammability, arc-resistance, and the like, based on the operating temperature.		
[i] If contacts of any metal and their supporting blades, busses, and connecting bars attain a temperature greater than 90°C (194°F) where a high ambient temperature or other external temperature prevails, or where affected by a bimetal heater or other heat source in the assembly, the control shall perform acceptably when subjected to overload and endurance tests conducted at the high temperatures involved.		
Exception: Contacts of silver of a silver alloy that do not attain a temperature higher than 100°C (212°F) need not be subjected to Overload and Endurance Tests conducted at the high temperature.		
[j] The maximum temperatures specified do not apply to equipment intended specifically for use in an ambient temperature exceeding 85°C (185°F).		
[k] A nonmetallic handle, lever, button, knob, or the like, that is plated or clad with metal 0.13 mm (0.005 in) thick or less is to be judged as a nonmetallic part.		

45.2 To determine if the robotic equipment complies with the Temperature Test requirements, it is to be operated through the full operating space with its rated payload, and at its maximum speed and acceleration, continuously at the rated voltage until temperatures reach thermal equilibrium.

45.3 A protective device shall not trip during the Temperature Test.

45.4 Permanently connected robotic equipment shall be tested with wire attached to each field-wiring terminal. The wire is to be of the smallest size having an ampacity of at least 125 percent of the test current for motor loads, continuous duty loads, and combination loads, and at least 100 percent for other loads. Wire size is to be determined in accordance with the National Electrical Code, NFPA 70. The size is to be based upon wire that is acceptable for a temperature of 60°C (140°F) for a rating of 100 A or less, and upon wire that is acceptable for 75°C (167°F) for a rating greater than 100 A. The type of insulation is not specified.

45.5 Permanently connected robotic equipment is to be installed so that it is located as close to the wall or corner as the construction will permit. Cord-connected equipment is to be placed on a horizontal supporting surface and spaced 25 mm (1 in) from a vertical wall surface of wood or comparable material, unless the arrangement of ventilation and similar cooling factors is such that operation against a wall, as compared with operation in the open, will not increase operating temperatures, or unless the construction of the equipment is such that a spacing greater than 25.4 mm (1 in) is maintained. Doors and covers that may be closed during operation of the equipment are to be closed during the test.

45.6 All values in Table 45.1 are based on an assumed ambient temperature of 25°C (77°F), but a test may be conducted at any ambient temperature within the range of 10 – 40°C (50 – 104°F). However, if the operation of an automatic thermal control during the test limits the temperatures under observation, no temperature shall exceed the specified temperature limit.

45.7 A short length of rubber- or thermoplastic-insulated flexible cord exposed to a temperature higher than that for which it is rated, such as at terminals, is acceptable if supplementary heat-resistant insulation having the necessary dielectric strength is employed on the individual conductors of the cord to reduce the likelihood of deterioration of the conductor insulation.

45.8 Robotic equipment intended specifically for use with a prevailing ambient temperature constantly more than 25° C (77° F) is to be evaluated at such higher ambient temperature, and the allowable temperature limits specified in Table 45.1 are to be reduced by the amount of the difference between the higher ambient temperature and 25°C.

45.9 If the robotic equipment is obviously not intended for continuous operation, the Temperature Test may be conducted so that the probable intermittent or short-time operation is considered.

45.10 Other than at coils, temperatures are to be measured by thermocouples consisting of wires not larger than 0.21 mm^2 (24 AWG). See 45.15.

45.11 When thermocouples are used to determine temperatures in electrical equipment, it is common practice to employ thermocouples consisting of iron and constantan wires (Type J), or similar suitable types, and a potentiometer-type instrument. Such equipment is to be used whenever referee temperature measurements by thermocouples are necessary.

