JOINT CANADA-UNITED STATES
NATIONAL STANDARD

ANSI/CAN/UL 5840:2022

STANDARD FOR SAFETY

Electrical Systems of Battery Powered Aviation Ground Support Equipment

ANSI/UL 5840-2022

SCC FOREWORD

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UL Standard for Safety for Electrical Systems of Battery Powered Aviation Ground Support Equipment, ANSI/CAN/UL 5840

First Edition, Dated May 25, 2022

Summary of Topics

This is the First Edition of ANSI/CAN/UL 5840, Standard for Electrical Systems of Battery Powered Aviation Ground Support Equipment, dated May 25, 2022 including applicable requirements for Canada. These requirements cover the electrical system of lithium based battery powered airport ground support equipment (GSE) with respect to a risk of fire, electric shock, and explosion hazards associated with the battery powered electrical system. These requirements also cover these electrical systems when they are used to convert fueled GSE to battery powered GSE.

The new requirements are substantially in accordance with Proposal(s) on this subject dated February 11, 2022.

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ANSI/UL 5840-2022

MAY 25, 2022

ANSI/CAN/UL 5840:2022

Standard for Electrical Systems of Battery Powered Aviation Ground Support Equipment

First Edition

May 25, 2022

This ANSI/CAN/UL Safety Standard consists of the First Edition.

The most recent designation of ANSI/UL 5840 as an American National Standard (ANSI) occurred on May 25, 2022. 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 25, 2022.

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Preface

This is the First Edition of ANSI/CAN/UL 5840, Standard for Electrical Systems of Battery Powered Aviation Ground Support Equipment.

UL 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 5840 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 to UL at any time. Proposals should be submitted via a Proposal Request in UL's On-Line Collaborative Standards Development System (CSDS) at http://csds.ul.com.

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http://www.shopulstandards.com/HowToOrder.aspx or call tollfree 1-888-853-3503.

This Edition of the Standard has been formally approved by the UL Standards Technical Panel (STP) on Battery Powered Aviation Ground Support Equipment, STP 5840.

This list represents the STP 5840 membership when the final text in this standard was balloted. Since that time, changes in the membership may have occurred.

STP 5840 Membership

Name	Representing	Interest Category	Region
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International Classification for Standards (ICS): 29.220; 53.060

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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.

CETTE NORME NATIONALE DU CANADA EST DISPONIBLE EN VERSIONS FRANÇAISE ET ANGLAISE

INTRODUCTION

1 Scope

1.1 These requirements cover the electrical system of lithium based battery powered airport ground support equipment (GSE) with respect to a risk of fire, electric shock, and explosion hazards associated with the battery powered electrical system.

1.2 These requirements also cover these electrical systems when they are used to convert fueled GSE to battery powered GSE.

1.3 In accordance with 1.1, the minimum GSE electrical system consists of the battery and integral battery management system, interconnecting cables, and input connections for recharging the battery. In addition, the electrical system can also include power train components, electric motors, electric brakes, charging equipment and the like based on manufacturer preference.

1.4 GSE that is capable of being moved and used as a temporary source of power for other equipment, whether that equipment is either located on board the GSE or off board the GSE, is additionally evaluated based on mobile energy storage systems requirements.

1.5 This standard does not address the functional or operations aspects of the GSE such as steering, lifting, towing, and the like.

1.6 This standard does not address any equipment or electrical systems of equipment that are not considered GSE as defined within this standard.

1.7 In relation to conversion systems, these requirements do not address the function or mechanical state of the GSE being converted, or the parts located external to the manufacturer's defined electrical conversion system that may be powered from the electrical conversion system.

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 UL 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 Products covered by this standard shall comply with the referenced installation codes and standards noted in this clause as referenced in the individual clauses of this standard.

4.3 The following publications are referenced in this Standard:

ANSI Z97.1, *Safety Glazing Materials Used in Buildings – Safety Performance Specifications and Methods of Test*

ASTM D1525, *Standard Test Method for Vicat Softening Temperature of Plastics*

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

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

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

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

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

CAN/CSA C22.2 No. 75, *Thermoplastic – Insulated Wires and Cables*

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

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

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

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

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

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

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

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

CAN/CSAC22.2 No. 281.1, *Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits; Part 1: General Requirements*

CAN/CSAC22.2 No. 281.2, *Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits; Part 2: Particular Requirements for Protection Devices for Use in Charging Systems*

CSA C22.2 No. 282, *Plugs, Receptacles, and Couplers for Electric Vehicles*

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

CAN/CSA-E60730-1, *Automatic Electrical Controls – Part 1: General Requirements*

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

IEC 60417, *Graphical Symbols for Use on Equipment*

IEC 61508, all parts, *Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems*

IEC 62061, *Safety of Machinery – Functional Safety of Safety-Related Electrical, Electronic, and Programmable Electronic Control Systems*

ISO 12100, *Safety of Machinery – General Principles for Design – Risk Assessment and Risk Reduction*

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*

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 508, *Industrial Control Equipment*

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 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, *Welding Cable*

UL 1310, *Class 2 Power Units*

UL 1426, *Electrical Cables for Boats*

UL 1449, *Surge Protective Devices*

UL 1564, *Industrial Battery Chargers*

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

UL 1998, *Software in Programmable Components*

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

UL 2231-1, *Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits, Part 1: General Requirements*

UL 2231-2, *Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits, Part 2: Particular Requirements for Protection Devices for Use in Charging Systems*

UL 2251, *Plugs, Receptacles, and Couplers for Electric Vehicles*

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

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

UL 2726, *Battery Lead Wire*

UL 2733, *Surface Vehicle On-Board Cable*

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

UL 9540, *Energy Storage Systems and Equipment*

UL 60335-2-29, *Household and Similar Electrical Appliances – Safety – Part 2-29: Particular Requirements for Battery Chargers*

UL 60730-1, *Automatic Electrical Controls – Part 1: General Requirements*

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

5 Glossary

5.1 For the purpose of this standard, the following definitions apply.

5.2 BATTERY – One or more electrical cells, electrically connected so that the combination furnishes current as a unit. There is one positive and one negative externally accessible connection and no externally accessible inter-cell connections.

5.3 BATTERY MANAGEMENT SYSTEM – The electrical, electronic and software monitoring and control system of a battery that is often relied upon to maintain the battery and its component cells within their specified operating region for charge and discharge, and may be source of memory of the battery operation throughout its life.

5.4 BATTERY PACK – Batteries that are ready for use in GSE, contained in a protective enclosure, with protective devices, with a battery management system, and monitoring circuitry and that may be removable by the user for charging separately from the device.

5.5 CONVERSION SYSTEM – A defined electrical system that is installed on an existing fueled GSE in order to convert the GSE to an electrically powered GSE. The conversion system boundaries are defined by the manufacturer.

5.6 ENCLOSURE – That portion of a unit that reduces the accessibility of a part that involves a risk of fire, electric shock or injury to persons, or reduces the risk of propagation of flame, sparks, and molten metal initiated by an electrical disturbance occurring within.

5.7 GROUND SUPPORT EQUIPMENT (GSE) – Mobile equipment that is powered from a battery power source and is designed and intended to be used for servicing or providing support for transport aircraft when located in the ramp area of an airport.

5.8 MOBILE ENERGY STORAGE SYSTEMS (MESS) – An energy storage system that is not portable, but has a means so that it can be moved (e.g. mounted on a wheeled trailer or skid) to a site to provide power on a temporary basis.

