ANSI/CAN/UL 3100:2024

JOINT CANADA-UNITED STATES
NATIONAL STANDARD

STANDARD FOR SAFETY

Automated Mobile Platforms (AMPs)

ANSI/UL 3100-2024

SCC FOREWORD

National Standard of Canada

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UL Standard for Safety for Automated Mobile Platforms (AMPs), ANSI/CAN/UL 3100

First Edition, Dated May 26, 2021

Summary of Topics

This revision of ANSI/CAN/UL 3100 dated May 23, 2024 includes the following changes in requirements:

– Revision of on board charger and charging station requirements: 5.3A, 6.2, 11.1, 11.2, and 11.3;

– Revision of requirements regarding motors and motor overload: 13.3 and 56.1;

– Revision of battery requirements: 7.4, 8.1, 32.1, and 37.6;

– Removal of Section 43;

– Clarification of requirements in Section 45.4: 7.4, 8.1, 32.1, and 37.6

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

The revised requirements are substantially in accordance with Proposal(s) on this subject dated October 6, 2023 and March 1, 2024.

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ANSI/UL 3100-2024

MAY 26, 2021
(Title Page Reprinted: May 23, 2024)

ANSI/CAN/UL 3100:2024

Standard for Automated Mobile Platforms (AMPs)

First Edition

May 26, 2021

This ANSI/CAN/UL Safety Standard consists of the First Edition including revisions through May 23, 2024.

The most recent designation of ANSI/UL 3100 as an American National Standard (ANSI) occurred on May 23, 2024. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, Preface or SCC Foreword.

This standard has been designated as a National Standard of Canada (NSC) on May 23, 2024.

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PREFACE

This is the First Edition of the ANSI/CAN/UL 3100 Standard for Automated Mobile Platforms (AMPs).

ULSE is accredited by the American National Standards Institute (ANSI) and the Standards Council of Canada (SCC) as a Standards Development Organization (SDO).

This Standard has been developed in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization.

This ANSI/CAN/UL 3100 Standard is under continuous maintenance, whereby each revision is approved in compliance with the requirements of ANSI and SCC for accreditation of a Standards Development Organization. In the event that no revisions are issued for a period of four years from the date of publication, action to revise, reaffirm, or withdraw the standard shall be initiated.

In Canada, there are two official languages, English and French. All safety warnings must be in French and English. Attention is drawn to the possibility that some Canadian authorities may require additional markings and/or installation instructions to be in both official languages.

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

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This Edition of the Standard has been formally approved by the Technical Committee (TC) on Automated Mobile Platforms (AMPs), TC 3100.

This list represents the TC 3100 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

TC 3100 Membership

Name	Representing	Interest Category	Region
Arab, Aliasghar	Agile Safe Autonomy by Narranj LLC	Testing & Standards Organization	USA
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Winrich, Marvin	Rockwell Automation	Supply Chain	USA
Woods, Benjamin	Rivian Automotive	Commercial/Industrial Users	USA
Yang, Shuping	Beijing Research Institute of Automation for Machinery Industry	International Delegate	China

International Classification for Standards (ICS): 25.040.30

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This Standard is intended to be used for conformity assessment.

The intended primary application of this standard is stated in its scope. It is important to note that it remains the responsibility of the user of the standard to judge its suitability for this particular application.

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INTRODUCTION

1 Scope

1.1 These requirements cover battery-operated mobile platforms with or without a payload, as specified in 1.2. These devices are intended to be used indoors only or as outdoor use devices in a commercial or industrial environment. The device is battery powered using either lead acid batteries or lithium based batteries that, if rechargeable, are charged through a conductive system while either on board or off board the device.

1.2 Mobile platforms that are covered by this Standard are intended for lifting, carrying, product picking, towing, and the like. These actions may be provided by a gripping attachment, suction attachment, scope attachment, and the like, to lift or carry the load.

1.3 Portions of a system, such as the charger, that are located off board the AMP, are intended to be installed in accordance with the National Electrical Code (NEC), NFPA 70 and the Canadian Electrical Code (CE Code), CSA C22.1.

1.4 This Standard does not include requirements for industrial robots, which are covered under the Standard for Robots and Robotic Equipment, UL 1740 and Industrial Robots and Robot Systems, CSA Z434. A robotic manipulator that is in compliance with these standards may be used as the payload for the integrated system.

1.5 This Standard does not include requirements for Automatic Guided Vehicles or Automated Vehicles that function as commercial and industrial floor cleaning equipment. This equipment is covered under the standard for Particular Requirements for Rechargeable Battery-Operated Commercial Robotic Floor Treatment Machines with Traction Drives, CSA C22.2 No. 336.

1.6 This Standard does not cover battery powered industrial trucks that are rated Type E, EE, ES, or EX, and marked as such, as defined in the Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations, NFPA 505. These truck types are covered under the Standard for Electric-Battery-Powered Industrial Trucks, UL 583 and the Guide for the Investigation of Electric-Battery-Powered Industrial Trucks, ULC/ORD-C583.

1.7 Automated mobile platforms are not provided with “forks” and are not intended to operate as “forklifts.” Any device with that capability is considered an industrial truck and is evaluated as indicated in 1.6.

1.8 This standard does not cover products intended to transport persons.

2 Components

2.1 A component of a product covered by this Standard shall:

a) Comply with the requirements for that component as specified in this Standard;

b) Be used in accordance with its rating(s) established for the intended conditions of use; and

c) Be used within its established use limitations or conditions of acceptability.

2.2 A component of a product covered by this Standard is not required to comply with a specific component requirement that:

a) Involves a feature or characteristic not required in the application of the component in the product;

b) Is superseded by a requirement in this Standard; or

c) Is separately investigated when forming part of another component, provided the component is used within its established ratings and limitations.

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

2.4 A component that is also intended to perform other functions such as overcurrent protection, ground-fault circuit-interruption, surge suppression, any other similar functions, or any combination thereof, shall comply additionally with the requirements of the applicable standard(s) that cover devices that provide those functions.

3 Units of Measurement

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

4 Referenced Publications

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

4.2 The following standards are referenced in this Standard, and portions of these referenced standards may be essential for compliance.

ANSI Z97.1, *Safety Glazing Materials Used In Buildings – Safety Performance Specifications And Methods Of Test*

ASTM E230/E230M, *Standard Specification and Temperature-Electromotive Force (emf) Tables for Standardized Thermocouples*

ASTM D1525, *Standard Test Method For Vicat Softening Temperature Of Plastics*

21 CFR Part 1040 series, *Performance Standards for Light-Emitting Products*

CSA C22.1, *Canadian Electrical Code (CE Code)*

CSA C22.2 No. 0.15, *Adhesive Labels*

CSA C22.2 No. 0.2, *Insulation Coordination*

CSA C22.2 No. 0.8, *Safety Functions Incorporating Electronic Technology*

CSA C22.2 No. 14, *Industrial Control Equipment*

CSA C22.2 No. 0.17, *Evaluation of Properties of Polymeric Materials*

CSA C22.2 No. 49, *Flexible Cords and Cables*

CSA C22.2 No. 66.1, *Low Voltage Transformers – Part 1: General Requirements*

CSA C22.2 No. 66.2, *Low Voltage Transformers – Part 2: General Purpose Transformers*

CSA C22.2 No. 66.3, *Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers*

CSA C22.2 No. 75, *Thermoplastic - Insulated Wires and Cables*

CSA C22.2 No. 94.2, *Enclosures for Electrical Equipment, Environmental Considerations*

CSA C22.2 No. 96, *Portable Power Cables*

CSA C22.2 No. 100, *Motors and Generators*

CSA C22.2 No. 107.1, *Power Conversion Equipment*

CSA C22.2 No. 107.2, *Battery Chargers*

CSA C22.2 No. 182.3, *Special Use Attachment Plugs, Receptacles, and Connectors*

CSA C22.2 No. 210, *Appliance Wiring Material Products*

CSA C22.2 No. 223, *Power Supplies with Extra Low Voltage Class 2 Outputs*

CSA C22.2 No. 248 series, *Low Voltage Fuses*

CSA C22.2 No. 336, *Particular Requirements for Rechargeable Battery-Operated Commercial Robotic Floor Treatment Machines with Traction Drives*

CSA C22.2 No. 60950-1, *Information Technology Equipment – Safety – Part 1: General Requirements*

CSA C22.2 No. 60335-2-29, *Household and Similar Electrical Appliances – Safety – Part 2-29: Particular Requirements for Battery Chargers*

CSA C22.2 No. 62133-2, *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 – Part 2: Lithium Systems*

CSA C22.2 No. 62368-1, *Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements*

CSA Z434, *Industrial Robots and Robot Systems*

IEC 60068-2-64, *Environmental Testing – Part 2-64: Tests – Test Fh: Vibration, Broadband Random and Guidance*

IEC 60417 (No. 5041), *Graphical Symbols for Use on Equipment*

IEC 60584-1, *Thermocouples – Part 1: EMF specifications and tolerances*

IEC 61508-1, *Electrical/Electronic/Programmable Electronic Safety-Related Systems – Part 1: General Requirements*

IEC 62061, *Safety Of Machinery – Functional Safety Of Safety-Related Electrical, Electronic And Programmable Electronic Control Systems*

IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*

ISO 10218-1, *Robots And Robotic Devices – Safety Requirements For Industrial Robots – Part 1: Robots*

ISO 12100, *Safety Of Machinery – General Principles For Design – Risk Assessment And Risk Reduction*

ISO 12405-1, *Electrically Propelled Road Vehicles – Test Specification for Lithium-Ion Traction Battery Packs and Systems – Part 1: High-Power Applications*

ISO 13849-1, *Safety of Machinery – Safety Related Parts of Control Systems – Part 1: General Principles for Design*

ISO 13849-2, *Safety of Machinery – Safety Related Parts of Control Systems – Part 2: Validation*

JIS C 1602, *Thermocouples*

NFPA 70, *National Electrical Code*

NFPA 79, *Electrical Standard For Industrial Machinery*

NFPA 505, *Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations*

SAE J1127, *Low Voltage Battery Cable*

SAE J1128, *Low Voltage Primary Cable*

UL 50E, *Enclosures for Electrical Equipment, Environmental Considerations*

UL 62, *Flexible Cords and Cables*

UL 66, *Fixture Wire*

UL 83, *Thermoplastic-Insulated Wires and Cables*

UL 94, *Tests for Flammability of Plastic Materials for Parts in Devices and Appliances*

UL 248 series, *Low Voltage Fuses*

UL 275, *Automotive Glass-Tube Fuses*

UL 275A, *Outline for Investigation for Automotive Blade Type Fuses*

UL 506, *Specialty Transformers*

UL 508, *Industrial Control Equipment*

UL 583, *Electric-Battery-Powered Industrial Trucks*

UL 723, *Test for Surface Burning Characteristics of Building Materials*

UL 746A, *Polymeric Materials – Short Term Property Evaluations*

UL 746B, *Polymeric Materials – Long Term Property Evaluations*

UL 746C, *Polymeric Materials – Use in Electrical Equipment Evaluations*

UL 758, *Appliance Wiring Material*

UL 796, *Printed-Wiring Boards*

UL 840, *Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment*

UL 969, *Marking and Labeling Systems*

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

UL 1004-1, *Rotating Electrical Machines – General Requirements*

UL 1004-2, *Impedance Protected Motors*

UL 1004-3, *Thermally Protected Motors*

UL 1004-7, *Electronically Protected Motors*

UL 1012, *Power Units Other Than Class 2*

UL 1063, *Machine-Tool Wires and Cables*

UL 1236, *Battery Chargers for Charging Engine-Starter Batteries*

UL 1276, *Outline for Investigation for Welding Cable*

UL 1310, *Class 2 Power Units*

UL 1426, *Electrical Cables for Boats*

UL 1561, *Dry-Type General Purpose and Power Transformers*

UL 1564, *Industrial Battery Chargers*

UL 1740, *Robots and Robotic Equipment*

UL 1977, *Component Connectors for Use in Data, Signal, Control and Power Applications*

UL 1989, *Standby Batteries*

UL 1998, *Software in Programmable Components*

UL 2202, *Electric Vehicle (EV) Charging System Equipment*

UL/ULC 2271, *Batteries for Use in Light Electric Vehicle (LEV) Applications*

UL/ULC 2580, *Batteries for Use in Electric Vehicles*

UL 2726, *Outline for Investigation for Battery Lead Wire*

UL 2734, *Outline for Investigation for Connectors and Service Plugs for Use with On-Board Electrical Vehicle (EV) Charging Systems*

UL 4127, *Outline for Investigation for Low Voltage Battery Cable*

UL 5085-1, *Low Voltage Transformers – Part 1: General Requirements*

UL 5085-2, *Low Voltage Transformers – Part 2: General Purpose Transformers*

UL 5085-3, *Low Voltage Transformers – Part 3: Class 2 and Class 3 Transformers*

UL 60335-1, *Safety of Household and Similar Electrical Appliances, Part 1: General Requirements*

UL 60950-1, *Information Technology Equipment – Safety – Part 1: General Requirements*

UL 62133-2, *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, Part 2: Lithium Systems*

UL 62368-1, *Audio/Video, Information and Communication Technology Equipment – Part 1: Safety Requirements*

ULC/ORD-C583, *Guide for the Investigation of Electric-Battery-Powered Industrial Trucks*

5 Glossary

5.1 The following terms apply for this document.

5.2 ACTUATOR – A part, system, or sub-system that engages the load for manipulation and/or support.

5.3 AMP PAYLOAD – A mass supported by or pulled by the mobile platform which could include product, a manipulator, a combination of the two, or other.