45.12 The thermocouples and related instruments are to be accurate and calibrated in accordance with good laboratory practice. The thermocouple wire is to conform with the requirements for:

a) Special tolerance thermocouples specified in the Special Tolerances thermocouples as listed in the Tolerances on Initial Values of EMF versus Temperature tables in the Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples, ASTM E230/E230M;

b) The table of Special Limits as outlined in the Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples, ASTM E230; or

c) The IEC 60584-2, Standard for Thermocouples Part 2: Tolerances, or JIS C 1602, Standard for Tolerances. Tolerance Class 1, 2 or 3; type and Class tolerance shall be selected according to the following:

1) The maximum tolerance value does not exceed ± 1.5 °C of reading for thermocouples identified in IEC 60584-2 or JIS C 1602;

2) Alternately, where higher temperature ranges of the selected thermocouple are measured, a tolerance value of 0.4 percent of reading may be applied to thermocouple tolerances as specified in IEC 60584-2 or JIS C 1602.

45.13 Thermal equilibrium is considered attained when a time sufficient for the temperature to reach a steady-state value, but not exceeding 8 h. It is assumed that a steady state is reached when the variation does not exceed 1 K per hour. Where appropriate, a robot system continuously operated for a minimum of 4 hours can be considered at thermal equilibrium.

45.14 A thermocouple junction and adjacent thermocouple lead wire are to be securely held in good thermal contact with the surface of the material under test. In most cases, good thermal contact results from securely taping or cementing the thermocouple in place but, if a metal surface is involved, brazing or soldering the thermocouple to the metal may be necessary.

45.15 The preferred method of measuring temperatures on coils is the resistance method, but temperature measurements by either the thermocouple or resistance method are acceptable, except that the thermocouple method is not to be used for a temperature at a point where supplementary heat insulation is employed.

45.16 The thermocouple method consists of the determination of temperature by the application of thermocouples to the hottest accessible parts.

45.17 The resistance method used in the determination of the temperature of a winding is to be calculated by the following formula:

$$t = \frac{R}{r}(k + t_1) - (k + t_2)$$

in which:

R is the resistance of the coil at the end of the test in ohms;

r is the resistance of the coil at the beginning of the test;

t_1 is the room temperature in °C at the beginning of the test;

t_2 is the room temperature in °C at the end of the test; and

k is 234.5 for copper, 225.0 for electrical conductor grade (EC) aluminum; values of the constant for other conductors are to be determined.

45.18 As it is generally necessary to de-energize the winding before measuring R, the value of R at shutdown may be determined by taking several resistance measurements at short intervals, beginning as quickly as possible after the instant of shutdown. A curve of the resistance values and the time may be plotted and extrapolated to give the value of R at shutdown. Instruments capable of measuring the winding resistance while the equipment is energized may be used.

46 Overvoltage and Undervoltage Tests

46.1 The robotic equipment shall operate as intended when tested as described in 46.2 at 85% and 110% of its rated voltage.

Exception: If limits of operating voltage that may be marked on the unit nameplate in addition to the rated voltage extend beyond the overvoltage and undervoltage values, the test potential for the overvoltage and undervoltage test is to be the marked value.

46.2 The robotic equipment is to be connected to a supply source maintained at the overvoltage until thermal equilibrium is reached. The potential is then to be reduced to the normal test voltage. The potential is to be maintained at the normal test voltage until the robotic equipment reaches thermal equilibrium. The potential is then to be reduced to the undervoltage condition and the robot operated as intended under this test condition until the robotic equipment reaches thermal equilibrium.

47 Leakage Current Test

47.1 The leakage current of cord-and-plug-connected robotic equipment rated for a nominal 120-, 208-, or 240 V supply when tested in accordance with 47.3 – 47.8 shall not be more than 3.5 mA for grounded, 3-wire, portable and stationary equipment employing a standard attachment plug rated 20 A, or less.

47.2 Leakage current refers to all currents, including capacitively coupled currents, that may be conveyed between exposed conductive surfaces of the robotic equipment and ground or other exposed surfaces of the equipment.

47.3 All exposed conductive surfaces are to be tested for leakage currents. Leakage currents from these surfaces are to be measured to the grounded supply conductor individually as well as collectively if simultaneously accessible, and from one surface to another if simultaneously accessible. Parts are considered to be exposed surfaces unless they are guarded by an enclosure considered acceptable for protection against the risk of electric shock. Surfaces are considered to be simultaneously accessible if they can be readily contacted by one or both hands of a person at the same time. These measurements do not apply to terminals operating at voltages that are not considered to involve a risk of electric shock. If all accessible surfaces are bonded together and connected to the grounding conductor of the power-supply cord, the leakage current can be measured between the grounding conductor and the grounded supply conductor. If exposed dead metal parts of the equipment are connected to the neutral supply conductor, this connection is to be open during the test.