CONSTRUCTION

6 General

6.1 The information provided in this section, and in Sections 7 – 10, is essential guidance for defining and structuring the evaluation path for GSE electrical systems. This information is general in nature, but shall be applied as applicable for the specific design and use cases of the GSE electrical system being evaluated.

6.2 In order to properly apply the requirements in this standard and correctly determine which requirements are applicable to a given product, all electrical systems on GSE shall be determined as containing hazardous voltage or energy in accordance with 8.2, Hazardous voltage and hazardous energy, or having inherently non-hazardous voltage and energy in accordance with Low voltage limited energy, 8.3. For electrical systems with hazardous voltage or energy, Section 10, User Protection During Charging, is applicable, but it is not applicable if the voltage and energy is non-hazardous.

6.3 For GSE that is intended to be used as a temporary source of power for other equipment, the GSE shall be evaluated to the applicable mobile energy storage systems requirements in UL 9540. This does not apply to other items on the GSE where the electrical system is located, such as electrical motors and the like. The requirement applies to GSE that carry a battery bank or larger battery that can be used to provide electrical power to an electrical device that does not contain its own power source or has a power source that has been depleted and requires an outside power source.

7 Conversion Systems

7.1 Electrical conversion systems are required to comply with all requirements in this standard. The electrical conversion system shall be defined based on what is included in the evaluated system. No component of the overall evaluated system can include components that were already located on the GSE prior to conversion.

7.2 The means of installation on the GSE, including all steps for removing existing components or systems, will need to be documented in accordance with the Installation Instructions, Section 43. These installation instructions shall provide statements related to any assessment criteria to determine if the GSE is capable of being converted including any reject criteria. Additionally, any maintenance steps that are required to correct or prepare the GSE for conversion shall be included.

8 Power Levels

8.1 General

8.1.1 For all products covered by this standard, a specific power level will be associated with the power transfer to the GSE during charging and with the use of the battery power source on the GSE. This will require rated voltage and current levels to be specified, but can also include voltages or currents that are available within the GSE being evaluated. Different approaches can be used based on the potential hazards associated with a given power level.

8.1.2 For the purposes of this standard, different designations will be used. This includes hazardous voltage and/or hazardous current resulting in hazardous energy, and in all cases these designations indicate a voltage, current or energy level that is potentially dangerous to the user and means of protection for the user is required. Additional designations cover Low Voltage, Limited Energy (LVLE) which indicates voltage and current levels that are not inherently hazardous to the user and the need for specific protection means may be reduced as indicated in this standard.

8.2 Hazardous voltage and hazardous energy

8.2.1 Any circuit that is operating at a voltage above 42.4 volts peak or 60 V dc is considered to be operating at a hazardous voltage. In these cases, the user must be protected against contact with the part or circuit by the use of an enclosure or proper insulation in both normal operation or under single fault operation. Single fault operation can include damage to the enclosure or failure of the insulation. The requirements for both enclosures and insulation are included in this standard and shall be applied as appropriate in all cases where hazardous voltages exist.

8.2.2 Hazardous energy exists in any circuit or part that is operating with a stored energy level of 20 J or more, or has an available continuous power level of 240 VA or more, at a potential of 2 volts or more. In these cases, the user shall be protected against contact with the part or circuit by the use of an enclosure or proper insulation in both normal operation or under single fault operation. Single fault operation can include damage to the enclosure or failure of the insulation. The requirements for both enclosures and insulation are included in this standard and shall be applied as appropriate in all cases where hazardous energy exist.

8.2.3 With respect to 8.2.2, a continuous power level is defined as any power level that is maintained in excess of the defined limit for longer than a duration of 1 min.

8.3 Low voltage limited energy

8.3.1 A Low-Voltage Limited Energy Circuit (LVLE) shall comply with the limits in Table 8.1.

Table 8.1
Low-Voltage, Limited-Energy Circuits

Inherently limited transformer (overcurrent protection not required)				Not-inherently-limited transformer (overcurrent protection required)			
Circuit voltage (volts)[a]	**0 – 20 volts AC or DC[b]**	**Over 20 volts but not more than 30 volts AC or DC[b]**	**Over 30 volts but not more than 60 volts DC[b]**	**0 – 15 volts AC or DC[b]**	**Over 15 volts but not more than 20 volts AC or DC[b]**	**Over 20 volts but not more than 30 volts AC or DC[b]**	**Over 30 volts but not more than 60 volts DC[b]**
Power limitation (volt-amperes)[c]	–	–	–	350	250	250	250
Current limitation (amperes)[d]	8	8	150/V[a]	1000/V[a]	1000/V[a]	1000/V[a]	1000/V[a]
Maximum overcurrent protection (amperes)	–	–	–	5	5	100/V[a]	100/V[a]

[a] Maximum output voltage, regardless of load, with applied rated voltage.

[b] The AC waveform shall be sinusoidal.

[c] Maximum volt-ampere output regardless of load, and overcurrent protection (if provided) bypassed.

[d] Maximum output after 1 min of operation under any noncapacitive load, including short circuit, and with overcurrent protection (if provided) bypassed.

8.3.2 The power limitations in Table 8.1 may be obtained by the use of any of the following configurations:

a) An inherently-limited transformer;

b) A non-inherently-limited transformer coupled with an overcurrent protective device in the output circuit;

c) A combination transformer and fixed impedance; or

d) An arrangement determined to be equivalent to (a), (b), or (c).

8.3.3 A part or device, other than the battery, located in or supplied by an LVLE circuit need not be investigated for fire or shock hazards. 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.

8.3.4 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 s after the application of the load. The resistor is to be continuously readjusted during this 1 min period to maintain maximum load current. The measured load current shall not exceed the value listed in Table 8.1.

8.3.5 With reference to the voltage limit specified in Table 8.1, measurement is to be made with the product connected to the intended source of supply, during battery operation and during charging, and with all loading circuits disconnected.

8.3.6 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 8.1. The device shall not be of the automatically reset type.

8.3.7 If a regulating network is used to limit the output under any conditions, the LVLE current limitation in Table 8.1 shall not be affected by malfunction of a single component, excluding resistors. The network shall comply with the value in Table 8.1 when the current is measured after 5 s.

9 Combination of Battery, Battery Management System, and Charger

9.1 A battery management system is designed and intended for use with a specific battery. The charger that is supplying the power for recharging the battery has specific output characteristics that are integrated into the overall evaluation of the combination. The charger shall comply with Section 15, Charging Equipment, and the battery and battery management system shall comply with Section 13, Batteries and Battery Management Systems.

9.2 The GSE electrical system evaluation shall be completed using the specific battery and battery management system combination. Additionally, the output characteristics of the charger shall also be factored into the overall evaluation, which may require testing with the specific charger that is intended to be used. Changes to the charger, battery or battery management system should be assessed to insure that the differences will not affect the evaluation or testing responses of the GSE electrical system.

9.3 With reference to 9.2, if the charger is included in the system being evaluated, the evaluation is to consider that charger alone and reliance on output characteristics will be integrally defined. This applies for both offboard and onboard charging equipment.

9.4 As part of the risk assessment in Section 11, Risk Assessment, the manufacturer shall indicate any hazards associated with changing the charger, the battery, or the battery management system in any way. These hazards shall be mitigated by prohibiting the changes or further protections will be required.