5.3A CHARGING UNIT – An accessory for the AMP, which is used for charging the AMP's battery.

5.4 LIVE PART – A conductive part, such as metal, within the unit that during intended use has a potential difference with respect to earth ground or any other conductive part.

5.5 MANIPULATOR – Mechanism consisting of an arrangement of segments, jointed or sliding relative to one another.

Note: A manipulator includes robot actuators.

5.6 RESTRICTED ACCESS LOCATION – A location where equipment is operated under conditions where access from unauthorized persons is prohibited and unauthorized access is detected by protection means which will cause a shutdown or other function to mitigate risks from the unauthorized access.

5.7 RISK OF ELECTRIC SHOCK – the condition that exists between any two conductive parts or between a conductive part and earth ground if the open circuit voltage exceeds the limits in Table 5.1, under normal or abnormal conditions.

Table 5.1
Risk of Electric Shock Threshold

Waveform type	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[a]	60 V	30 V
[a] 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.		

5.8 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.

5.9 ROBOT ACTUATOR – Powered mechanism that converts energy to effect motion of the manipulator.

Note: Energy can be electrical, hydraulic, pneumatic, or more.

5.10 WET LOCATION – AMPs used in areas that are exposed to weather, such as outdoors or other applications of water exposure, such as spraying, cleaning, and the like.

CONSTRUCTION

6 General

6.1 Unless otherwise stated, compliance with the requirements in this Standard is determined by evaluation and testing on a representative model of the device under evaluation.

6.2 AMPs covered by this Standard shall be provided with a means of connection to the external charging device, with the exception of applications where batteries are intended to be removed for charging. While connected to the charger, the AMP shall not be capable of being energized in a manner that would allow movement of the AMP that would strain connections to the charger or cause the

connection to break under load, unless evaluated for those conditions. Energizing systems for other than operation, such as communications, is allowed during charging.

6.3 No modification of the AMP shall be permitted to be performed by the user. The user shall not be instructed on how to modify the AMP. Instructions shall indicate that no modification is allowed, see 78.6.

6.4 All AMPs are considered suitable for use in an ordinary location. For any AMP that is intended to be operated in an area that is considered classified, further evaluation to determine suitability in that location is required.

6.5 AMPs are intended for indoor use only or as outdoor use devices. AMPs shall include the enclosure type rating on its nameplate label. See Environmental Considerations, Section 33. For indoor use only AMPs, the default ambient range is 0 °C to 40 °C (32 °F to 104 °F); and for indoor/outdoor use AMPs, the default ambient range is -30 °C to 40 °C (-22 °F to 104 °F). A manufacturer may choose an ambient range that extends outside this default range, such as a temperature lower than the lower limit or above the upper limit, but all AMPs shall meet the default range as a minimum.

6.6 A risk assessment covering the equipment and its intended function is to be completed to determine compliance with this standard. Any hazard that is identified shall be provided with a means to mitigate that risk. Any requirement that pertains to a hazard that has been deemed mitigated by design or intended use may be omitted from the overall evaluation. For example, if a product is used in a restricted access location where no humans are present, the bumper activation force is no longer applicable since it applies to forces exerted on humans. See the requirements and guidance provided in Risk Assessment, Section 21.

6.7 AMPs covered by this standard shall be evaluated for functionality in relation to safety systems that are used to protect people and property in the vicinity of the AMP or near the AMPs defined travel path as described in 6.6. Human overrides are allowed to shut down the AMP but shall not be the primary means of protecting people and property. See Risk Assessment, Section 21 and Functional Safety, Section 22.

7 Battery and Battery Management Systems

7.1 The battery provided with the AMP shall be in accordance with Lithium Based Batteries, Section 8 or Lead Acid Batteries, Section 9.

7.2 For battery packs that are provided with an integral battery management system, the battery management system shall be evaluated as part of the battery pack in accordance with the requirements outlined below. If the battery management system or a portion of the battery management system resides in external components, such as the charger, then the combination of the external components and the battery pack are critical and shall be evaluated together in accordance with this Standard, including faults in the battery management system on parts located outside the battery pack.

7.3 For swapped/removable batteries, the battery pack or its connections shall be keyed or configured in a manner that will prevent reverse polarity connections of the battery when it is replaced.

7.4 The terminals of a battery shall be protected or located so they are unlikely to be inadvertently short-circuited during installation, replacement, or while in service.

8 Lithium Based Batteries

8.1 Lithium based battery packs shall be provided with an appropriate Battery Management System (BMS) and shall be designed to withstand anticipated abuse conditions for the AMP involved without resulting in a risk of fire, shock, injury or explosion. A lithium-based battery pack used in AMPs covered by this standard shall be in accordance with one of the following:

a) UL/ULC 2580;

b) UL/ULC 2271;

c) UL 62133-2 and CSA C22.2 No. 62133-2; or

d) IEC 62619

8.2 A lithium based battery pack in accordance with 8.1(c) shall comply with the requirements in the Overcharge Test, Section 58, with single fault conditions in the battery control circuits; Imbalanced Charging Test, Section 59; Vibration Test, Section 60; Shock Test, Section 61; and the Thermal Cycling Test, Section 62.

8.3 A lithium-based battery pack that relies on additional battery management external to the battery pack shall be subjected to the tests in 8.2 including single fault conditions in the battery control circuits external to the battery pack.

9 Lead Acid Batteries

9.1 Lead acid batteries shall be of the insulated type complying with UL 1989 and measures shall be taken to reduce the risk of connections becoming loose and causing arcing or overheating.

9.2 For lead acid batteries that are enclosed, means shall be provided to vent the off-gassing during charging. No arcing or sparking parts shall be present in the battery compartment.

10 Accessory Batteries

10.1 Batteries used to power accessories, and provided as an integral part of the accessory, shall be in accordance with the applicable standard for that accessory.

11 Chargers

11.1 For charging batteries, whether the battery is located on board the AMP or the battery is intended to be removed from the AMP, the charger or charging unit shall comply with one of the following:

a) UL 1310 and CSA C22.2 No. 223.

b) UL 1012 and CSA C22.2 No. 107.1.

c) UL 60950-1 and CSA C22.2 No. 60950-1.

d) UL 62368-1 and CSA C22.2 No. 62368-1.

e) UL 2202 and CSA C22.2 No. 107.1.

f) UL 1564 and CSA C22.2 No. 107.2.

g) UL 1236 and CSA C22.2 No. 107.2.

h) UL 60335-1 and CSA C22.2 No. 60335-2-29.

Note: If recharging of the battery is intended to be performed outdoors, then the charger or charging unit and its connection to the AMP shall be suitable for outdoor use. If the AMP is intended for outdoor use but is only intended to be charged indoors, this should be indicated in the Operating Instructions, Section 80.

11.2 If motion during charging would present a hazard, as determined by risk assessment per Section 21, AMP motion shall be prevented.

11.3 When charging via a charging unit, the AMP and associated charging unit shall be designed such that the reachable charging contacts are only activated when the AMP is connected to the charging unit.

12 Transformers

12.1 Transformers provided as part of an AMP, shall comply with one of the following:

a) UL 506;

b) UL 1561; or

c) UL 5085-1 and CSA C22.2 No. 66.1, and one of the following:

1) UL 5085-2 and CSA C22.2 No. 66.2; or

2) UL 5085-3 and CSA C22.2 No. 66.3.

13 Motors

13.1 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.

13.2 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.

13.3 The overload protection required by 13.2 shall consist of one of the following:

a) Impedance protection complying with the requirements in UL 1004-2 and UL 1004-1 and CSA C22.2 No. 100; or

b) Thermal protection complying with the applicable requirements in UL 1004-3 and UL 1004-1 and CSA C22.2 No. 100;

c) Electronically protected motors shall comply with the applicable requirements in UL 1004-7, UL 1004-1, CSA C22.2 No. 100 and CSA C22.2 No. 0.8; or

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

14 Printed Wiring Boards

14.1 A printed-wiring board shall comply with UL 796.

14.2 A printed-wiring board containing circuits involving a risk of fire or electric shock shall have a flame rating as specified in requirements in UL 94, and CSA C22.2 No. 0.17, of V-2 minimum. Printed-wiring boards not involving a risk of fire or electric shock shall be rated HB minimum.

14.3 A conformal coating employed on the surface of a printed-wiring board, intended to be used for the acceptance of reduced spacings as described in Spacings and Separation of Circuits, Section 41, may be acceptable if it complies with UL 796.

15 Stop Function

15.1 The AMP shall be provided with a stop safety function where the intended result is to stop within the stopping time or distance specified by the manufacturer. This safety function shall be in accordance with Functional Safety, Section 22, as applicable.

16 Lasers

16.1 Equipment which employs laser-radiation shall be provided with documentation of compliance, as applicable, with the Federal requirements 21 CFR Part 1040 (Lasers) of the Department of Health and Human Services (DHHS). This includes determination of laser class, instructions, markings, and protective components. The laser shall be class 1 or shall be included as part of the risk assessment.

17 Lamps / Horns / Alarms / Indicators

17.1 An AMP shall be provided with a signaling device to indicate when it is ready to start moving and when it is moving. The signaling device shall be either audible or visual. The visual signal shall be readily visible to people in the area of the AMP movement from any location around the AMP.

17.2 The signaling devices in 17.1 are allowed to be configurable based on the end product integration. This includes adjusting light intensity, sound volume, and the like. The means of configuration shall be set at the time of integration and then once configured shall be provided with a means to prevent changes to those configuration settings by anyone other than the trained and authorized personnel.

17.3 The visual indicator shall indicate the travel direction if the AMP is capable of moving in more than one direction. The ability to move in more than one direction refers to forward, reverse, or sideways.

17.4 The visual indicator shall comply with all of the following:

a) The visual indicator shall follow the guidance of NFPA 79. Yellow (amber) is the default color for this type of indicator.

b) A visual indicator, subjected to the effects of vibration in use, shall:

1) Not be a screw-in type indicator, and

2) Not be a filament type indicator.

18 Object Detection and Avoidance

18.1 AMPs shall be provided with object detection and avoidance systems to prevent injury or other hazards due to impact of the AMP with persons in the travel path. Object detection and avoidance systems may be provided with a means to mute the object detection safety function when alternate risk reduction is provided to mitigate the risk of impact with an object, e.g., safety-reduced speed, and the like, when an AMP is approaching a load or operating in a restricted access location.

18.2 With reference to 18.1, the muting of the object detection and avoidance system shall not be performed when operating in a normal area where personnel are allowed to be located or to enter freely. The controls used to program or set the mute function shall be provided with a means to prevent changes to those settings by anyone other than the trained and authorized personnel. Additionally, if the AMP goes into a power down mode, due to a depleted battery or other reason, the muting shall go to the off state (unmuted) and object detection and avoidance protection shall be turned on and active upon re-energization.

18.3 For object detection and avoidance systems, object detection in the form of object sensing at a distance from the AMP shall be required. As a minimum, the object sensing shall be in the direction of travel. Additional directional sensing is required if deemed necessary by the risk assessment

18.4 Object detection that is monitoring the travel path shall be capable of monitoring the travel path such that people located within the travel path would be detected. If the AMP can choose its path or direction of movement, then the object detection shall also be capable of monitoring the area to each side of the AMP before a change in direction so that the AMP does not turn into people.

18.5 Object detection that is monitoring the travel path shall have an effective monitoring distance that exceeds the distance required to safely stop the AMP when it is fully loaded and operating at maximum speed.

18.6 For all AMPs using a bumper or touch sensor as a protection device in lieu of object detection, the bumper or touch system shall be designed and integrated to comply with (a) through (d) below. The bumper system or touch sensors integration shall be analyzed to determine the proper location of the bumper or sensor to reduce the risk if the contact can cause a fall. Multiple bumpers or sensors could be required. The bumper or touch sensor shall also comply with the Bumper/Touch Sensor Activation Test, Section 68.

a) The AMP shall exert not more than a maximum of 100 N (22.5 lbf) impact to a person;

b) The bumper or touch sensor shall actuate before the AMP exerts more than 100 N (22.5 lbf) to the person;

c) The AMP shall immediately cease motive power once the bumper or touch sensor is activated; and

d) The bumper and touch sensor shall be located so that the impact does not cause a person to fall.