47.4 If a conductive surface other than metal is used for the enclosure or part of the enclosure, the leakage current is to be measured using a metal foil with an area of 10 by 20 cm (4 by 8 in) in contact with the surface. If the surface is less than 10 by 20 cm (4 by 8 in), the metal foil is to be the same size as the surface. The metal foil is not to remain in place long enough to affect the temperature of the equipment.

47.5 The measurement circuit for leakage current for single phase equipment is to be as illustrated in Figure 47.1. For 3-phase equipment, the leakage current shall be the sum of measurements from each phase to neutral. The measurement instrument is defined in (a) – (c). The meter that is actually used for a measurement need only indicate the same numerical value for a particular measurement as would the defined instrument; it need not have all the attributes of the defined instrument.

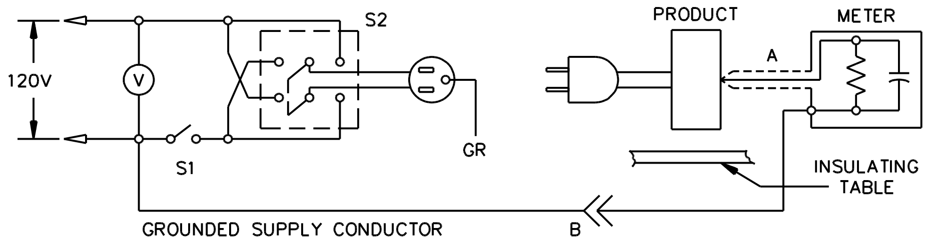
a) The meter is to have an input impedance of 1500 ohms resistive shunted by a capacitance of 0.15 microfarad.

b) The meter is to indicate 1.11 times the average of the full-wave rectified composite waveform of voltage across the resistor or current through the resistor.

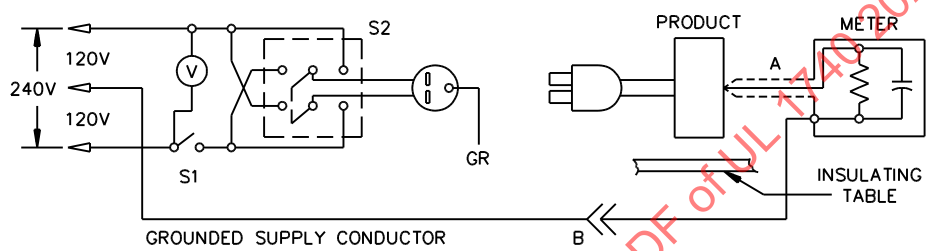
c) Over a frequency range of 0 – 100 kHz, the measurement circuitry is to have a frequency response – ratio of indicated to actual value of current – that is equal to the ratio of the impedance of a 1500-ohm resistor shunted by a 0.15-microfarad capacitor to 1500 ohms. At an indication of 3.5 mA, the measurement is to have an error of not more than 5 percent at 60 Hz.

Figure 47.1

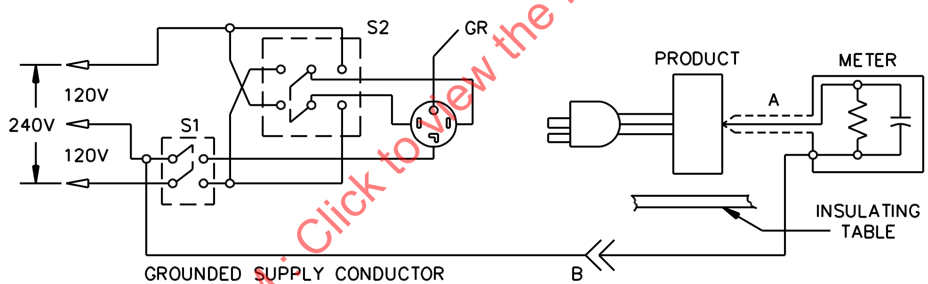
Leakage-current measurement circuits



Equipment intended for connection to a 120 V power supply, as illustrated above.