10 User Protection During Charging

10.1 General

10.1.1 Charging of the battery may occur while the battery is installed on board the GSE, with the battery removed from the GSE, or both options may apply based on user preference. If the battery is only intended to be charged when it is removed from the GSE, then an inherent means shall be provided to insure that this option is the only option for charging the battery. If no inherent means is provided, and it is possible to charge the battery while on the GSE, the battery shall be considered to be charged both on board and off board the GSE.

10.1.2 If the battery is intended to be charged while on the GSE, whether by inherent construction or user preference, then the requirements in Charging battery on board the GSE, 10.2 apply. If the battery is only capable of being charged when removed from the GSE, then the requirements in 10.2 do not apply.

10.1.3 The requirements in 10.1.1 and 10.1.2 are to be used in conjunction with the requirements in Power Levels, Section 8. If energy levels are such that no hazard exists, then protection means may be reduced as indicated in this standard.

10.2 Charging battery on board the GSE

10.2.1 Charging of the battery on the GSE, where voltage or energy levels exceed the lower limits for shock hazards or electric energy hazards, will require that the exposed conductive surfaces of the GSE are protected and monitored during charging to prevent a hazard due to the charging energy supplied to the GSE. The personnel protection system supplied shall be as indicated in 10.2.2.

10.2.2 For equipment where the specifics of the installation of the on board electrical system is part of the evaluation, the GSE shall be provided with a system of protection that is considered suitable to protect the user. This may include suitable means such as double insulation systems onboard the GSE. The suitability of the protection system shall be judged based on the requirements in this standard. If the specifics of the installation of the electrical systems and its associated protections is not included in the evaluation, such as with conversion systems, then a system of personnel protection in accordance with UL 2231-1 and CAN/CSA-C22.2 No. 281.1 and UL 2231-2 and CAN/CSA-C22.2 No. 281.2 is required to be provided in the charging equipment such that the GSE conductive surfaces are monitored during the power transfer.

10.2.3 The GSE electrical system shall be provided with a means to prevent the provision of power to any electric motor intended for motive power when the GSE is connected to the charger. This means shall be integral to the GSE electrical system, or within the GSE, and shall not be capable of being defeated by the operator.

10.3 Charging battery off board the GSE

10.3.1 For batteries that are removed from the GSE for charging, the charger used to charge the battery shall include all protections for the recharging process. No protection systems in accordance with UL 2231-1 and CAN/CSA-C22.2 No. 281.1 and UL 2231-2 and CAN/CSA-C22.2 No. 281.2 are required to be provided and no protection for recharging is required to be provided on the GSE.

11 Risk Assessment

11.1 A risk assessment of the potential hazards associated with the electrical system of the GSE shall be completed by the manufacturer. The risk assessment shall be completed based on the following:

a) Identify the conditions of use, under normal and reasonably foreseeable misuse, associated with charging, discharging and general use of the GSE electrical system.

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 GSE. 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.

11.2 When completing the risk assessment for conversion systems, specific consideration of hazards that could develop due to the condition of the GSE being converted shall be included. This includes damage from collision, wear and tear, rust, and the like. See Conversion Systems, Section 7.

11.3 The process to complete the risk assessment outlined in 11.1 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 shall be reviewed for each iteration to assess if additional analysis is required.

11.4 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 Section 12, Functional Safety, with a safety level defined by a corresponding hazard and risk analysis.

11.5 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 Section 12, Functional Safety.

11.6 The protective measures or other risk mitigation means shall be shown to be reliable for their intended purpose and function. This shall be accomplished through functional safety evaluations in accordance with Section 12, Functional Safety, or where indicated, by other requirements as outlined in this standard.

12 Functional Safety

12.1 For all components, circuits, and systems identified in the risk assessment of Section 11, Risk Assessment, as being relied upon to mitigate a hazard, functional safety evaluations are required for all software controlled and programmable component mitigating means. Other safety critical components, circuits and systems shall also be evaluated for reliable functionality unless the reliability is already assessed by the requirements and tests in this standard.

12.2 Functional safety criteria can be found in the following standards. These standards, one or more, shall be used to judge functional safety of a component, circuit or system that is relied on for safety in accordance with 12.1.

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

b) IEC 61508, all parts;

c) ISO 13849-1 and ISO 13489-2; or

d) IEC 62061.

12.3 This standard does not assign performance levels or safety integrity levels. These shall be assigned based on the risk assessment of Section 11, Risk Assessment, and the guidance in the specific functional safety standard in 12.2. These values, once assigned, will guide the functional safety evaluation.

13 Batteries and Battery Management Systems

13.1 A battery pack, consisting of a battery and integral battery management system (BMS), shall be provided to power the GSE. The BMS shall monitor operational parameters, including current, voltage and

temperature, of the battery and/or its cells and control the charging and discharging of the battery such that there are no excursions outside the operating parameters of the battery.

13.2 The battery and its BMS shall comply with the requirements in UL/ULC 2580 or UL/ULC 2271.

13.3 Connectors shall be provided as needed for connecting the battery to the GSE electrical system and for connecting off board charging equipment to the GSE, as applicable. One connector can serve both purposes.

13.4 On board the GSE, all connectors shall be suitably rated for the application and shall comply with the requirements of UL 1977 and CSA C22.2 No. 182.3 or UL 2734. If the connectors are provided at the ends of cable, the cable shall be as short as possible to perform the interconnection without interfering with the connection or disconnection of the connector and without placing stress on the connections. The cable shall be provided with insulation that is appropriate for the intended use conditions, rated for the voltage involved, secured so as not to touch hot parts, and in compliance with UL 2726 or UL 2733.

13.5 Connectors used for the connection of the off board charging equipment to the GSE shall comply with UL 1977 and CSA C22.2 No. 182.3 or UL 2251 and CSA C22.2 No. 282.

13.6 If the battery is intended to be removed for charging, or removed to be exchanged with a previously charged battery, then the connector associated with the battery output shall be keyed or configured in a manner that prevents reverse connection. As an alternative, the overall shape of the battery shall inherently prevent reverse connection. The connector shall comply with the requirements in 13.4 and Battery Connector Endurance, Section 37.

14 Battery Compartments

14.1 Support and protection shall be provided for the battery. This may be the enclosure provided by the battery pack itself if one is provided, or it may be accomplished by providing an enclosure or compartment for the battery in the GSE. If an enclosure is provided, it shall comply with the applicable requirements to Section 16, Enclosures of Hazardous Parts.

14.2 The cover of a compartment or enclosure that houses a battery shall remain closed by the force of gravity or shall be provided with a fastener.

14.3 Means shall be provided as a part of the GSE to restrain a battery from moving, from its installed position, more than a total of 12.7 mm (1/2 in) in any horizontal direction due to movement of the GSE.

15 Charging Equipment

15.1 arging equipment consists of a device that transfers power to the GSE in order to recharge the battery. A device with an AC output is referred to as a charge station, and a device with a DC output is referred to as a charger. A charger converts the AC power to DC power for recharging the battery. If a charge station provides AC power to the GSE, then an onboard charger will be required. If a charger provides DC power to the GSE, then no onboard charger is required. If the power transferred to the GSE is considered a hazard in accordance with Power Levels, Section 8, then user protection in accordance with Section 10, User Protection During Charging, is required.