18.7 The reliability and functionality of the object detection and avoidance system, or bumper/touch sensor system, shall comply with the functional safety analysis in accordance with Functional Safety, Section 22.

18.8 The object detection and avoidance system, regardless of type of system, shall not be capable of being inadvertently defeated by environmental aspects, such as lack of light, direct sunlight exposure, objects left on the AMP, and the like.

18.9 Instructions to the user shall include the required training about the use, hazards, protective measures and the limitations of the protective measures, for example:

a) AMPs have their own travel paths – keep out of the AMP travel path!

1) DO NOT walk in the travel path or directly toward the AMP.

2) DO NOT run towards the AMP.

b) The object detection and stopping of the AMP does not address approaches from the side!

1) DO NOT cross into the travel path while the AMP is in motion.

c) AMPs are not intended to transport people!

1) DO NOT attempt to board or ride the AMP.

d) AMPs can move without notice, particularly if no obstacle is detected!

1) DO NOT attempt to crawl over or climb across the AMP.

2) DO NOT attempt to use the AMP as a stepladder.

18.10 Instructions to the user shall indicate that the AMP shall not be routed through doorways or pathways that are intended for persons unless there is sufficient room for both to pass through without risk. If it is deemed that sufficient room is available, there shall be designated AMP and people paths. The instructions shall indicate that the AMP shall not be routed near stairways, edges of raised platforms, and the like. If the AMP is provided with a system of sensing that allows it to identify stairways and the like, and that system complies with Functional Safety, Section 22, then the instructions may be omitted.

19 Brakes and Braking Distance

19.1 Braking systems shall be provided on all AMPs. The braking system shall perform the functions of slowing the AMP for motion control and hazard avoidance, stopping the AMP for motion control and hazard avoidance, and holding (restraining) the AMP from moving when it is required to be stationary, such as during loading/unloading or charging.

19.2 Braking systems shall automatically operate to safely stop the AMP when an object is detected in the travel path. Braking systems shall also automatically operate to safely stop the AMP and minimize coasting in the event of power loss including power loss due to a fault.

19.3 Braking systems shall be coordinated with any object sensing devices in order to stop the AMP within the distance that the sensors can detect the object. The AMP shall be capable of stopping while fully loaded prior to contacting the detected object. For AMPs that use a bumper or touch system for detection, the braking system shall activate upon detection in a manner that prevents a hazard in accordance with Object Detection and Avoidance, Section 18.

19.4 The braking action of the AMP shall not cause instability of the AMP or its load, if any. The AMP shall be provided with instructions detailing proper loading such that braking will not cause load stability due to misloading.

19.5 Either separate or as part of the overall braking system, an emergency brake shall be provided that will stop the AMP in a safe manner once a fault is detected in any system that is included as part of the overall motion control of the AMP.

19.6 Either separate or as part of the overall braking system, a parking brake shall be provided to prevent inadvertent movement of the AMP when it is intended to be parked, such as while charging.

19.7 Either separate or as part of the overall braking system, a service brake shall be provided such that if the AMP requires maintenance and it is being moved manually (e.g., pushing), the person or persons moving the AMP can apply brakes to stop or slow the motion of the AMP while it is being manually moved.

19.8 With reference to 19.5, 19.6, and 19.7, these brake functions can be separate systems or components or can be part of one overall system. If the brake functions are included, at least one braking system shall satisfy the requirements. The brakes can be electromechanical, electrical or mechanical in nature.

19.9 Electromechanical brakes that operate at hazardous voltage levels shall comply with Miscellaneous Devices, in UL 508 and the applicable requirements of CSA C22.2 No. 14. Mechanical brakes shall be subjected to the Brake Test, Section 65.

19.10 The braking system, and its components and functions, shall be included in the risk assessment and comply with functional safety analysis in accordance with Risk Assessment, Section 21, and Functional Safety, Section 22.

20 Ramp/Slope Operation

20.1 The AMP shall be capable of meeting all requirements for operation and control on a level grade, defined as an even grade and a sloped grade up to 3 % of grade. If the AMP can operate on a sloped grade above 3 % based on manufacturer's specifications, then the AMP shall be evaluated for use on level grade and that manufacturer's specified maximum grade. AMPs not evaluated for use on a grade exceeding 3 % shall be marked in accordance with 76.8.

20.2 The sloped grade mentioned in 20.1 includes both uphill and downhill operation.

21 Risk Assessment

21.1 A risk assessment for the AMP shall be completed by the manufacturer and shall address the risks of fire, shock, and injury associated with the use of the AMP. The risk assessment shall be completed based on the following:

a) Identify the conditions of use associated with charging, discharging and general use of the AMP electrical system. The conditions of use shall take into account normal and reasonably foreseeable misuse.

b) Identify the potential hazards associated with the conditions of use identified in (a) under normal conditions and single fault conditions within the electrical system of the AMP. Subsequent faults due to the single fault condition shall be included.

c) Identify the protective measures or other protective means provided or implemented in order to mitigate the hazards identified in (b).

Note: A risk assessment following the guidelines in ISO 12100 is considered to be in compliance with the process described above.

21.2 The process to complete the risk assessment outlined in 21.1 may require more than one iteration to address all potential hazards. The protective measures or other risk mitigation means may create additional use conditions or potential hazards. In order to have a complete and robust risk assessment, the process should be reviewed for each iteration to assess if additional analysis is required.

21.3 When conducting the risk assessment, active devices shall not be relied on as the sole means to safely mitigate a risk unless:

a) They are provided with a redundant passive protection device; or

b) They are provided with redundant active protection that remains functional and energized upon loss of main power or failure of the first level active protection; or

c) They are determined to fail safe upon loss of power to the active circuit; or

d) They are part of a protective circuit that has been shown to comply with an appropriate functional safety requirements as outlined in Functional Safety, Section 22, with a safety level defined by a corresponding hazard and risk analysis.

21.4 Once the risk assessment is complete, the manufacturer shall provide that risk assessment as part of the product evaluation. The risk assessment provides the inputs into the functional safety evaluation of Functional Safety, Section 22.

21.5 The protective measures or other risk mitigation means shall be shown to perform the associated risk mitigation reliable. This shall be accomplished through functional safety evaluations in accordance with Functional Safety, Section 22.

22 Functional Safety

22.1 For all components, circuits, and systems relied upon to provide a safety function as identified in the risk assessment, see Section 21, Risk Assessment, functional safety evaluations are required unless the reliability of the component, circuit or system is already assessed by the requirements in this Standard. Examples of safety functions may include, but are not limited to, load stability, load arrangement, oversized load detection, deviation from travel path, object sensing, low battery, safe starting, braking force, bumper activation, loss of braking, loss of power, maximum load determinations, and the like.

22.2 Functional safety criteria can be found in one of the following standards. These standards shall be used to judge functional safety of a component, circuit or system that is relied on for safety in accordance with 22.1.

a) UL 991, UL 1998, and CSA C22.2 No. 0.8;

b) IEC 61508, all parts

c) ISO 13849-1 and ISO 13849-2

d) IEC 62061

22.3 Due to the fact that all designs are different, and the combinations and methods of protective measures are numerous, this Standard does not assign performance levels or safety integrity levels. These shall be assigned based on the risk assessment Section 21, Risk Assessment, and the guidance in the specific functional safety standard in 22.2. These values, once assigned, will guide the functional safety evaluation.

23 Open Bus Bar Connection Systems

23.1 An AMP that uses an open bus bar connection system to automatically conductively connect to the charging system shall be constructed so that the connection system is located in an ordinary location indoors. The open bus bar system on the AMP shall also be protected from exposure to elements. Installation instructions shall include this information.

23.2 The connection system shall have maximum operating voltages less than 60 Vdc and shall not allow make and break under load unless evaluated for that use.

23.3 Copper bus bars shall be used. If the bus bars are bent at any point in the design and fabrication of the connection, there shall be no evidence of cracks in the copper.

23.4 The current density of the bus bar shall not exceed the values specified in Table 23.1 unless the bus bar has characteristics that do not result in maximum bus bar temperatures exceeding the values in Table 47.1. Forced air ventilation is allowed to maintain the bus bar temperature below the values in Table 47.1.

Table 23.1
Rating and Sizes of Single Bus Bars – 800 A Maximum

Current rating in A	Copper bus			
	Bus size[a,b]		Cross section	
	mm	(inch)	mm^2	($inch^2$)
225	3.2 by 22.2	(0.125 by 0.875)	70.3	(0.109)
400	6.4 by 38.1	(0.250 by 1.500)	242.0	(0.375)
600	6.4 by 50.8	(0.250 by 2.000)	322.6	(0.500)
800	6.4 by 76.2	(0.250 by 3.000)	483.9	(0.750)

NOTES –

1 See 23.5 – 23.7. The minimum contact area at a clamped joint shall provide not less than 6.5 cm^2 (1 square inch) per 200 A.

[a] A bus bar having other dimensions is allowed when it has not less than the cross-sectional area specified in the table and when it has equivalent rigidity.

[b] Minimum conductivity of 55 % of International Annealed-Copper Standard.

23.5 The cross section of the bus shall not be reduced by more than 5 % due to rounding or shaping.

23.6 Removing part of the bus material for slots or holes (whether used or not) is allowed when:

a) The remaining material at any cross section along the length of the bus bar has at least 70 % of the required ampacity in accordance with Table 23.1 and 23.5, and

b) The remaining metal in any 152 mm (6 inch) length of bus is at least 93 % of the metal of a bus having the required ampacity in accordance with Table 23.1 and 23.5. For example, a 25.4 mm (1 inch) wide bus is capable of having 7.1 mm (9/32 inch) holes on 25.4 mm centers or a 102 mm (4 inch) wide bus is capable of having 10.3 mm (13/32 inch) wide slots 81.3 mm (3.2 inch) long every 152.4 mm (6 inch).

Exception: The above limitations do not apply to a bus bar having characteristics that do not result in maximum bus bar temperatures exceeding the values specified in Table 47.1 under the test conditions indicated in Temperature Test, Section 47.

23.7 The limitations on current density mentioned in Table 23.1 do not apply to a:

a) Connecting strap, bus, or similar device comprising a part of a circuit breaker, switch, or fuseholder employed in the unit.

b) Portion of a strap, bus, jumper, or similar part adjacent and connected to a terminal of a switch, circuit breaker, or fuseholder, and not more than 25.4 mm (1 inch) from the terminal, when a reduced cross section in that portion is required because of the recessing of the terminal or because of barriers adjacent to it.

24 Parts Subject to Pressure

24.1 Any part or system within an AMP that is subjected to vapor or liquid pressure shall be rated and found suitable for the application. Pressurized systems shall be subjected to the Hydrostatic Strength Test, Section 70.

24.2 For any pressure relief valves that are provided in the pressurized system, the risk assessment of Section 21, Risk Assessment, shall include assessment of risk associated with discharge of the pressure relief valve and failure of the pressure relief valve. A pressure relief valve shall be installed such that the valve drains back to a reservoir or to open air. If venting to open air, the discharge opening shall be located

and directed so that no moisture is discharged onto electrical parts and so that no discharge is directed towards persons in the area.

25 Load Handling Device

25.1 An AMP provided with an actuator for load handling shall be provided with a function that, when activated, will stop any further movement of the actuator. Activation of this function shall not compromise the actuators ability to support the load. A means shall be provided, by way of a manual control or other method, to allow the load to be positioned safely on a supporting structure or the ground before releasing the load.

25.2 The AMP shall be provided with a system or interlock that prevents movement of the AMP if the actuator is not seated in the travelling position as indicated by the manufacturer. The positioning of the actuators load engaging elements, such as arms, clamp pads, friction pads, or platforms, is allowed within the working envelope of the AMP as defined by the manufacturer.

25.3 Visible or audible signals shall be provided to indicate that the actuator is prepared to move or is moving. This indicator can be an individual signal or combined with the movement indicator referenced in 17.1. In both cases, the visual indicator shall comply with the requirements in Lamps / Horns / Alarms / Indicators, Section 17.

25.4 A means shall be provided to limit the motion of any robot actuator unless the design anticipates and intends for a full range of motion. Limiting means may include mechanical stops to restrict motion or may include electrical components or programmable components to limit the range of motion. When mechanical stops are provided, they shall be capable of stopping the motion of the robot actuator under the conditions of rated load, maximum speed, and maximum extension. The mechanical means shall comply with the Endurance of Actuator Stop Means, Section 71. When electrical or programmable components are provided to restrict the motion of the actuator, the circuit or component shall be included in the risk assessment of Section 21, Risk Assessment, and shall comply with the functional safety analysis of Section 22, Functional Safety.

25.5 For AMPs that have load capacity ratings, the manufacturer shall specify the maximum rated load capacity of the AMP and/or the actuator in kilograms (pounds).

25.6 Any electrical or programmable means that is provided, and intended to act as risk mitigation by preventing overloading of the AMP's loading capacity, shall comply with the functional safety analysis in accordance with Functional Safety, Section 22.