Equipment intended for connection to a 3-wire, grounded neutral power supply, as illustrated above.



Equipment intended for connection to a 3-wire, grounded neutral power supply, as in the 240 V example illustrated above.

A – Probe with shielded lead.

B – Separated and used as clip when measuring currents from one part of equipment to another.

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47.6 Unless the meter is being used to measure leakage from one part of the equipment to another, the meter is to be connected between the accessible parts and the grounded supply conductor.

47.7 A sample of the robotic equipment is to be tested for leakage current starting with the as-received condition – as-received being without prior energization except as may occur as part of the production-line testing. The grounding conductor, if any, is to be open at the attachment plug. The rated supply voltage is to be used. The test sequence, with reference to the measuring circuit, Figure 47.1, is to be as follows:

a) With switch S1 open, the equipment is to be connected to the measuring circuit. Leakage current is to be measured using both positions of switch S2, and with the equipment switching devices in all their normal operating positions.

b) Switch S1 is then to be closed energizing the appliance and within 5 seconds the leakage current is to be measured using both positions of switch S2, and with the equipment switching devices in all their normal operating positions.

c) The leakage current is to be monitored until thermal stabilization. Both positions of switch S2 are to be used in determining this measurement. Thermal stabilization is considered to be obtained by operation as in the normal temperature test.

47.8 Normally a sample will be carried through the complete leakage-current-test programs described in 47.7, without interruption for other tests. With the concurrence of those concerned, the Leakage Current Tests may be interrupted for the purpose of conducting other nondestructive tests.

48 Robots Intended for Use in Water Environments

48.1 Cord-and-plug connected equipment rated for a nominal 120, 208, or 240 V supply that is intended for use in an environment that involves the presence of water, such as water jet cutting, glass beveling, and polishing, shall comply with the requirements for Leakage Current Test, Section 47, following exposure to 7 hours of water under the most severe intended mode of operating conditions, as stated in the manufacturer's user manual. At the conclusion of the leakage current measurement, a visual inspection is to be performed if water entry may involve a risk of fire, electric shock, or injury to persons.

48.2 Permanently connected equipment shall be exposed to a minimum of 7 hours of water under intended operating conditions or its rated water exposure (TYPE or IP), whichever condition is more severe. At the conclusion, a visual inspection is to be performed if water entry may involve a risk of fire, electric shock, or injury to persons.

49 Outdoor-Use Tests

49.1 A robot or robotic system intended to be used outdoors shall be evaluated to determine the effects of anticipated environmental conditions to which they will be exposed. These include, but are not limited to: Ultraviolet Exposure and Rain Tests described in the Standard for Enclosures for Electrical Equipment, Environmental Consideration, UL 50E.

50 Maximum Low Voltage Measurement

50.1 The maximum voltage on electrolytic capacitors in a hazardous energy circuit, having a diameter greater than 10 mm (0.39 in), shall be measured during operation within the marked rating under all of the following conditions of operation, as applicable:

a) Any combination of fuses can be removed;

b) An automatic voltage-regulating device, assembly, or circuit is to be rendered inoperative.

Exception: This requirement does not apply when the device, assembly, or circuit, upon investigation, is found to guard against any unacceptable increases in voltage. The investigation is to take into consideration any likely malfunction or breakdown in either the regulating device or the equipment, and the possibility of the device being disconnected if it is not permanently connected in the circuit.

c) A connector or comparable part that is likely to be disconnected during equipment operation or user servicing is to be both connected and disconnected;

d) The equipment is to be connected to its rated supply voltage;

e) If a complex voltage is present, the peak value of the voltage is to be measured.

51 Energy Storage and Energy Storage Circuit Tests – Electrical

51.1 Battery or super-capacitor (Ultra-cap) overcharge

51.1.1 A fully charged rechargeable battery or super-capacitor is to be overcharged:

a) With the charging circuit adjusted for the maximum charging rate; and again

b) With any single junction or part of an electronic device or electrolytic capacitor in the charging circuit either short-circuited or open-circuited.