15.2 A charge station shall comply with UL 2594. No additional protection in accordance with Section 10, User Protection During Charging, would be required.

15.3 A charger shall comply with one of the following.

a) UL 1310 and CAN/CSA C22.2 No. 223;

b) UL 1012 and CAN/CSA C22.2 No. 107.1;

c) UL 2202 and CAN/CSA C22.2 No. 107.1;

d) UL 1564 and CAN/CSA C22.2 No. 107.2;

e) UL 1236 and CAN/CSA C22.2 No. 107.2;

f) UL 62368-1 and CAN/CSA C22.2 No. 62368-1; or

g) UL 60335-2-29 and CAN/CSA C22.2 No. 60335-2-29.

If the charger complies with UL 2202 and CAN/CSA C22.2 No. 107.1, then no additional protection in accordance with Section 10, User Protection During Charging, is required.

15.4 Utilizing an onboard charger with a direct cord and plug connection to a receptacle is not allowed.

16 Enclosures of Hazardous Parts

16.1 General

16.1.1 Enclosures 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.

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

16.1.3 The design of the electrical system shall not make use of the frame or chassis of the GSE to carry current during intended operation.

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

16.1.5 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.

16.2 Materials

16.2.1 Metallic materials

16.2.1.1 A metallic enclosure shall comply with the requirements for the Glass Cover Impact, Section 35.

16.2.1.2 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.

16.2.1.3 A cast-metal enclosure shall be at least 3.2 mm (1/8 in) thick at every point and more than 3.2 mm (1/8 in) 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 in) thick for an area greater than 155 cm^2 (24 in^2) or having any dimension more than 152 mm (6 in); and at least 1.6 mm (1/16 in) thick for an area

of 155 cm^2 (24 in^2) or less having no dimension more than 152 mm (6 in). The area considered for material at least 1.6 mm (1/16 in) thick may be bounded by reinforcing ribs subdividing a larger area.

16.2.1.4 The thickness of a sheet-metal enclosure shall not be less than that specified in Table 16.1 and Table 16.2, except that at points to which a wiring system is to be connected, uncoated steel shall be at least 0.81 mm (0.032 in) thick, zinc-coated steel at least 0.86 mm (0.034 in) thick, and nonferrous metal at least 1.14 mm (0.045 in) thick.

16.2.1.5 Table 16.1 and Table 16.2 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.

16.2.1.6 With reference to Table 16.1 and Table 16.2, 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.

Table 16.1
Thickness of Sheet Metal for Enclosures – Carbon Steel or Stainless Steel

Without supporting frame[a]				Without supporting frame[a]				Minimum thickness			
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length		Uncoated		Metal coated	
cm	(in)	cm	(in)	cm	(in)	cm	(in)	mm	(in)	mm	(in)
10.2	(4.0)	Not limited		15.9	(6.25)	Not limited		0.51	(0.020)[d]	0.58	(0.023)[d]
12.1	(4.75)	14.6	(5.75)	17.1	(6.75)	21.0	(8.25)				
15.2	(6.0)	Not limited		24.1	(9.5)	Not limited		0.66	(0.026)[d]	0.74	(0.029)[d]
17.8	(7.0)	22.2	(8.75)	25.4	(10.0)	31.8	(12.5)				
20.3	(8.0)	Not limited		30.5	(12.0)	Not limited		0.81	(0.032)	0.86	(0.034)
22.9	(9.0)	29.2	(11.5)	33.0	(13.0)	40.6	(16.0)				
31.8	(12.5)	Not limited		49.5	(19.5)	Not limited		1.07	(0.042)	1.14	(0.045)
35.6	(14.0)	45.7	(18.0)	53.3	(21.0)	63.5	(25.0)				
45.7	(18.0)	Not limited		68.6	(27.0)	Not limited		1.35	(0.053)	1.42	(0.056)
50.8	(20.0)	63.5	(25.0)	73.7	(29.0)	91.4	(36.0)				
55.9	(22.0)	Not limited		83.8	(33.0)	Not limited		1.52	(0.060)	1.60	(0.063)
63.5	(25.0)	78.7	(31.0)	88.9	(35.0)	109.2	(43.0)				
63.5	(25.0)	Not limited		99.1	(39.0)	Not limited		1.70	(0.067)	1.78	(0.070)
73.7	(29.0)	91.4	(36.0)	104.1	(41.0)	129.5	(51.0)				
83.8	(33.0)	Not limited		129.5	(51.0)	Not limited		2.03	(0.080)	2.13	(0.084)
96.5	(38.0)	119.4	(47.0)	137.2	(54.0)	167.6	(66.0)				

Table 16.1 Continued on Next Page

Table 16.1 Continued

Without supporting frame[a]				Without supporting frame[a]				Minimum thickness			
Maximum width[b]		Maximum length[c]		Maximum width[b]		Maximum length		Uncoated		Metal coated	
cm	(in)	cm	(in)	cm	(in)	cm	(in)	mm	(in)	mm	(in)
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 16.3.3.

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

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

[d] Sheet steel for an enclosure intended for outdoor use shall not be less than 0.86 mm (0.034 in) thick when metal coated and not less than 0.81 mm (0.032 in) thick when uncoated.

Table 16.2
Thickness of Sheet Metal for Enclosures – Aluminum, Copper, or Brass

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

[a] See 16.3.3.

Table 16.2 Continued on Next Page

Table 16.2 Continued

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

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

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

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

16.2.1.7 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.

16.2.1.8 The requirement in 16.2.1.7 applies to all enclosing cases whether of sheet steel or cast iron, and to all parts upon which proper mechanical operation may depend.

16.2.2 Nonmetallic materials

16.2.2.1 A nonmetallic enclosure shall comply with the requirements in Glass Cover Impact, Section 35.

16.2.2.2 Nonmetallic materials used in the construction of enclosures shall have a flammability rating in accordance with Flammability, Section 19.

16.2.2.3 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. Compliance is determined by the Mold Stress, Section 36.

16.2.2.4 The minimum thickness of a nonmetallic enclosure shall be such as to comply with the requirements of 16.2.2.1 – 16.2.2.3.

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

16.2.2.6 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;

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

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 CAN/CSA C22.2 No. 0.17.

16.2.2.7 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 31, for the specific application of the insulating material.

16.2.2.8 A nonmetallic material used for the enclosure of live parts shall be suitable for exposure to water and ultraviolet light, and shall be subjected to the applicable tests in UL 746C and CAN/CSA C22.2 No. 0.17.