26 Towing Capacity

26.1 For AMPs that have towing capability, the manufacturer shall specify the maximum drawbar pull force and the normal rated drawbar pull force for the AMP in Newtons (pounds).

27 Enclosure of Hazardous Live Parts and Moving Parts

27.1 AMPs shall be constructed and assembled so that they 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, access to hazardous electrical or moving parts, or other serious defects.

27.2 The enclosure shall prevent molten metal, burning insulation, flaming particles, or similar materials from falling on combustible materials outside the enclosure.

27.3 The frame or chassis of the AMP shall not be used to carry current during intended operation.

27.4 Contactors and fuses shall be located so as to be readily accessible for servicing, such as complete replacement or the replacement of contacts and inspection after the removal of a cover or covers. Other arcing and operating parts shall be accessible for servicing and inspection.

27.5 A part, such as a dial, display face, or nameplate, that serves as a functional part of the enclosure shall comply with the enclosure requirements in this Standard.

27.6 An AMP that is intended for outdoor operation shall comply with the environmental considerations in accordance with Environmental Considerations, Section 33. These requirements apply to the enclosures that are relied on to protect the user. Structural parts of the AMP that are not related to electrical safety are not included.

28 Metallic Materials

28.1 A metallic enclosure shall comply with the requirements for the Impact Test, Section 64.

28.2 A metallic enclosure constructed of aluminum, steel, stainless steel, or similar metals is considered to comply with flammability requirements without test. Magnesium shall not be used as an enclosure material.

28.3 A cast-metal enclosure shall be at least 3.2 mm (1/8 inch) thick at every point and more than 3.2 mm (1/8 inch) thick at reinforcing ribs and door edges. Malleable iron and die-cast or permanent mold cast aluminum, brass, bronze, or zinc shall be at least 2.4 mm (3/32 inch) thick for an area greater than 155 cm^2 (24 $inch^2$) or having any dimension more than 152 mm (6 inch); and at least 1.6 mm (1/16 inch) thick for an area of 155 cm^2 (24 $inch^2$) or less having no dimension more than 152 mm (6 inch). The area considered for material at least 1.6 mm (1/16 inch) thick may be bounded by reinforcing ribs subdividing a larger area.

28.4 The thickness of a sheet-metal enclosure shall not be less than that specified in Table 28.1 and Table 28.2, except that at points to which a wiring system is to be connected, uncoated steel shall be at least 0.81 mm (0.032 inch) thick, zinc-coated steel at least 0.86 mm (0.034 inch) thick, and nonferrous metal at least 1.14 mm (0.045 inch) thick.

Table 28.1
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	(inch)	cm	(inch)	cm	(inch)	cm	(inch)	mm	(inch)	mm	(inch)
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)
185.4	(73.0)	228.6	(90.0)	261.6	(103.0)	322.6	(127.0)				

[a] See 30.3.

[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 inch) or fastened to adjacent surfaces not normally removed in use.

Table 28.2
Thickness of Sheet Metal for Enclosures – Aluminum, Copper, or Brass

Without supporting frame[a]				With supporting frame or equivalent reinforcing[a]					
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length		Minimum thickness	
cm	(inch)	cm	(inch)	cm	(inch)	cm	(inch)	mm	(inch)
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 30.3.

[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 inch) or fastened to adjacent surfaces not normally removed in use.

28.5 Table 28.1 and Table 28.2 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.

28.6 With reference to Table 28.1 and Table 28.2, 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.

28.7 Metallic parts shall be inherently resistant to corrosion or shall be protected against corrosion by enameling, galvanizing, plating, or other equivalent means. Small minor parts such as washers, screws, bolts, and the like need not be protected.

28.8 The requirement in 28.7 applies to all enclosing cases whether of sheet steel or cast iron, and to all parts upon which proper mechanical operation may depend.

29 Nonmetallic Materials

29.1 A nonmetallic enclosure shall comply with the requirements for the Impact Test, Section 64.

29.2 Nonmetallic materials used in the construction of enclosures shall have a flammability rating in accordance with Flammability, Section 39.

29.3 Enclosures of molded or formed thermoplastic material shall be constructed so that any shrinkage or distortion of the material over time will not allow for the user to be exposed to hazardous live parts or hazardous moving parts. Compliance is determined by the Mold Stress Test, Section 51.

29.4 The minimum thickness of a nonmetallic enclosure shall be such as to comply with the requirements of 29.1 – 29.3.

29.5 A polymeric material enclosure having in any single unbroken section, a projected surface area greater than 0.93 m^2 (10 $feet^2$) or a single linear dimension greater than 1.83 m (6 feet) shall have a flame-spread rating of 200 or less when tested in accordance with UL 723.

29.6 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.

g) A material shall not display a loss of these properties beyond the minimum acceptable level as a result of aging. Tests on nonmetallic enclosures shall be conducted in accordance with requirements in UL 746C and CSA C22.2 No. 0.17.

29.7 A polymeric material used for the enclosure of live parts shall have a relative thermal index rating higher than the temperature observed on that polymeric part during the Temperature Test, Section 47, for the specific application of the insulating material.

29.8 For an AMP that contains nonmetallic enclosures, the nonmetallic materials shall comply with the water exposure and UV exposure requirements in UL 746C and CSA C22.2 No. 0.17. If the nonmetallic enclosure is located on the AMP in a manner that prevents water exposure, UV exposure or both, then, based on review of the design, the specific requirements may not be applicable to that particular enclosure.

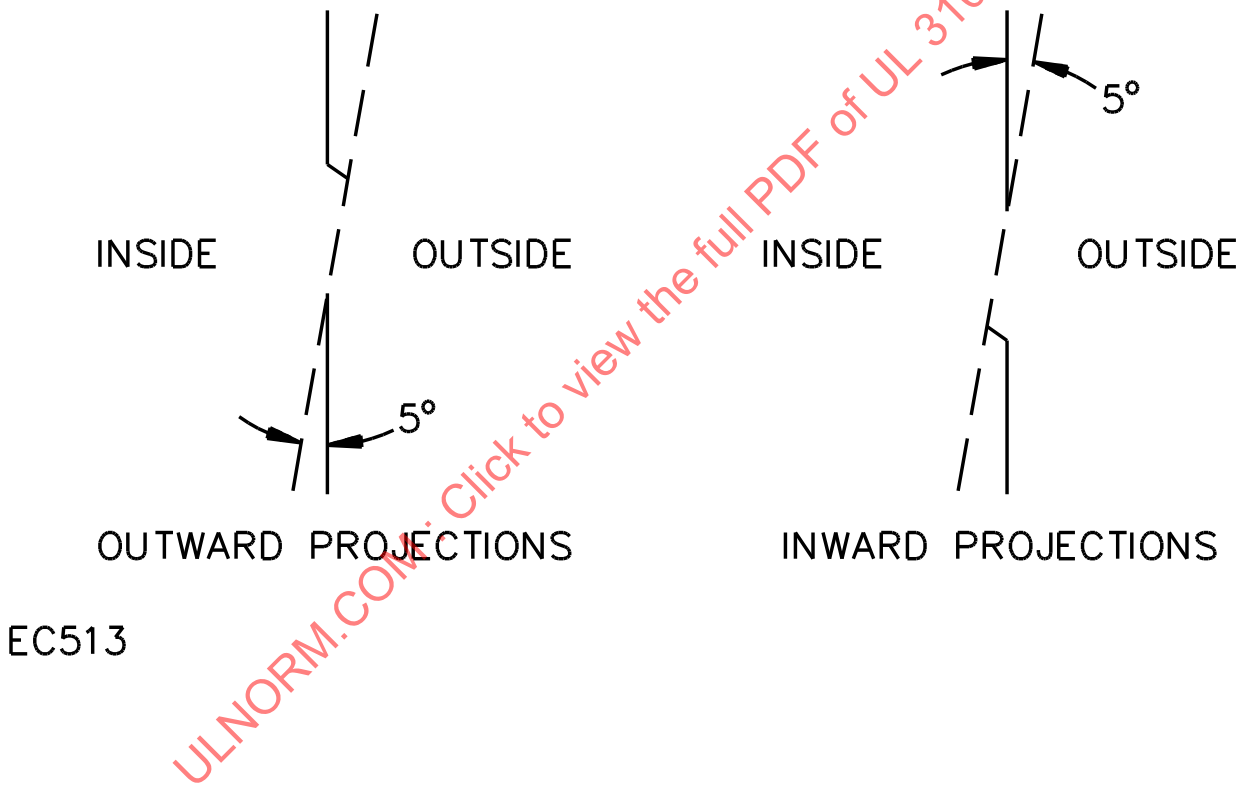
30 Openings for Indoor use AMPs

30.1 The minor dimension of any ventilation opening in the top of an enclosure directly over an uninsulated live part involving a risk of electric shock shall not exceed 4.8 mm (3/16 inch) unless the configuration is such that the risk of direct vertical entry of a falling object to uninsulated live parts is reduced by means of a trap or restriction. The minor dimension of a ventilation opening is the diameter of the largest cylindrical probe that is capable of being inserted through the opening.

30.2 The minor dimension of any ventilation opening located on the side of an enclosure shall not exceed 4.8 mm (3/16 inch) unless the openings are provided with louvers that are shaped to deflect outwards an external vertically falling object – see Figure 30.1.

Figure 30.1

Examples of Louver Design

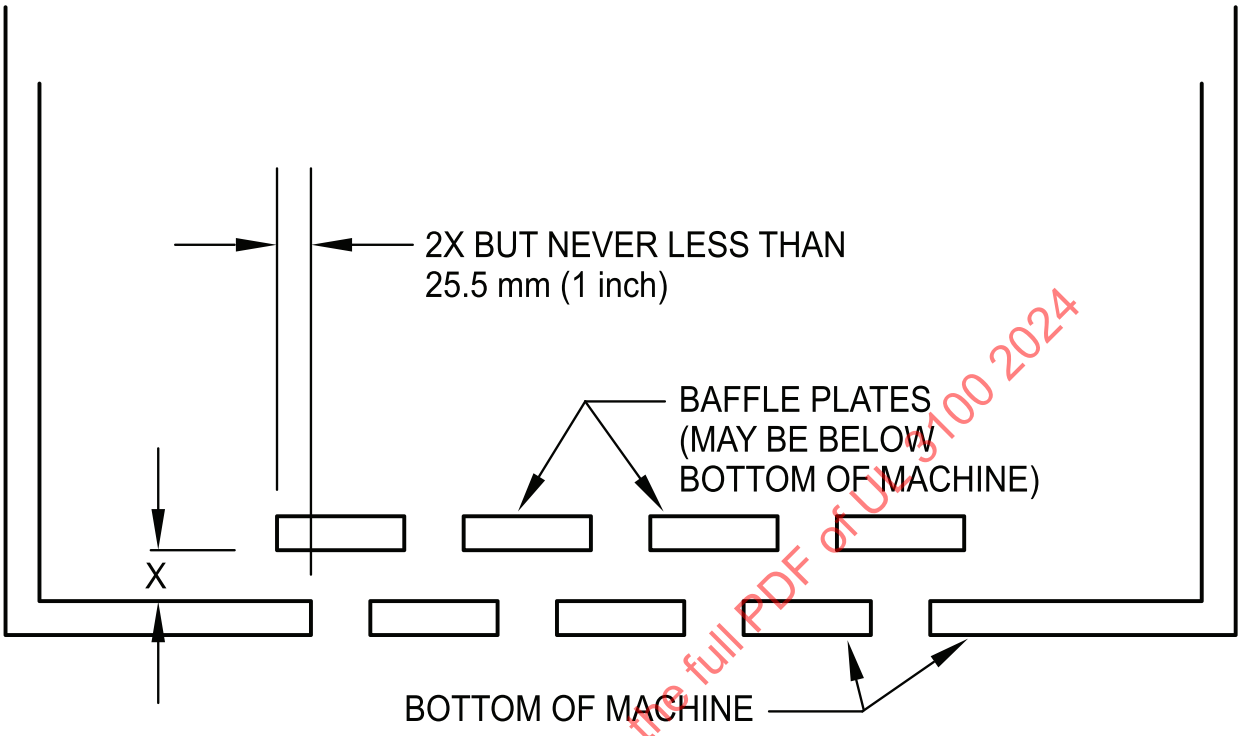


30.3 For ventilation openings located in a portion of the enclosure that is not above uninsulated live parts or moving parts, or the openings are so located that an object, upon entering the enclosure, is unlikely to fall on uninsulated live parts involving a risk of fire or electric shock, there are no specified dimensions. However, the openings shall not allow access to uninsulated live parts or moving parts when evaluated using the accessibility probes as outlined in Accessibility, Section 34.

30.4 Ventilation openings in the bottom panel are allowed when noncombustible baffle plates are provided to reduce the risk of materials from falling directly onto the supporting surface or any other location under the AMP. An example of such a baffle is illustrated in Figure 30.2.