51.1.2 The robotic equipment incorporating a battery or super-capacitor is to be connected to a rated supply circuit and fused appropriately. A single layer of a flame indicator, of the type described in 55.1, is to be draped loosely over the battery or super-capacitor enclosure and a 3 A nontime-delay fuse is to be connected from accessible conductive parts to earth ground.

51.1.3 In addition to any of the unacceptable conditions described in 51.4.1 there shall not be any indication of fire or rupturing of the 3 A nontime-delay fuse.

51.2 Battery or super-capacitor discharge

51.2.1 Short-circuiting of unreliable components – such as microprocessor memory devices, semiconductors – (one at a time) connected to the terminals of a fully charged (rechargeable) battery or super-capacitor shall not result in any of the unacceptable conditions described in 51.1.3 and 51.4.1.

51.3 Battery / battery pack drop

51.3.1 Each of three samples of a fully charged user replaceable rechargeable battery or battery pack is to be dropped three times from a minimum height of 915 mm (3 ft) onto a concrete floor in the position most likely to produce adverse results without producing any of the unacceptable conditions described in 51.4.1.

Exception: Batteries that have been previously evaluated to the Battery Drop Test do not need to be retested.

51.4 Energy storage test results

51.4.1 The results of the tests shall be considered unacceptable if one or more of the following occur:

a) The battery or super capacitor case cracks.

b) Battery or super capacitor electrolyte leaks from the case.

c) The battery or super-capacitor explodes.

51.5 Energy Source low voltage – program memory loss

51.5.1 To determine that no hazard exists should the memory backup energy source deplete to an unfunctional level and not be replaced or recharged, primary power is to be shut down for a minimum of 30 minutes, and the control system is allowed to lose all memory previously retained by the energy storage backup. This may cause the robot to be unaware of its position and job function. Then the system is to be reenergized with primary power and not result in risk of injury to persons when normal functions are attempted without energy memory backup. As an option, the battery or super-capacitor circuit terminals may be discharged.

52 Pendant Tests: Drop, Handle and Mounting Means

52.1 General

52.1.1 A pendant is to be dropped three times from a height of 915 mm (3 ft) onto a concrete floor in the position most likely to produce adverse results without producing any of the unacceptable conditions described in 52.1.2.

52.1.2 The Pendant Drop Test results shall be considered unacceptable if one or more of the following occurs:

a) Access to shock hazard voltage and current, exceeding 42.4 V peak (60 V dc) and 3.5 mA, using the Finger Probe described in Figure 11.1.

b) Any breakage of parts that could cause lacerating injuries.

c) Hazardous or unintended motion of the robot.

Loss of emergency stop function, enabling device, or other safety function, either through mechanical or electrical damage shall not result in a hazard.

52.2 Pendant: Handle and mounting means

52.2.1 The pendant handle and wrist strap, if provided, are to be loaded uniformly over a 83.2 mm (3 in) width at the center, without clamping. The controller panel mounting means, on the controller or other mounting surfaces, are to be mounted in accordance with manufacturer's instructions. Each is to be subjected to a force equal to three times the pendant weight but not less than 89 N (20 lbf) applied through the approximate center of gravity. The force is to be increased gradually to reach the required value in 5 – 10 seconds and is to be maintained at that value for 1 minute. There shall not be unacceptable damage of the securing means, handle, strap, or enclosure to which these are attached.

52.3 Pendant: Enabling device

52.3.1 Human reaction to an emergency condition can be to release or compress the enabling device. During manual motion control including manual mode, robot motion shall stop when the operator releases or compresses the enabling device from its center operating position. If the enabling device is compressed, causing cessation of robot motion, the robot system shall not restart when the enabling device is returned to the center position, without being fully released. The robot shall only resume when the enabling device is fully released, then recompressed to the center position. An additional human action shall be required to resume motion. If the robot is integrated into a workcell, and additional equipment is under the robot pendant control, the associated hazards shall also be controlled as described above.