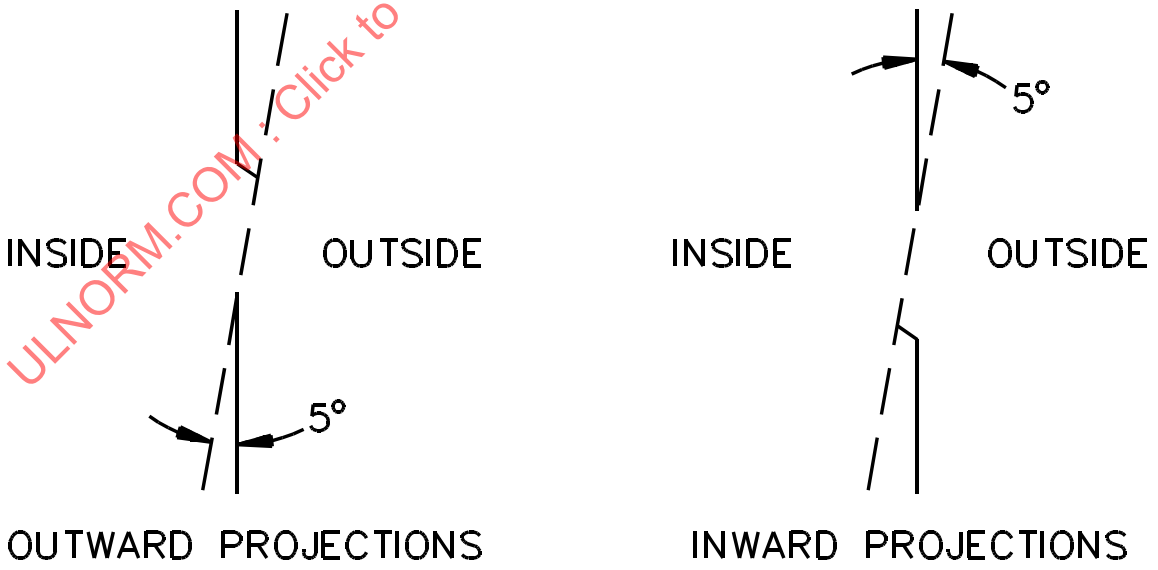
16.3 Openings

16.3.1 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 in) 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.

16.3.2 The minor dimension of any ventilation opening located on the side of an enclosure shall not exceed 4.8 mm (3/16 in) unless the openings are provided with louvers that are shaped to deflect outwards an external vertically falling object – see Figure 16.1.

Figure 16.1

Examples of Louver Design

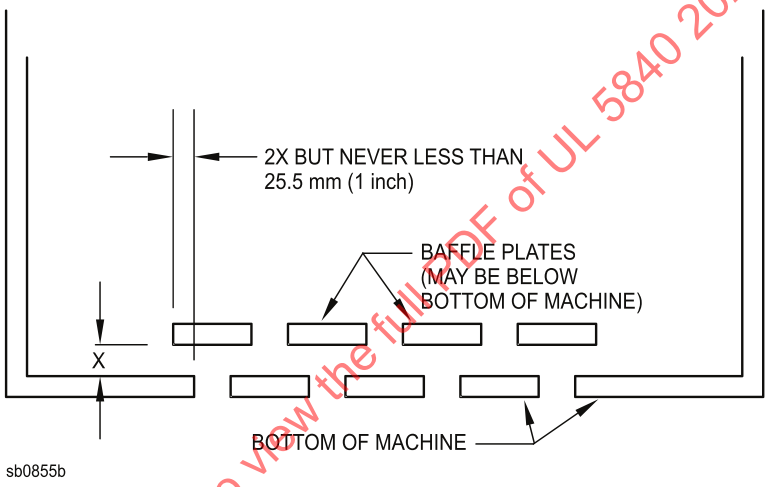


16.3.3 For ventilation openings located in a portion of the enclosure that is not above uninsulated live parts or moving parts, or the openings are so located that an object, upon entering the enclosure, is unlikely to fall on uninsulated live parts involving a risk of fire or electric shock, there are no specified dimensions. However, the openings shall not allow access to uninsulated live parts or moving parts when evaluated using the accessibility probes as described in Accessibility of hazardous parts, 16.6.

16.3.4 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 GSE. An example of such a baffle is illustrated in Figure 16.2.

Figure 16.2

Example of a Bottom Enclosure Baffle



16.4 Doors/Covers/Windows

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

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

16.4.3 A hinged cover provided in accordance with the requirement in 16.4.2 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.

16.4.4 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.

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

a) The glass shall be of a 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 ft·lbf) impact specified in Glass Cover Impact, Section 35.

16.5 Environmental considerations

16.5.1 GSEs are intended for use outdoors in inclement weather. As such, any enclosures shall prevent the entrance of water that could wet hazardous live parts. Enclosures shall comply with the Rain Test, Section 33. As an alternative, an enclosure that complies with an outdoor use rating in accordance with UL 50E and CSA C22.2 No. 94.2 is also acceptable.

16.6 Accessibility of hazardous parts

16.6.1 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 less than 25.4 mm (1 in), such a part or wire shall not be contacted by the probe illustrated in Figure 16.3.

b) For an opening that has a minor dimension of 25.4 mm (1 in) or more, such a part or wire shall be spaced from the opening as specified in Table 16.3.

Exception: A motor need not comply with these requirements if it complies with the requirements in 16.6.2.