Figure 30.2

Example of a Bottom Enclosure Baffle



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31 Doors / Covers / Windows for Indoor use AMPs

31.1 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.

31.2 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 AMP.

31.3 A hinged cover provided in accordance with the requirement in 31.2 may be provided with a snap latch or a captive multiturn 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.

31.4 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.

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

a) The glass shall be of a nonshattering or tempered type that, when broken, shall conform to the performance specifications in ANSI Z97.1; or

b) The glass shall withstand the 3.39 J (2.5 feet·lbf) impact specified in Impact Test, Section 64.

32 Battery Compartments/Enclosures

32.1 Support and protection shall be provided for the battery or battery pack by means of a compartment that is an integral part of the AMP or a separate enclosure, such as a tray and cover.

Exception: In cases where the battery or battery pack provides its own protection, a compartment or separate enclosure is not required.

32.2 The cover of a compartment or separate enclosure that houses a power source shall remain closed by the force of gravity or shall be provided with a fastener.

32.3 The compartment or separate enclosure that is intended to house a lead acid battery shall be provided with means for ventilation that reduces the likelihood of accumulation of explosive hydrogen-air mixtures.

32.4 Means shall be provided as a part of the AMP to restrain a battery or battery pack from moving more than a total of 12.7 mm (1/2 inch) in any direction during starting, stopping and normal use.

32.5 The material used to form the compartment or the enclosure for the battery or battery pack shall comply with the requirements for materials in Metallic Materials, Section 28.

32.6 For outdoor use AMPs, the battery enclosure shall comply with the environmental considerations in Environmental Considerations, Section 33.

32.7 Accessory batteries are covered in Accessory Batteries, Section 10.

33 Environmental Considerations

33.1 All enclosures shall be rated for one of the enclosure types in UL 50E and CSA C22.2 No. 94.2. As a minimum, the enclosure shall be rated Type 3R for outdoor use AMPs. The enclosure rating shall be suitable for the intended use of the AMP.

33.2 All enclosures shall comply with the applicable test requirements for the manufacturer specified enclosure rating in accordance with UL 50E and CSA C22.2 No. 94.2.

33.3 For any gaskets that are provided to meet the enclosure rating, the gaskets shall be tested in accordance with UL 50E and CSA C22.2 No. 94.2.

33.4 The openings provided in the enclosure shall be in accordance with the allowance for openings in UL 50E and CSA C22.2 No. 94.2. Doors and covers shall also meet the requirements of UL 50E and CSA C22.2 No. 94.2.

34 Accessibility

34.1 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 34.5) less than 25.4 mm (1 inch), such a part or wire shall not be contacted by the probe illustrated in Figure 34.1.

b) For an opening that has a minor dimension of 25.4 mm (1 inch) or more, such a part or wire shall be spaced from the opening as specified in Table 34.1.

Exception: A motor need not comply with these requirements if it complies with the requirements in 34.2.

Figure 34.1

Articulate Probe with Web Stop

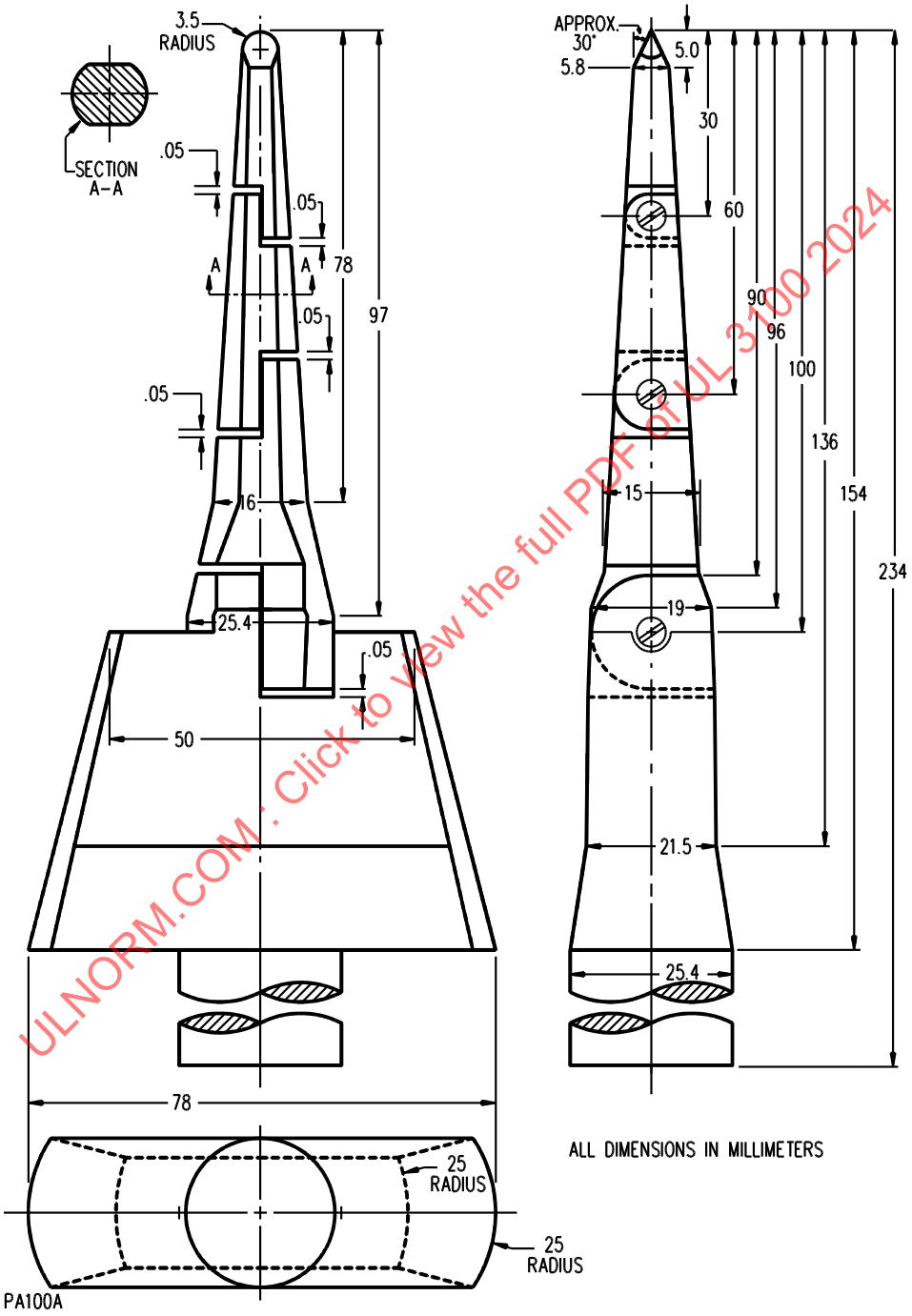


Table 34.1
Minimum Acceptable Distance from an Opening to a Part that may Involve a Risk of Electric Shock or Injury to Persons

Minor dimension[a] of opening		Minimum distance from opening to part,	
mm[b]	(inch)[b]	mm[b]	(inch)[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 34.5.

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

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

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

34.2 With reference to a part or wire in an integral enclosure of a motor as mentioned in the Exception to 34.1:

a) An opening that has a minor dimension (see 34.5) less than 19.1 mm (3/4 inch) is acceptable if:

1) A moving part cannot be contacted by the probe illustrated in Figure 34.2;

2) Film-coated wire cannot be contacted by the probe illustrated in Figure 34.3;

3) In a directly accessible motor (see 34.6), an uninsulated live part cannot be contacted by the probe illustrated in Figure 34.4; and

4) In an indirectly accessible motor (see 34.6), an uninsulated live part cannot be contacted by the probe illustrated in Figure 34.2.

b) An opening that has a minor dimension of 19.1 mm (3/4 inch) or more is acceptable if a part or wire is spaced from the opening as specified in Table 34.1.