Hazards associated with equipment in the workcell, to be controlled by the robot pendant, shall be determined by the risk assessment. See Enabling Device Verification, Section 61.

53 Interconnecting Cords and Cables Test

53.1 To determine compliance with 19.2.5, electrical connectors that are likely to be disconnected and are not provided with a means to prevent unintended separation are to be evaluated to determine if contact with exposed accessible terminals could result in a hazard.

53.2 When disconnected, all exposed terminals of external interconnecting cables shall be evaluated to determine that:

a) A risk of electric shock does not exist per 2.34; and

b) Live parts are not accessible to contact as determined by use of the Articulated Probe shown in Figure 11.1.

54 Abnormal Operation Test

54.1 General

54.1.1 While operating at stabilized temperatures as in the Temperature Test, and when the abnormal conditions described in 54.2 – 54.6 are imposed and maintained until ultimate results are obtained, there shall be no:

a) Emission of flame or molten metal;

b) Opening of a printed wiring board conductor or an individual wire;

c) Risk of electric shock as determined by a Dielectric Voltage-Withstand Test, Section 66, at the conclusion of each Abnormal Test or at the conclusion of a series of Abnormal Tests; or

d) Risk of personal injury.

Temperature- or current-sensitive devices or systems that cause termination of the test shall comply with the requirements for such devices. Opening or shorting of one or more output-power semiconductor devices is an acceptable result.

54.2 Loss of primary power single phase test

54.2.1 Three phase robotic equipment is to be operated with one phase disconnected at the input. There shall be no risk of fire, electric shock, or personal injury during this test. Risk of fire can be determined by a glow or flame of a single layer of a flame indicator as described in the Component Breakdown Test, Section 55.

54.2.2 The test is to be conducted by disconnecting one phase with the equipment operating as in the temperature test, until ultimate results.

54.2.3 The robotic equipment shall be restarted and operated normally after reconnection of the disconnected phase.

54.2.4 The robotic equipment shall have a phase disconnected while de-energized and started with 2 phases connected. The test is concluded after ultimate results are achieved. This test is to be repeated for each phase, one at a time.

54.3 Locked ventilation motor test

54.3.1 Robotic equipment having forced ventilation is to be operated with the rotor of a blower motor or motors locked until temperatures stabilize.

54.4 Blocked mechanical filter test

54.4.1 Enclosed robotic equipment having filtered ventilation openings is to be operated with the openings blocked to represent clogged filters. The test is to be conducted initially with the ventilation openings blocked approximately 50 percent, which is intended to represent the most severe blockage; the test is then to be repeated under full-blocked condition. The test may also be conducted with only 100 percent blockage without conducting the test at 50 percent blockage.

54.5 Locked drive motor test

54.5.1 Each drive motor shall be operated in a locked-rotor condition until a stop is initiated and an awareness signal is generated or ultimate results are obtained.

54.6 Locked brake test

54.6.1 If a motor brake is provided, each drive motor shall be operated with its brake applied for 4 hours or until ultimate results are obtained.

55 Component Breakdown Test

55.1 As a result of the tests in this section, there shall be no ignition or glow of a single layer of a flame indicator as follows: cheesecloth, or medical gauze, or wrapping tissue, or surgical cotton.

55.2 The flame indicator shall be dry, and loosely-placed over all openings of ventilated robotic equipment or totally around open equipment when power circuit components, such as capacitors, diodes, or other solid-state components are short- or open-circuited, one at a time.

55.3 Cheesecloth is to be a bleached cotton cloth, having a thread count of 32 by 28 threads per (in) (2.54 mm), and a weight of approximately 14 – 15 square yards per pound (35 – 38 g/m^2).

55.4 Medical gauze is to be U.S. Pharmaceutical Type II gauze, which is a bleached cotton cloth, having a nominal thread count of 32 by 28 threads per (in) (2.54 mm), and a weight between 32.9 and 41.9 g/m^2 (13.0 to 16.5 yards per pound).

55.5 Wrapping tissue is to be soft and strong, lightweight wrapping paper of a weight generally between 12 g/m^2 and 30 g/m^2, primarily intended for protective packaging of delicate articles and for gift wrapping.