Figure 16.3

Articulate Probe with Web Stop

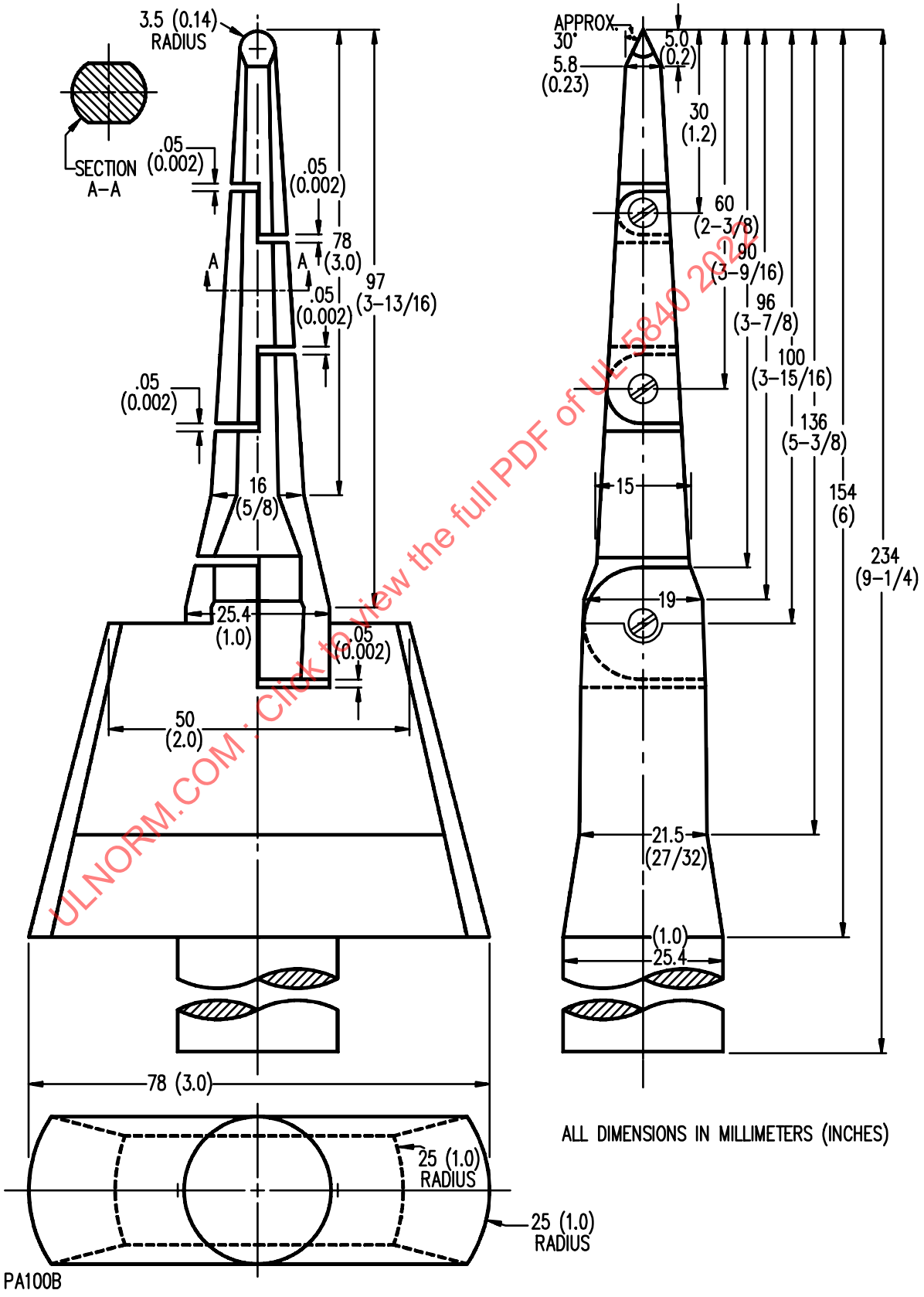


Table 16.3
Minimum Acceptable Distance From an Opening to a Part That May Involve a Risk of Electric Shock or Injury to Persons

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

[a] See 16.6.5.

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

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

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

16.6.2 With reference to a part or wire in an integral enclosure of a motor as mentioned in the Exception to 16.6.1:

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

1) A moving part cannot be contacted by the probe illustrated in Figure 16.4;

2) Film-coated wire cannot be contacted by the probe illustrated in Figure 16.5;

3) In a directly accessible motor, an uninsulated live part cannot be contacted by the probe illustrated in Figure 16.6; and

4) In an indirectly accessible motor, an uninsulated live part cannot be contacted by the probe illustrated in Figure 16.4.

b) An opening that has a minor dimension of 19.1 mm (3/4 in) or more is acceptable if a part or wire is spaced from the opening as specified in Table 16.3.