Figure 34.2

Probe for Moving Parts and Uninsulated Live Parts

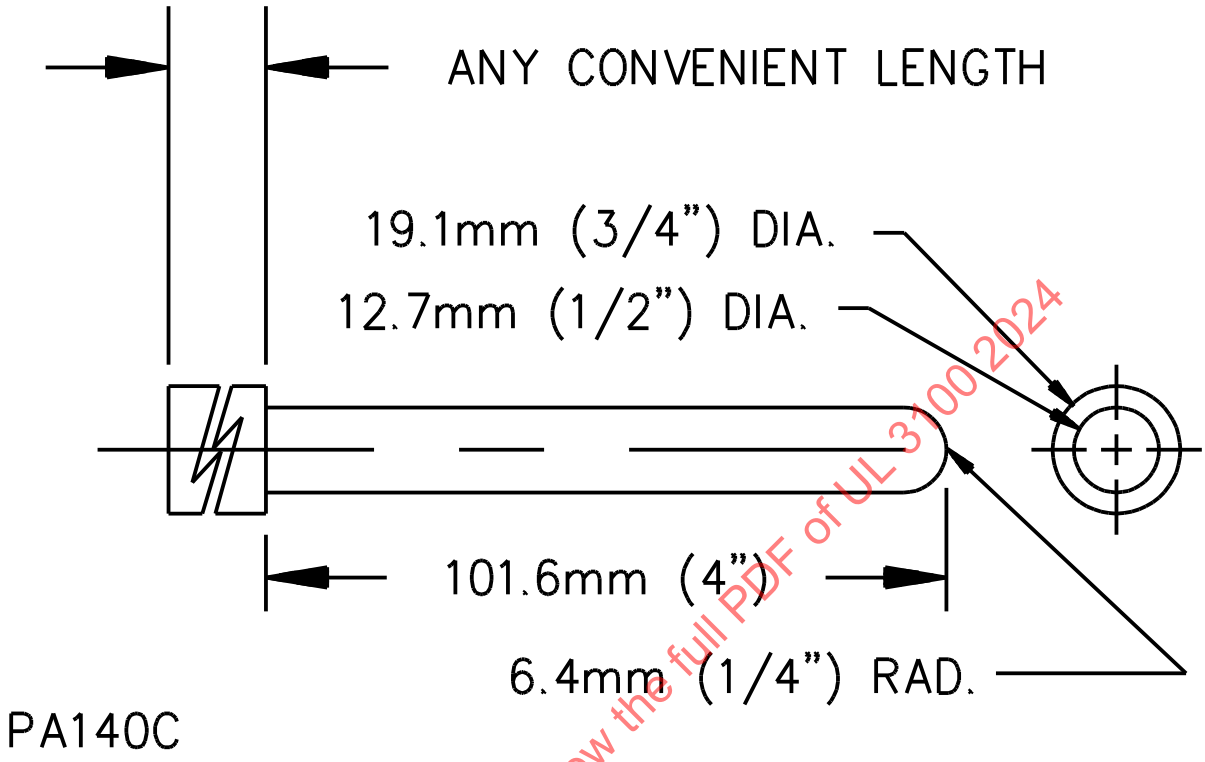


Figure 34.3

Probe for Film-Coated Wire

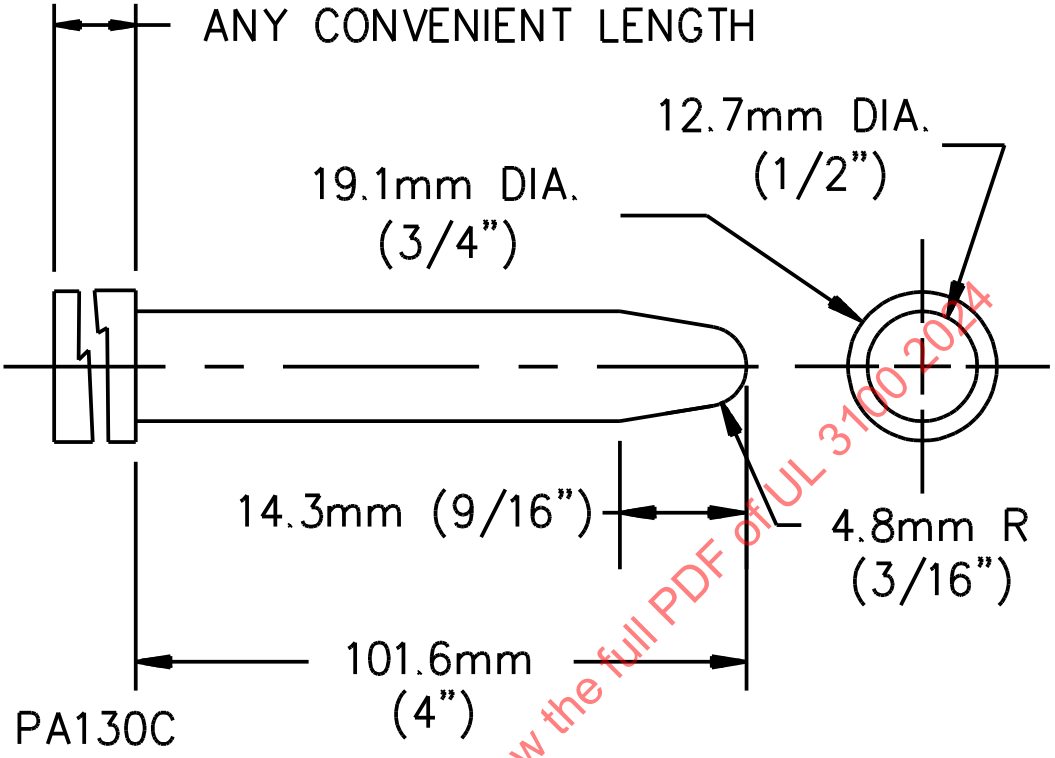
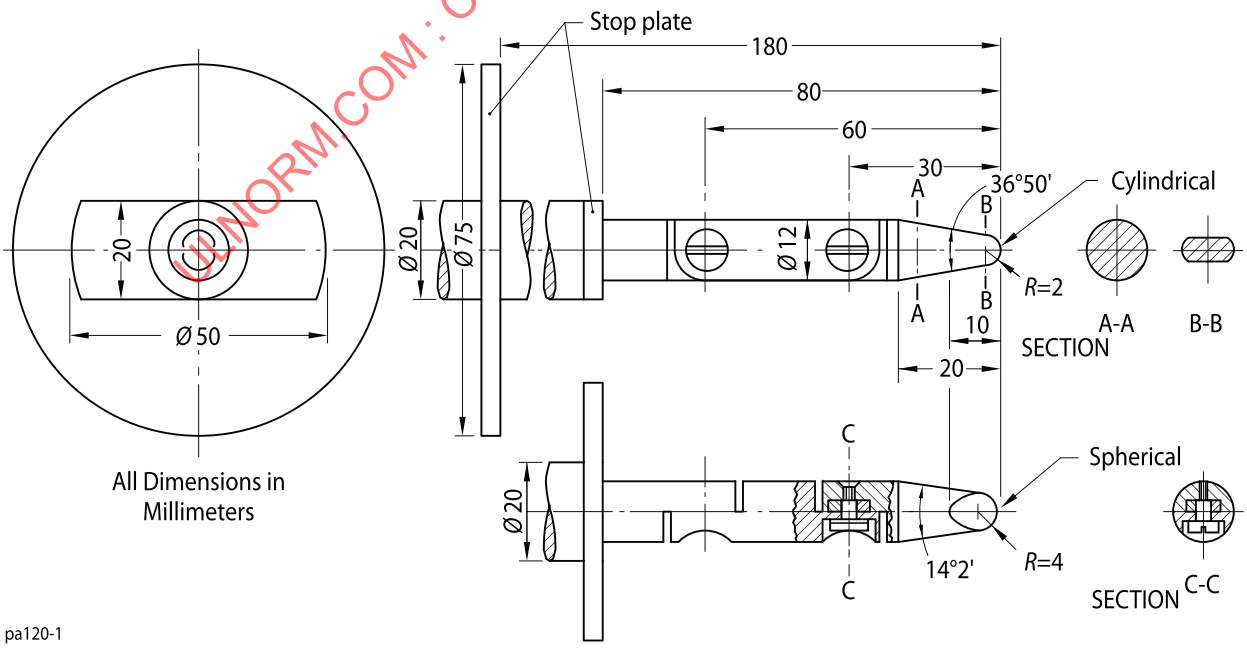


Figure 34.4

Articulate Probe



34.3 The probes mentioned in 34.1 and 34.2 and illustrated in Figure 34.1 – Figure 34.4 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 34.1 and Figure 34.4 are to be applied in any possible configuration; and, if necessary, the configuration is to be changed after insertion through the opening.

34.4 The probes mentioned in 34.1 and 34.2 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.

34.5 With reference to the requirements in 34.1 and 34.2, 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.

34.6 With reference to the requirements in 34.2:

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.

34.7 During the examination of a product to determine whether it complies with the requirements in 34.1 and 34.2, 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.

34.8 With reference to the requirements in 34.1 and 34.2, insulated brush caps are not required to be additionally enclosed.

35 Internal Wiring

35.1 The internal wiring of the AMP shall comply with one of the following. The wiring shall be considered with respect to the temperature and conditions of service to which the wiring is to be subjected in, the intended use:

a) UL 758 and CSA C22.2 No. 210;

b) UL 83 and CSA C22.2 No. 75;

c) UL 62 and CSA C22.2 No. 49;

d) SAE J1128;

e) UL 66;

f) UL 1276 and CSA C22.2 No. 96;

g) UL 1426; or

h) UL 1063.

35.2 Wiring located within a battery compartment shall comply with one of the following. The wiring shall be considered with respect to the temperature and conditions of service to which the wiring is to be subjected to in the intended use:

a) UL 2726;

b) SAE J1127;

c) UL 4127;

d) For wiring smaller than 13.3 mm^2 (6 AWG), the requirements in 35.1 would apply and the effects of acid exposure need not be evaluated.

35.3 The wiring of an AMP shall be rated for the particular application with respect to the temperature and voltage, exposure to oil or grease, and other conditions of service to which the wiring is subjected.

35.4 A bare conductor is permitted to be insulated with insulating tubing or with noncarbonizable beads.

35.5 A short length of rubber-insulated conductor exposed to temperatures that normally are in excess of the maximum acceptable temperatures for the compound involved – for example, at a resistor terminal – is acceptable if supplementary heat-resistant insulation having the adequate dielectric strength is employed on the individual conductor to protect against breakdown of the insulation resulting from deterioration of the rubber. An insulating sleeve shall be secured in place.

35.6 Wiring shall be protected against mechanical damage by:

a) Enclosing it in the body of the AMP; or when mounted on masts, booms, lifts or similar parts, the wiring shall be installed so as to reduce the likelihood of mechanical damage and kinking;

b) Enclosing it in metal raceway, such as armored cable, rigid metal conduit, or electrical metallic and nonmetallic tubing, flexible nonmetallic conduit or nonmetallic insulated tubing; or

c) Other suitable method in which the wiring is protected sufficiently against mechanical damage.

35.7 *Deleted*

35.8 All of the splices and connections shall be mechanically secure and shall provide electrical contact without stress on connections and terminals. A splice shall be provided with insulation equivalent to that on the wires involved.

35.9 A hole by means of which insulated conductors pass through a sheet-metal wall shall be provided with a smooth, rounded bushing, or shall have smooth, rounded surfaces upon which the insulated conductors may bear.

35.10 Wireways shall be smooth and free from sharp edges, burrs, fins, or moving parts that may damage wiring.

35.11 An internal-wiring connection shall be made with a solder lug or a pressure terminal connector.

35.12 A terminal lug shall be arranged so that in any position it cannot contact either the frame of the AMP or other electrical circuits, or the shank of the lug shall be provided with insulation equivalent to that on the conductor.

36 Current Carrying Parts

36.1 A current carrying part shall be of silver, copper, a copper-based alloy, stainless steel, aluminum, or other material determined to be acceptable for the application. Plated iron or steel shall not be used for parts that are depended upon to carry current. Wire binding screws shall not be of iron or steel.

36.2 Iron or steel, if protected against corrosion by zinc, tin, or equivalent plating, can be used for screws, plates, yokes, or other parts that are employed as a means of clamping the conductor, providing such parts are not the primary current carrying members.

36.3 Suitable means shall be provided for retaining live parts within such limits of alignment as to ensure that plugs will enter receptacles, connectors, and the like in the intended manner.

36.4 Uninsulated live parts shall be secured in place so that they do not turn or shift, when turning or shifting results in a reduction in the clearance and creepage distances below those required in Spacings and Separation of Circuits, Section 41.

36.5 A current carrying part shall be prevented from turning relative to the surface on which it is mounted if such turning would adversely affect the performance of the part or can result in a hazard.

37 Connections (Battery to AMP, Battery to Charger, AMP to Charger)

37.1 An AMP shall be equipped with connectors for connection of the battery pack to the AMP. Additionally, connectors shall be provided for the electrical connection for recharging the battery. If the battery is intended to be removed for charging, the connector mating with the AMP may also serve as the connector for recharging. All connectors provided shall be suitably rated for the application and shall comply with the requirements of UL 1977 and CSA C22.2 No. 182.3 for indoor use AMPs or UL 2734 for outdoor use AMPs. If clamps are provided for connection to battery terminals, such as for lead acid batteries, then the clamps shall be suitable for the purpose.

37.2 With reference to 37.1, if a particular connection on an AMP for outdoor use is enclosed within an enclosure that meets the environmental considerations of 23.6, then the connection can comply with the requirements for indoor or outdoor connectors in accordance with 37.1.

37.3 If the connectors referred to in 37.1 are interconnected using a length of cable, the length of the cable attached between the connectors shall be as short as practical, without interfering with the disconnecting operation and without placing stress on terminals. The cable shall be provided with insulation that is appropriate for the intended operation, rated for the voltage involved, secured so as not to touch hot parts or moving parts, and in compliance with 35.2.

37.4 Live parts shall be recessed from the face of the connector to reduce the possibility of a short circuit.

37.5 If a connector is not used in lieu of an open contact type connection system, that connection system shall comply with Open Bus Bar Connection Systems, Section 23.

37.6 The terminals of a battery shall be protected or located so they are unlikely to be inadvertently short-circuited during installation, replacement, or while in service.

38 Fuses

38.1 Fuses shall be acceptable for the current and voltage of the circuit they are protecting, and they shall comply with the applicable part of the UL 248 series CSA C22.2 No. 248 series and UL 275 and UL 275A.

38.2 For user replaceable fuses, a fuse replacement marking shall be located adjacent to each fuse or fuse holder, or on the fuse holder, or in another location if it is obvious to which fuse the marking applies and giving the fuse ratings. Where user replaceable fuses with special fusing characteristics such as time delay or breaking capacity are necessary, the type shall also be indicated. Information on proper fuse replacement of user replaceable fuses shall also be included in the instructions. See Maintenance Instructions, Section 79.

39 Flammability

39.1 Nonmetallic materials used for enclosures shall have a minimum flammability rating of V-1 in accordance with the requirements in UL 94 and CSA C22.2 No. 0.17. As an alternative, finished enclosures may be tested in accordance with the 20 mm end-product flame test in UL 746C and CSA C22.2 No. 0.17. Metallic materials used for enclosures are considered to comply without further evaluation, except magnesium shall not be used for enclosure materials.

39.2 Nonmetallic materials used for internal parts within the overall enclosure shall be rated V-2 minimum.

39.3 Internal parts of components shall comply with the flammability requirements of the component standard in accordance with Components, Section 2.

39.4 Small parts, and gaskets, that are not located near live parts, and are located in a manner such that they cannot propagate flame from one area to another within the equipment, are not required to have a specific flame rating.

39.5 Nonmetallic materials located outside the enclosure, and not used to complete the enclosure, are considered decorative parts. These parts shall be rated HB minimum.

39.6 Printed wiring board materials shall be rated as indicated in 14.2.

39.7 For the requirements outlined in 39.2 – 39.6, the flammability rating of the material shall be provided as part of the material rating or the flammability rating may be determined in accordance with UL 94 and CSA C22.2 No. 0.17.

40 Low-Voltage Limited Energy Circuit (LVLE)

40.1 A LVLE is a circuit involving an alternating current voltage of not more than 30 volts rms (42.4 volts peak) or a direct current voltage of not more than 60 volts and supplied by:

a) Class 2 transformer or Class 2 Power Unit, or

b) A combination of a battery source or an isolated transformer secondary winding and one or more resistors, or a regulating network complying with 40.3, 40.4, and 40.6, or

c) A battery with output current limited by overcurrent protection in accordance with 40.5 and Table 40.1.

Table 40.1
Rating for Secondary Fuse or Circuit Protector

Circuit voltage (Vrms)	Current (A)
20 or less	5
More than 20 but not greater than 60	100/V[a]
[a] V is the maximum output voltage, regardless of the load, with the primary energized.	

40.2 A part or device located in or supplied by an LVLE circuit need not be investigated. The secondary winding of the transformer, the fuse or circuit protective device, or the regulating network, and all wiring up to the point at which the current and voltage are limited shall be judged under the applicable requirements in this Standard.

40.3 The maximum load current is to be drawn under any condition of loading, including short circuit, using a resistor. The current is to be measured 60 seconds after the application of the load. The resistor is to be continuously readjusted during this 1 minute period to maintain maximum load current. The measured load current shall not exceed the value listed in Table 40.1.

40.4 With reference to the voltage limit specified in 40.1, measurement is to be made with the unit connected to the intended supply voltage and with all loading circuits disconnected.

40.5 The over-current protective device provided in the LVLE circuit used to limit the current shall be rated or set at not more than the values specified in Table 40.1.

40.6 If a regulating network is used to limit the output under any conditions, the LVLE current limitation in Table 40.1 shall not be affected by malfunction of a single component, excluding resistors. The network shall comply with the value in Table 40.1.