55.6 Surgical cotton is to be absorbent 100 percent cotton.

55.7 With reference to 55.1, the test is not required:

a) If circuit analysis indicates that no other component or portion of the circuit will be seriously overloaded as a result of the assumed open- or short-circuiting of another component.

b) For components in Class 2 circuits, or other circuits that need not be investigated in accordance with this standard.

c) On power semiconductor devices, if equivalent testing is accomplished during other tests.

d) On devices that have been subjected to the component evaluation specified in Functional Safety Analysis, Section 83.

e) If the circuit components are contained in a complete enclosure without ventilating openings.

56 Overload Test

56.1 The robot shall operate without a risk of fire, electric shock or injury to persons when the robot is loaded to 125 percent of its rated payload and operated through the operating space, and at its maximum speed and acceleration for 7 hours, or until thermal equilibrium is reached, or be prevented from operation by overload protection means at any time during this period. See 56.3 for explanation of thermal equilibrium.

56.2 For a robot that is obviously not intended for continuous operation, the probable intermittent or short-time operation of the robot is to be taken into consideration when conducting the temperature test.

56.3 Thermal equilibrium is considered attained when three successive temperature measurements are made with 15-minute intervals indicate no change between any two readings of more than ±1°C, relative to the ambient. Where appropriate, robotic equipment continuously operated for a minimum of 4 hours can be considered at thermal equilibrium.

57 Endurance Test

57.1 The robot shall be operated through a minimum of 100,000 cycles. The robot is to be operated through the full operating space with its rated payload, and at its maximum speed and acceleration. If there are special environmental conditions for the intended use, test conditions shall address the special environmental conditions. At the conclusion of a minimum of 100,000 cycles, a function check of the limiting devices shall be performed. The functional test can be conducted by movement of the robot arm into mechanical and electromechanical limiting devices, and the like, if provided. This test may be performed concurrently with the Flexing Test, Section 70.

58 End of Travel Hardstop Test

58.1 At the conclusion of the Endurance Test the mechanical stops shall be capable of stopping robot motion under rated load, maximum speed conditions and at maximum extension. There shall be no evidence of loss of mechanical integrity or safety function.

59 Power Loss and Power Restoration Test

59.1 During a loss of power (due to power line interruption or power shutdown) the robot shall not introduce a risk of injury to persons that can be caused by dropping a payload, or unintended movement. If the results of a risk assessment determine that a release of a payload does not result in a hazard, then loss of a payload may be permitted.To determine this, power is to be removed while the robot is operating in each mode (such as auto, manual [teach], and the like) and carrying rated payload. After a minimum of 30 minutes, power is then to be restored to determine the effect.

60 Emergency Stop Operation Test and Maximum Stopping Time and Distance or Angle Verification

60.1 While the robot is operated through the full operating space, with its rated payload, and at its maximum speed, the emergency stop function is to be actuated. The time and distance or angle to stop shall be recorded for the first three axes with greatest displacement (a robot may include less than three axes). Consideration should be given to special environmental conditions for the intended use. Stopping time and distance or angle of the robot with its highest rated payload under the stated conditions shall not exceed the specifications in the manufacturer's documentation.

60.2 For installed systems, when safety rated speed limits per Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 1: Robots, ISO 10218-1, are used to reduce the maximum speed, the test may be performed using the configured speed limit, which may be less than the maximum speed capability of the robot. The maximum payload that the system will experience shall be used.

61 Enabling Device Verification

61.1 The robot shall be operated through the full operating space, with its rated payload, during manual mode, and the enabling device shall be actuated by:

a) Release of the enabling device;

b) Compression of the enabling device beyond the center position.

Releasing the enabling device or compressing it beyond the center position shall stop hazards, including robot motion.

After returning the enabling device to the center position, an additional human action shall be required to initiate a hazardous operation, including resuming motion.

Furthermore, if the enabling device is compressed beyond the center position, the robot control system shall not enable hazardous operations when the enabling device is returned to the center position without being fully released. Hazardous operations shall only be enabled when the enabling device is fully released, then recompressed to the center position.