Figure 16.4

Probe for Moving Parts and Uninsulated Live Parts

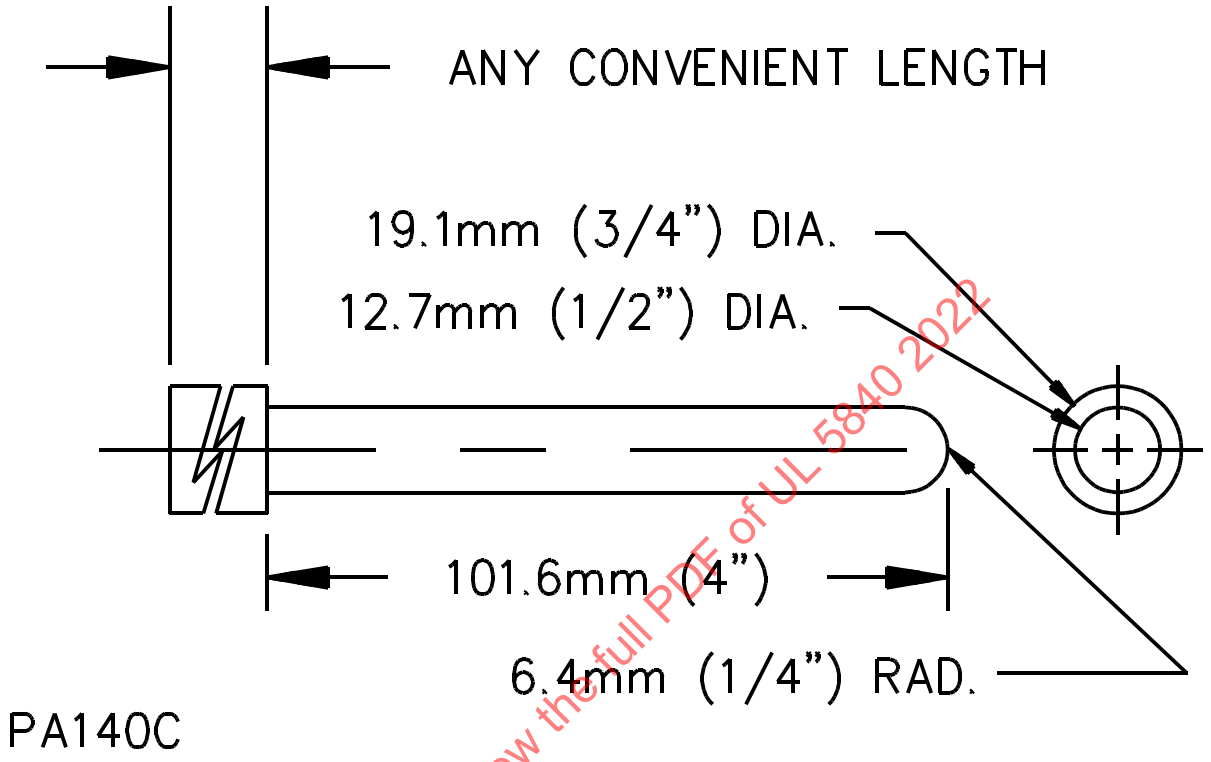


Figure 16.5

Probe for Film-Coated Wire

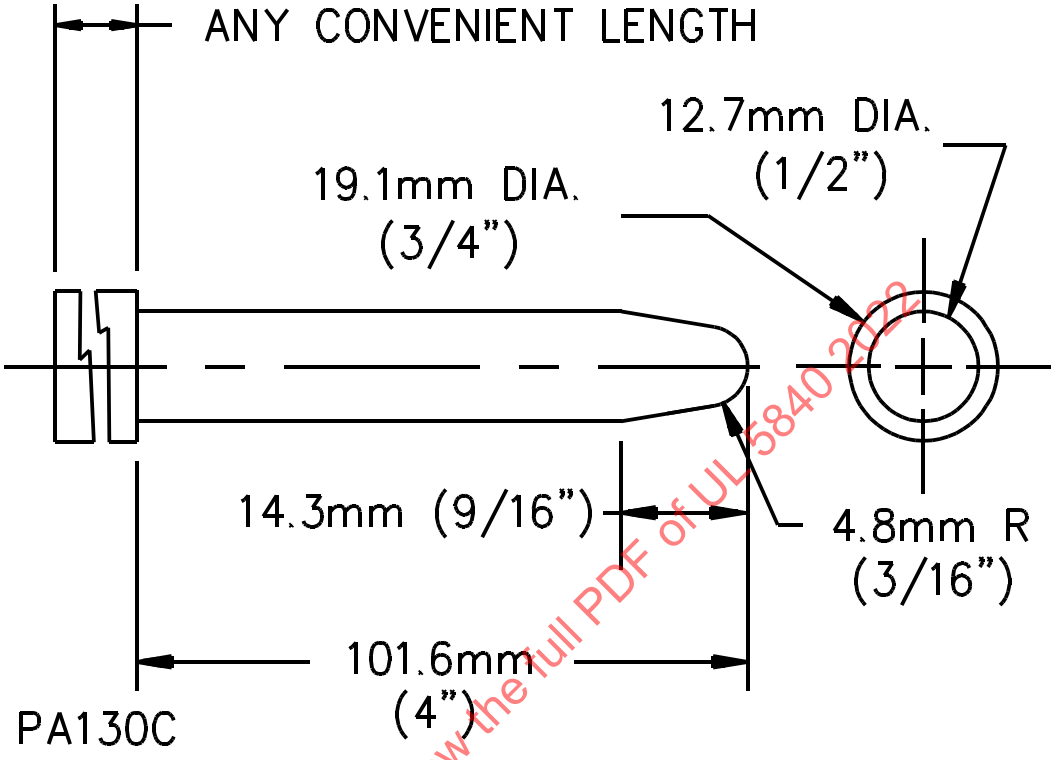
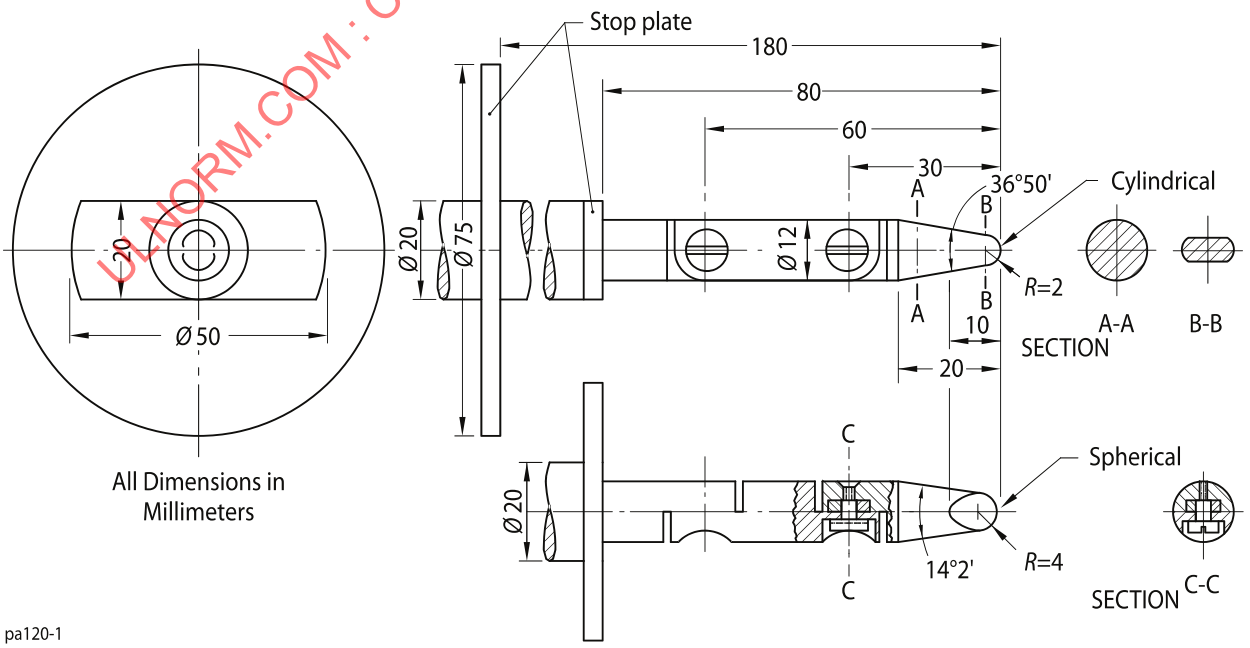


Figure 16.6

Articulate Probe



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16.6.3 The probes mentioned in 16.6.1 and 16.6.3 and illustrated in Figure 16.3 – Figure 16.6 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 16.3 and Figure 16.6 are to be applied in any possible configuration; and, if necessary, the configuration is to be changed after insertion through the opening.

16.6.4 The probes mentioned in 16.6.1 and 16.6.2 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.

16.6.5 With reference to the requirements in 16.6.1 and 16.6.2, 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.

16.6.6 With reference to the requirements in 16.6.2:

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.

16.6.7 During the examination of a product to determine whether it complies with the requirements in 16.6.1 or 16.6.2, 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.

16.6.8 With reference to the requirements in 16.6.1 and 16.6.2, insulated brush caps are not required to be additionally enclosed.

17 Overcurrent Protection

17.1 Power, control and auxiliary circuits shall have overcurrent protection that is sized to prevent overheating of the smallest size conductor.

17.2 An overcurrent device rated or set for 15 amperes is acceptable for protection of a 1 mm^2 (18 AWG) and larger conductors.

17.3 Overcurrent devices in the control and power circuit shall be as close as practicable to the battery. Non-resettable overcurrent devices shall be identified as to the replacement rating of the device. Required marking shall be provided with the GSE separate from the overcurrent device.

17.4 The need for overcurrent protection in the LVLE circuits is to be determined on the basis of the testing described in Low-voltage limited energy circuit, 8.3.

17.5 The overcurrent protective device shall be either a circuit breaker, fuse or positive temperature coefficient device.

17.6 A fuse or circuit breaker shall be either:

a) Acceptable for branch circuit use; or

b) A supplementary type.

17.7 A positive temperature coefficient device shall comply with Manufacturing Deviation and Drift, Clause 15; Endurance, Clause 17; and Requirements for Controls Using Thermistors, Annex J, in UL 60730-1 and CAN/CSA-E60730-1.

18 Motors and Electromechanical Brakes

18.1 For all motors or electromechanical brakes included as part of the electrical system, the following requirements apply.

18.2 Motors shall comply with UL 1004-1 and CSA C22.2 No. 100.

Exception: A motor located in an LVLE circuit is not required to comply with this requirement.

18.3 When lead wires of a motor do not pass out of the motor directly into an acceptable raceway, or when they are brought out through the motor case, they shall pass through openings that are insulated.

18.4 Electromechanical brakes shall comply with Part XVI, Miscellaneous Devices, of UL 508 and the applicable requirements of CSA C22.2 No. 14.

Exception: An electromechanical brake located in an LVLE circuit is not required to comply with this requirement.

19 Flammability

19.1 Nonmetallic materials used for enclosures on board the GSE shall have a minimum flammability rating of 5V in accordance with the requirements in UL 94 and CAN/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.

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

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

19.4 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.

19.5 Nonmetallic materials located outside the enclosure, and not used to complete the enclosure, are considered decorative parts and are not required to have a specific flame rating.

19.6 Printed wiring board materials shall be rated as indicated in Section 23, Printed Wiring Boards.

19.7 For the requirements outlined in 19.2 – 19.6, 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 CAN/CSA C22.2 No. 0.17.

20 Mechanical Assembly

20.1 Loosening of parts as a result of handling and intended operation of the device shall not result in a risk of fire, a risk of electric shock, or a risk of injury to persons.

20.2 Screws with lock washers applied as intended, screws tightened by means of a power tool, rivets, and staked and upset screws are considered to comply without further evaluation. See 20.3.

20.3 The construction of staked and upset screws is to consist of an interference fit between the nut and bolt resulting in uneasy turning of the screw. This shall be accomplished by the use of a center punch applied to the end of a bolt after assembly, mismatching of the nut and bolt threads, or the equivalent.

20.4 Except as indicated in 20.5, a rotating part that, when loosened, results in a risk of fire, electric shock, or injury to persons shall be assembled so that the direction of the rotation tends to tighten the means that hold the rotating part in place.

20.5 A keyed part, a press fit, a part locked in place with a pin, or equivalent means to hold a rotating part in place is considered to comply with this requirement.