41 Spacings and Separation of Circuits

41.1 Spacings shall not be less than the applicable values specified in Table 41.1.

Table 41.1
Spacings

Potential involved in Vrms (peak)		Minimum spacing, mm (inch)					
		Equipment with a volt-ampere rating that is not limited				Equipment having a limited volt ampere rating	
		A				B	
		0 – 50 (0 – 70.7)	>51 – 150 (70.7 – 212.1)	>150 – 300 (212.1 – 424.3)	>300 – 600 (424.3 – 848.5)	>50 – 300 (70.7 – 424.3)	300 – 600 (424.3 – 848.5)
Between any uninsulated live part of opposite polarity and any uninsulated grounded part other than the enclosure, or exposed metal part[c,d]	Through air or oil	1.6[a] (1/16)[a]	3.2[a] (1/8)[a]	6.4 (1/4)	9.6 (3/8)	1.6[a] (1/16)[a]	4.8[a] (3/16)[a]
	Over Surface	1.6[a] (1/16)[a]	6.4 (1/4)	9.6 (3/8)	12.7 (1/2)	3.2[a] (1/8)[a]	9.6 (3/8)

Table 41.1 Continued on Next Page

Table 41.1 Continued

Potential involved in Vrms (peak)		Minimum spacing, mm (inch)					
		Equipment with a volt-ampere rating that is not limited				Equipment having a limited volt ampere rating	
		A				B	
		0 – 50 (0 – 70.7)	>51 – 150 (70.7 – 212.1)	>150 – 300 (212.1 – 424.3)	>300 – 600 (424.3 – 848.5)	>50 – 300 (70.7 – 424.3)	300 – 600 (424.3 – 848.5)
Between any uninsulated live part and the walls of a metal enclosure including fittings for conduit or armored cable[b]	Shortest distance	1.6 (1/16)[a]	6.4 (1/4)	12.7 (1/2)	12.7 (1/2)	6.4 (1/4)	12.7 (1/2)

[a] The spacing between field-wiring terminals of opposite polarity and the spacing between a field-wiring terminal and a grounded dead metal part shall not be less than 6.4 mm (1/4 inch) if a short-circuiting or grounding of such terminals results from projecting strands of wire.

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

[c] In a safety circuit the spacing between wiring terminals, regardless of polarity, and the spacing between a wiring terminal and a grounded dead metal part – including the enclosure – shall not be less than 6.4 mm (1/4 inch).

[d] In a safety circuit the spacing between same polarity live parts on opposite sides of a switching mechanism, except at contact point, shall not be less than 0.8 mm (1/32 inch) through air and 1.6 mm (1/16 inch) over surface.

41.2 As an alternative to the spacing requirements of 41.1, as applicable, the spacing requirements in UL 840 and CSA C22.2 No. 0.2, may be used. The spacing requirements of UL 840 and CSA C22.2 No. 0.2 shall not be used for field wiring terminals and spacings to a dead metal enclosure. The pollution degree for an indoor use AMP is Pollution Degree 2 for commercial applications and Pollution Degree 3 for industrial applications. For outdoor use AMPs, the pollution degree is Pollution Degree 3. In all cases, the overvoltage category is considered Overvoltage Category II.

41.3 A spacing at a wiring terminal is to be measured with appropriate wires connected to each terminal and other parts as in actual service.

41.4 For the purpose of these requirements, the voltage and volt-ampere ratings are those measured with the AMP connected to its rated battery supply circuit.

41.5 Uninsulated live parts connected to different circuits shall be spaced from each other as if they were parts of opposite polarity, in accordance with the requirement in 41.1, and shall be judged based on the highest voltage involved.

41.6 Safety critical circuits shall be judged as primary circuits with regard to spacings.

41.7 The spacings specified in column B of Table 41.1 are applicable to devices or circuits rated 1 horsepower or less, 720 VA or less – break pilot duty; or not more than 15 A at 51 – 150 V, 10 A at 151 – 300 V, or 5 A at 301 – 600 V.

41.8 Spacings inherent in a component are judged under the requirements for the component. Spacings from such a component to another component and the enclosure, and spacings at wiring terminals shall comply with the requirements in 41.1 and Table 41.1.

41.9 Spacings at a fuse and fuseholder are to be measured with a fuse that has the maximum standard dimensions for the rating in place and shall not be less than those specified in column A of Table 41.1.

41.10 An insulating barrier or liner that is used to provide spacings, including spacings in conjunction with the required over surface spacings, shall not be less than 0.71 mm (0.028 inch) thick. A barrier or liner that is used in conjunction with a spacing through air not less than 0.33 mm (0.013 inch) thick, provided the barrier or liner is an acceptable insulating material resistant to moisture and has the necessary mechanical strength if exposed or otherwise likely to be subject to mechanical damage, reliably held in place, and located so that it will not be adversely affected by operation of the equipment in service – particularly arcing.

Exception: As provided in 42.1.

41.11 An insulating barrier or liner used as the sole separation between live parts and grounded parts, or between live parts of opposite polarity, shall be a material that is acceptable for mounting uninsulated live parts and is not less than 0.71 mm (0.028 inch) thick. Otherwise, a barrier shall be used in conjunction with at least a 0.8 mm (1/32 inch) air spacing.

Exception: As provided in 42.1.

42 LVLE Circuits

42.1 If a short circuit between the parts in an LVLE safety control may result in a risk of fire, electric shock, or injury to persons, spacings shall be as specified in 42.2 – 42.4.

42.2 Spacing between an uninsulated live part and the wall of a metal enclosure shall not be less than 3.2 mm (1/8 inch). A greater spacing may be required if an enclosure is not sufficiently rigid to maintain the required spacing because of its size, shape, or the material used.

42.3 Spacing between wiring terminals, regardless of polarity, and between a wiring terminal and a dead metal part – including the enclosure – that may be grounded when the equipment is installed shall not be less than 6.4 mm (1/4 inch).

42.4 Spacing between uninsulated live parts, regardless of polarity, and between an uninsulated live part and a dead metal part, other than the enclosure, that may be grounded when the equipment is installed shall not be less than 0.8 mm (1/32 inch) if the construction is such that spacings will be permanently maintained.

43 Other than Safety Circuits

43.1 *Deleted*

43.2 *Deleted*

44 Separation of Circuits

44.1 Insulated conductors shall be segregated or separated from other insulated conductors or uninsulated live parts by reliable means in accordance with 44.2.

44.2 Segregation of insulated conductors in accordance with 44.1 may be accomplished by clamping, routing, or equivalent means, or by providing a barrier between conductors and/or parts.

44.3 If insulated conductors of different circuits are all provided with insulation suitable for the highest voltage involved, then segregation is not required.

PERFORMANCE

45 General

45.1 Unless otherwise stated, compliance with the performance requirements shall be determined by testing a representative model of a new AMP. The performance of an AMP shall be investigated by subjecting a representative sample or samples to the tests described in Sections 46 – 72, as applicable. Consideration shall be given to the working environment, rated loads, electrical and mechanical ratings, and other construction criteria in selecting samples for testing.

45.2 Unless indicated otherwise, batteries shall be fully charged in accordance with the manufacturer's specifications for conducting the tests in this Standard. After charging and prior to testing, the batteries shall be allowed to rest for a maximum period of 8 hours at room ambient.

45.3 All tests, unless noted otherwise, are conducted in a room ambient 25 ±5 °C (77 ±9 °F).

45.4 *Deleted*

45.4A 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 temperature measurements by thermocouples are necessary.

45.4B The thermocouples and related instruments are to be accurate and calibrated in accordance with good laboratory practice. The thermocouple wire shall conform with one of the following requirements:

a) Special tolerance thermocouples specified in the Special Tolerances thermocouples as listed in the Tolerances on Initial Values of EMF versus Temperature tables in ASTM E230/E230M; or

b) The table of Special Limits as outlined in ASTM E230; or

c) IEC 60584-1 or JIS C 1602. 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 (±2.7 °F) of reading for thermocouples identified in IEC 60584-1 or JIS C 1602; or

2) Alternately, where higher temperature ranges of the selected thermocouple are measured, a tolerance value of 0.4 % of reading may be applied to thermocouple tolerances as specified in IEC 60584-1 or JIS C 1602.

45.5 If there is a specific reference to a single fault condition in the individual test methods, the single fault is to consist of a single failure (i.e. open, short or other failure means) of any component in the AMP electrical system that could occur and affect the results of the test. This fault is implemented in conjunction with the test being conducted (i.e. overcharge, short circuit, etc.) or may be conducted as part of a verification of a protective circuit. A protective device determined to be reliable may remain in the circuit without being faulted. A protective device determined to be reliable is one that has been shown to comply with an appropriate component safety standard and is used within its ratings.

45.6 The tests contained in this Standard may result in explosions, fire and emissions of flammable and/or toxic fumes as well as electric shock. It is important that personnel use extreme caution and follow local and regional worker safety regulations when conducting any of these tests and that they be protected from flying fragments, explosive force, and sudden release of heat and noise that could result from testing. The test area is to be well ventilated to protect personnel from possible harmful fumes or gases. As an additional precaution, the temperatures on the surface of at least one cell/module within the battery pack

can be monitored during the test for safety and information purposes. All personnel involved in the testing are to be instructed to never approach the sample or the battery pack until temperatures are falling and have returned to within ambient temperatures.

45.7 In the tests in this Standard, wherever there is a reference to the use of cheesecloth, the cheesecloth is to be untreated cotton cloth running 26 – 28 m^2/kg (14 – 15 $yards^2$/lb), and having, for any square inch, a count of 32 threads in one direction and 28 in the other direction. Wherever there is a reference to the use of medical gauze, the 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 2.54 mm (1 inch) and a weight between 24 – 30 m^2/kg (13 – 16.5 $yards^2$/lb).

45.8 Unless noted otherwise in the individual test methods, the tests shall be followed by a 1-hour observation time prior to concluding the test and temperatures are to be monitored in accordance with 45.6.

45.9 An AMP's electrical systems that are operational after the following tests shall be subjected to a minimum of one cycle of charging and discharging in accordance with the manufacturer's specifications to determine that there are no non-compliant results as stated in this Standard for that test:

a) Electrical Tests – Overcharge, short circuit, imbalanced charging; and

b) Mechanical Tests – Vibration, shock.

46 Power Rating Verification Test

46.1 The input rating to the AMP, or the output rating of an off board power supply or charger, shall not exceed the manufacturer’s specified rating by more than 10 percent.

46.2 AMPs where the battery is charged while the battery remains on the AMP shall be tested in accordance with 46.3. AMPs where the battery is removed and charged off board the AMP shall be tested in accordance with 46.4.

46.3 An AMP with a fully discharged battery is connected to an off board charger or power supply as intended. The connection is made through a meter that can measure the input current to the AMP. This measured value is recorded and compared to the manufacturer's specified input rating for the AMP during charging.

46.4 A fully discharged battery is removed from the AMP and connected to the off board charger. The connections are made through a meter that can measure the output current of the charger or power supply. The measured value is recorded and compared to the output rating of the charger or power supply.

47 Temperature Test

47.1 This test is conducted to determine whether or not temperature sensitive safety critical components and temperature sensitive materials in the AMP are being maintained within their temperature ratings based upon the maximum operating temperature limits of the component or material. Temperatures on accessible surfaces, which may be contacted by the user, are also monitored.

47.2 The test consists of charge and discharge cycles until temperatures are stable as described in each requirement below. Stability of temperatures is determined in accordance with 45.4.

47.3 With reference to 47.2, a charge cycle consists of charging a battery from the fully discharged level to the fully charged level based on manufacturer’s specification for each. A discharge cycle consists of depleting a battery from fully charged to fully discharged levels.

47.4 An AMP with a non-removable battery is tested in accordance with AMPs with Non-Removable Batteries, Section 48. An AMP with a battery that is inherently required to be removed for charging, shall be tested in accordance with AMPs with Removable Batteries, Section 49. For an AMP that provides the user with an option and allows for charging both on board or off board the AMP, the test shall be in accordance with both Section 48 and 49.

47.5 Temperatures measured on components shall not exceed their specifications. See Table 47.1 and Table 47.2 for surface and component temperature limits. Measured values for temperatures during these tests shall be adjusted to reflect the manufacturer's maximum specified ambient for the AMP. For all AMPs intended to be used in an ambient above 40 °C (104 °F) based on manufacturer specification, the test shall be performed in a chamber at that ambient temperature.