62 Emergency Movement of Robot Without Drive Power Test (See 35.4)

62.1 Each axis of a robot shall be tested to determine if it is capable of emergency movement without drive power.

63 Gripper (End-Effector) Test

63.1 If provided or recommended (specific accessory), the gripper assembly, or similar end-effector, shall be subjected to a minimum of 10,000 cycles of grasping and releasing (with jaws to be fully opened). The robot is operated through the full operating space at 125 percent of its rated payload, and at its maximum speed and acceleration. The gripper shall perform its intended function without unintentional release of the gripper payload which may become a projectile and introduce a risk of injury to persons. This test may be performed concurrently during any portion of the Flexing Test, Section 70.

64 Manual Mode Reduced Speed Measurement

64.1 In manual mode reduced speed, the speed of any part of the robot shall be limited:

a) When operating with the arm fully extended – each axis moved, one at a time – the speed of the tool center point (TCP) shall not exceed 250 mm/second (10 in/second); and

b) When operating with coordinated motion (simultaneous motion of any combination of robot axes), any combination of axis motion, the maximum speed of each joint shall be reduced so that the speed of any part of the robot shall not exceed 250 mm/second (10 in/second).

64.2 A singularity condition shall be checked to confirm at least one of the following:

a) The maximum speed of any part of the robot does not exceed 250 mm/second (10 in/second);

b) The robot control stops robot motion and provides a warning prior to the robot passing through or correcting for a singularity during motion initiated from the pendant;

c) The robot control generates an audible or visible warning signal and continues to pass through the singularity with the speed of any part of the robot limited to a maximum speed of 250 mm/second (10 in/second).

65 Voltage Surge Test

65.1 Line supplied robotic equipment shall be subjected to the test specified in 65.2 – 65.4. There shall be no risk of fire, electric shock, or personal injury following operation in the Automatic, and Manual modes and with the power off, to determine the effects of the transient voltage on robotic equipment operation.

65.2 Robotic equipment is to be subjected to a combination wave applied as in 65.4, three times in the positive (+) direction and three times in the negative (-) direction, at phase angles of 90 and 270 (-90) degrees as shown in Table 65.1.

Table 65.1
Voltage surge test conditions

	Applied voltage	Rise time / Fall time	Available current	Rise time / Fall time
Cord Connected Equipment	4 kV	1.2 µs / 50 µs	2 kA	8.0 µs / 20 µs
As an alternative for Cord Connected Equipment	6 kV	1.2 µs / 50 µs	500 A	8.0 µs / 20 µs
Permanently Connected Equipment	6 kV	1.2 µs / 50 µs	3 kA	8.0 µs / 20 µs

65.3 The maximum peak let-through voltage shall not exceed 300 percent of the peak working voltage for that circuit, or 300 V, whichever is greater.

Exception: Voltages do not need to be measured for Robotic equipment where transient voltages are known and controlled by a Surge Protective Device (SPD), installed at the input side of the circuit, with a suitable surge handling capability and VPR (Voltage Protection Rating) or Measured Limiting Voltage (MLV) of the SPD ≤ 300 percent of the instantaneous peak working voltage for that circuit, or 300 Volts, whichever is greater. The Surge Protective Device (SPD) shall be a Type 1, 2, 3, 1CA, 2CA or 3CA. If the Surge Protective Device (SPD) is a Type 4CA or Type 5, the Nominal Current Discharge Rating (In) shall be equal or greater to the Available Current in Table 65.1 or voltages do need to be measured.

65.4 The equipment is to be connected to the source of supply operating at rated voltage with the impulse generator connected across the equipment. For equipment operating at 3-phase, the surge is to be applied from phase to phase in all combinations, and from each phase to neutral and each phase to ground, if applicable. For single-phase equipment, the surge is to be applied from line to line, and from each line to neutral and each line to ground.

66 Dielectric Voltage-Withstand Test

66.1 General

66.1.1 The equipment shall withstand for one minute without breakdown the application of an alternating potential of 1000 V plus twice maximum rated voltage (a DC voltage can be used, for one minute, with values based on Table 84.1):