Table 47.1
Temperatures on Components
Temperature Limits

Materials and components	Temperature limit	
	°C	°F
A. MOTORS		
1. Class A insulation systems on coil windings of motors having a diameter of more than 178 mm (7 inch)		
a. In an open motor:		
Thermocouple method	90[a]	194[a]
Resistance method	100	212
b. In a totally enclosed motor:		
Thermocouple method	95	203
Resistance method	105	221
2. Class A insulation systems on coil windings of motors having a diameter of 178 mm (7 inch) or less		
a. In an open motor:		
Thermocouple or resistance method	100	212
b. In a totally enclosed motor:		
Thermocouple or resistance method	105	221
3. Class B insulation systems on coil windings of motors having a diameter of more than 178 mm (7 inch)		
a. In an open motor:		
Thermocouple method	110[a]	230[a]
Resistance method	120	248
b. In a totally enclosed motor:		
Thermocouple method	120	248
Resistance method	125	257
4. Class B insulation systems on coil windings of motors having a diameter of 178 mm (7 inch) or less		
a. In an open motor:		
Thermocouple or resistance method	120	248
b. In a totally enclosed motor:		

Table 47.1 Continued on Next Page

Table 47.1 Continued

Materials and components	Temperature limit	
	°C	°F
Thermocouple or resistance method	125	257
B. COMPONENTS		
1. Capacitors:		
a. Electrolytic types	65[b]	149[b]
b. Other than electrolytic	90[b]	194[b]
2. Field wiring terminals	75	167
3. Vulcanized fiber employed as electric insulation	90	194
4. Plated bus bar	90[c]	194[c]
5. Unplated bus bar and a joint	75[c]	167[c]
6. Relays, solenoids, and similar devices		
a. Class 105 coil insulation systems:		
Thermocouple method	90[a]	194[a]
Resistance method	110	203
b. Class 130 coil insulation systems:		
Thermocouple method	110[a]	230[a]
Resistance method	120	248
7. Transformer insulation systems:		
a. Class 105:		
Thermocouple method	90[a]	194[a]
Resistance method	95	203
b. Class 130:		
Thermocouple method	110[a]	203[a]
Resistance method	120	248
c. Class 155:		
Thermocouple method	135[a]	275[a]
Resistance method	140	284
d. Class 180:		
Thermocouple method	150[a]	302[a]
Resistance method	160	320
e. Class 200:		
Thermocouple method	165[a]	329[a]
Resistance method	175	347
f Class 220: .		
Thermocouple method	180[a]	356[a]
Resistance method	190	37
8. Phenolic composition employed as electrical insulation or as a part the deterioration of which results in a risk of fire or electric shock	150[d]	302[d]
9. Wood and other combustible material	90	194
10. Rubber- or thermoplastic-insulated wire and cord	60[d,e]	140[d,e]

Table 47.1 Continued on Next Page

Table 47.1 Continued

Materials and components		Temperature limit	
		°C	°F
11.	Other types of insulated wires	g	g
12.	A surface upon which a portable unit is mounted in service, and surfaces that are adjacent to the unit when so mounted	90	194
13.	Any point on or within a terminal box or compartment of a fixed unit on which field-installed conductors rests	60	140
14.	Thermoplastic sealing compound	h	h
15.	Selenium rectifier	75[d,h]	167[d,h]
16.	Power semiconductor	I	I
17.	Printed-wiring board		j

[a] At a point on the surface of a coil where the temperature is affected by an external source of heat, the temperature measured by means of a thermocouple is not prohibited from being 5 °C (9 °F) higher than that specified when the temperature of the coil as measured by the resistance method is not more than that specified.

[b] A capacitor that operates at a temperature of more than 65 °C (149 °F) for electrolytic and more than 90 °C (194 °F) for other types is allowed to be judged on the basis of its marked temperature limit.

[c] For a bus bar having a current density in accordance with 19.4, it is not required to measure the temperature since it has characteristics which result in temperatures not exceeding the indicated values.

[d] The temperature limitations on phenolic composition and on rubber and thermoplastic insulation do not apply to a compound that has heat-resistant properties in accordance with UL 746B and CSA C22.2 No. 0.17.

[e] A short length of rubber- or thermoplastic-insulated cord inside the unit is exposed to a temperature of more than 60 °C (140 °F) when supplementary insulation on each individual conductor is rated for the measured temperature and has dielectric properties in accordance with UL 746A, UL 746B and CSA C22.2 No. 0.17.

[f] The temperature is not to exceed the temperature limit of the wire except as noted in note e.

[g] The sealing compound temperature limit is 15 °C (27 °F) less than the softening point of the compound as determined in accordance with ASTM D1525.

[h] A temperature limit of 85 °C (185 °F) meets the intent of the requirement when the stack assembly is insulated with phenolic composition or other insulating material rated for a temperature of 150 °C (302 °F).

[i] For a power-switching semiconductor and similar components the temperature limit on the case is the maximum case temperature specified by the semiconductor manufacturer.

[j] For a printed wiring board, the temperature limit is the specified limit of the board.

Table 47.2
Temperatures on User Accessible Surfaces

Accessible surfaces	Maximum surface temperatures		
	Metal °C (°F)	Glass, porcelain and vitreous materials °C (°F)	Plastic and rubber[a] °C (°F)
Handles, knobs, grips, etc., continuously held in normal use	55 (131)	65 (149)	75 (167)
Handles, knobs, grips, etc., held or touched for short periods only	60 (140)	70 (158)	85 (185)
External surfaces of equipment which may be touched[b]	70 (158)	80 (176)	95 (203)
Parts inside equipment which may be touched[c]	70 (158)	80 (176)	95 (203)

[a] For each material, account shall be taken of the data from that material to determine the appropriate maximum temperature.

[b] For areas on the external surface of equipment and having no dimension exceeding 50 mm (2.0 inch), and which are not likely to be touched in normal use, temperatures up to 100 °C (212 °F) are permitted.

Table 47.2 Continued on Next Page

Table 47.2 Continued

Accessible surfaces	Maximum surface temperatures		
	Metal °C (°F)	Glass, porcelain and vitreous materials °C (°F)	Plastic and rubber[a] °C (°F)
[c] Temperatures exceeding the limits are permitted provided that the following conditions are met: 1) Unintentional contact with such a part is unlikely; 2) The part has a marking indicating that this part is hot. It is permitted to use the symbol (IEC 60417, No. 5041) to provide this information.			

48 AMPs with Non-Removable Batteries

48.1 For this test, one complete test cycle will consist of one charge cycle followed by one discharge cycle. The test is terminated after two complete test cycles and the maximum temperature is recorded.

48.2 During this test, an AMP is tested under conditions of normal operation. If the AMP is intended to carry a load or to tow a load, then 125 % of the maximum load as specified by the manufacturer is to be applied during this test.

48.3 At the conclusion of the test, the AMP and battery shall be subjected to an observation period in accordance with 45.8. An AMP that contains hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 73.

49 AMPs with Removable Batteries

49.1 For this test, the complete test cycle is defined to represent the worst case possible use. This would include operation of the AMP to deplete the battery from fully charged to fully discharged and then that battery is immediately removed and replaced with a fully charged battery. Operation of the AMP is to continue until the temperatures stabilize in accordance with 45.4. This continuous operation until temperatures stabilize is one complete test cycle and only one cycle is needed for this test.

49.2 During this test, the battery pack that is not in use will be charging. In order to correlate the use of alternating battery packs, the charge cycle will need to be completed in advance of the discharge cycle such that the AMP is not allowed to cool while the replacement pack is charging. In order to coordinate the test, more than two battery packs can be used such that one is always charged and ready to be used in the AMP.

49.3 The loading parameters and use parameters for this test shall be as specified in 48.2.

49.4 At the conclusion of the test, the AMP and battery, as well as all other batteries used in the test, shall be subjected to an observation period in accordance with 45.8. An AMP that contains hazardous operating voltages shall be subjected to a Dielectric Voltage Withstand Test, Section 73.

50 Dielectric Strength Test

50.1 This test is an evaluation of the electrical spacings and insulation at hazardous voltage circuits within the AMP.

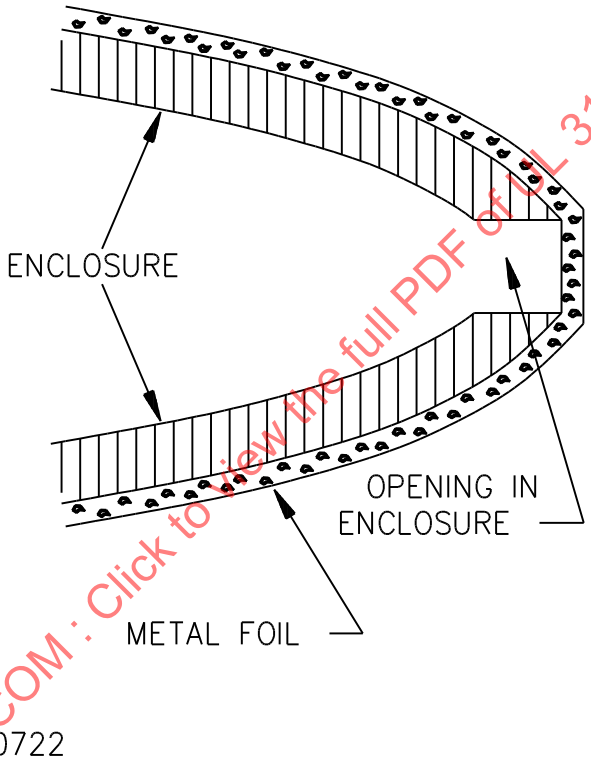
50.2 Circuits at 60 Vdc or higher shall be subjected to a dielectric withstand voltage consisting of a dc potential of twice the rated voltage.

50.3 The test voltage is to be applied between the hazardous voltage circuits of the AMP and non-current carrying conductive parts that may be accessible.

50.4 If the accessible parts of the AMP are covered with insulating material that may become live in the event of an insulation fault, then the test voltages are applied between each of the live parts and metal foil in contact with the accessible parts. The metal foil shall be wrapped tightly around and in intimate contact with the accessible part. The foil is to be drawn tightly across any opening in the enclosure or other accessible parts to form a flat plane across such opening. See Figure 50.1.

Figure 50.1

Method of Covering Enclosures with Foil for Measurement and Tests



50.5 The test voltages shall be applied for a minimum of one minute with the battery disconnected to prevent charging during application of the voltage.

50.6 The test equipment shall be capable of delivering the required dc output. There is no trip current setting for the test equipment since the test is checking for insulation breakdown, which results in a large increase of current. Setting a trip current may result in a false failure of this test, as it may not be indicative of insulation breakdown.

50.7 There shall be no evidence of a dielectric breakdown (breakdown of insulation resulting in a short through insulation/arcing over electrical spacings) as evidenced by an appropriate signal from the dielectric withstand test equipment as a result of the applied test voltage. Corona discharge or a single momentary discharge is not regarded as a dielectric breakdown (i.e. insulation breakdown).

51 Mold Stress Test

51.1 This test is intended to evaluate whether any shrinkage or distortion exists on a molded or formed thermoplastic enclosure due to release of internal stresses caused by the molding or forming operation and result in the exposure of hazardous parts or reduction of electrical spacings.

51.2 The sample, or the part in question, is to be placed in a full-draft circulating-air oven maintained at a uniform temperature equal to 10 °C (18 °F) higher than the highest temperature observed on the enclosure or a temperature of 70 °C (158 °F) whichever is higher. The samples are to remain in the oven for seven hours.

51.3 To prevent hazards from overheating energized cells, the batteries shall be removed prior to this test.

51.4 After careful removal from the oven, the sample shall be allowed to cool to room temperature prior to examination. After the conditioning, the sample shall not show any signs of distortion, deterioration, shrinkage, warping, or softening that would allow access to live parts or other hazardous parts such as moving parts.

52 Abnormal Operations

52.1 An AMP shall not emit flame or molten metal or become a risk of fire, electric shock, explosion, or injury to persons when subjected to the tests specified in Sections 53 – 61. Separate samples are to be used for conducting each test, unless using a sample for more than one test is agreeable to all concerned.

52.2 Following each test for AMPs with hazardous voltage circuits, a Dielectric Voltage Withstand Test, Section 73, is to be conducted.

52.3 During these tests, the AMP is to be placed on a softwood surface covered with a white tissue paper and a single layer of cheesecloth or medical gauze is to be draped loosely over the entire enclosure. If it is impractical to drape cheesecloth or medical gauze over the entire enclosure, only the ventilation openings are required to be covered.

52.4 The AMP shall be powered from a fully charged battery for this test. If the test relates to a battery only, the battery is to be supplied from the applicable charger. For all tests performed when the AMP battery is not charging, the inherent protective components associated with the supply of battery power are to remain in place.

52.5 Each test is to be continued until further change as a result of the test condition is reduced significantly. When an automatically reset protector functions during a test, the test is to be continued for seven hours. When a manual reset protector functions during a test, the test is to be continued until the protector is operated for ten cycles using the minimum resetting time, and not faster than ten cycles of operation per minute. The following are examples of acceptable test terminations:

a) Opening or shorting of one or more components such as capacitors, diodes, resistors, solid state devices, printed wiring board traces, or similar devices, when the opening or shorting of the component terminates operation.

b) Opening of an internal fuse or other protective device.

53 Component Faults

53.1 A component, such as a capacitor, diode, solid state device, resistor, or similar component, connected in the AMP's electrical system are to be short- or open-circuited, any two terminals one at a