20.6 switch, fuseholder, attachment plug, or other component that is handled by the operator shall be mounted securely, and shall not turn when handled. In addition, the connection shall comply with the requirements in 20.7.

20.7 The means of securing components mentioned in 20.6 shall include more than friction between surfaces. A lock washer is an example of a means to secure a device having a single hole mounting means.

21 Spacings and Separation of Circuits

21.1 General

21.1.1 The spacings in an electrical system of a GSE shall not be less than the minimum acceptable values specified in Table 21.1 unless otherwise specified in this section.

21.1.2 Minimum acceptable spacings are not specified for a rotating part, such as an armature assembly, of a motor rated 24 volts-nominal or less or a motor of the control, blower, or signal-circuit type that is employed in a 50-volt or lower-voltage circuit, that has a locked-rotor current of 15 amperes or less, and that is protected by an overcurrent-protective device having a maximum rating or setting of 15 amperes if:

a) The armature winding is insulated with an alkyd-base, silicone-base, or equivalent insulating varnish that is resistant to moisture, acid, and oil;

b) The end of the commutator segments – where the insulating material is placed between the commutator bars and the retaining V-ring – is coated with an alkyd-base, silicone-base, or equivalent insulating compound that is resistant to moisture, acid, and oil; and

c) The device complies with the Dielectric Strength Test, Section 29.

21.1.3 Minimum acceptable spacings are not specified in an LVLE circuit.

21.1.4 The minimum acceptable spacings within a component – for example, a switch – supplied as a part of GSE electrical systems shall not be less than the minimum acceptable spacings for the component or the minimum acceptable spacings specified in Table 21.1, whichever are smaller.

Table 21.1
Minimum Acceptable Spacings

Location	Nominal voltage 24 volts or less				Nominal voltage greater than 24 volts			
	Through air,		Over surface,		Through air,		Over surface,	
	mm	(in)	mm	(in)	mm	(in)	mm	(in)
In a power circuit - between a bare live part and (1) a bare live part of opposite polarity, or (2) a bare grounded part other than the enclosure	1.6[a]	(1/16)	3.2[a]	(1/8)	3.2[b]	(1/8)	6.4[b]	(1/4)
In a power circuit at a location where conductive dust cannot accumulate, such as a small totally enclosed cavity [c]	0.8	(1/32)	1.6	(1/16)	1.6	(1/16)	3.2	(1/8)
In other than a power circuit – between a bare live part and (1) a bare live part of opposite polarity, or (2) a bare grounded part other than the enclosure	1.6	(1/16)	1.6	(1/16)	1.6	(1/16)	1.6	(1/16)
In other than a power circuit at a location where conductive dust cannot accumulate, such as a small totally enclosed cavity [c]	0.8	(1/32)	0.8	(1/32)	0.8	(1/32)	0.8	(1/32)
Between any uninsulated live part and the ultimate enclosure [d]	12.7	(1/2)	12.7	(1/2)	12.7	(1/2)	12.7	(1/2)
Between any uninsulated live part and the ultimate enclosure where the enclosure is formed of 3.2 mm (1/8 in) thick cast metal or 6.4 mm (1/4 in) thick steel plate [d]	6.4	(1/4)	6.4	(1/4)	6.4	(1/4)	6.4	(1/4)

[a] These spacings apply to a system not electrically connected to the frame.

[b] These spacings also apply to a nominal 24-volt or lower-voltage system electrically connected to the frame.

[c] Such as a point where a motor terminal passes through the motor frame.

[d] If deformation of the enclosure at the point of measurement of spacings is likely, the spacings after deformation shall be as specified.

21.1.5 Solid state circuitry (e.g. motor controllers, dc-dc converters, machine controls, etc.) as used in GSE electrical systems and evaluated by this standard may employ, as an alternative to the spacing requirements of Table 21.1, the spacing requirements in UL 840 and CSA C22.2 No. 0.2. When UL 840 and CSA C22.2 No. 0.2 is used, the following considerations shall apply:

a) The spacing requirements of UL 840 and CSA C22.2 No. 0.2 shall not be used for spacings to an ultimate dead metal enclosure;

b) When a component employs a voltage limiting device for application of the requirements in UL 840 and CSA C22.2 No. 0.2, the device shall comply with UL 1449; and

Exception: This does not apply to circuits supplied only by batteries.

c) Components supplied by battery circuits shall be considered over-voltage category II. An over-voltage category is the grouping of products based on a typical installed location with respect to over-voltage protection and available energy as defined in UL 840 and CSA C22.2 No. 0.2.

21.2 Barriers

21.2.1 An insulating barrier or liner used as the sole separation between an uninsulated live part and a dead metal part, including the enclosure, or between uninsulated live parts of opposite polarity shall be of a suitable material. The barrier or liner shall not be less than 0.71 mm (0.028 in) thick.

Exception No. 1: In circuits rated 24 volts or less, the thickness shall not be less than 0.33 mm (0.013 in).

Exception No. 2: The thickness is not required if the insulating material complies with 21.2.4.

21.2.2 An insulating barrier or liner used in addition to an air space in place of the required spacing through air shall not be less than 0.8 mm (1/32 in) thick.

Exception No. 1: In circuits rated 24 volts or less, the thickness shall not be less than 0.33 mm (0.013 in).

Exception No. 2: The thickness is not required if the insulating material complies with 21.2.3 and 21.2.4.

21.2.3 For electrical systems rated more than 24 volts, a barrier or liner of suitable material and used in addition to not less than half of the required minimum acceptable spacing through air shall have a minimum thickness of not less than 0.33 mm (0.013 in). For electrical systems rated 24 volts or less, the minimum thickness shall be not less than 0.15 mm (0.006 in).

Exception: The thickness is not required if the insulating material complies with 21.2.4.

21.2.4 Insulating material having a thickness less than that specified in 21.2.1 – 21.2.3 is permitted to be used if, upon investigation, the material is found to be equivalent in performance to the materials specified in those paragraphs.

21.2.5 A barrier or liner as mentioned in 21.2.1 – 21.2.3 shall be secured in place and shall be located so as to minimize the possibility of damage during operation of the equipment.

21.3 Separation of circuits

21.3.1 An LVLE circuit shall be separated from all other circuits either by:

a) Locating the circuit in a separate enclosure,

b) Providing through-air and over-surface spacings as specified in Table 21.1 and 21.1.5, or

c) The use of barriers in accordance with Barriers, 21.2.

21.3.2 An insulated conductor of internal wiring of a LVLE circuit shall be either:

a) Separated by barriers or segregated from live parts connected to different circuits, or

b) Provided with insulation acceptable for the highest voltage involved.

21.3.3 Segregation of insulated conductors is to be accomplished by clamping, routing, or equivalent means that provides permanent separation from live parts of a different circuit.

21.3.4 A live part in a LVLE circuit shall be constructed so that the possibility of the live part touching dead metal or touching live parts of other circuits is minimized.

21.3.5 The barriers mentioned in 21.3.1 are permitted to be grounded metal not less than 0.51 mm (0.020 in) thick, or insulating material not less than 0.71 mm (0.028 in) thick.

22 Internal Wiring

22.1 The wiring used within the GSE electrical system that is located within an enclosure 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 CAN/CSA C22.2 No. 210;

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

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

d) SAE J1128;

e) UL 66;

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

g) UL 1426; or

h) UL 1063.

Exception: This requirement does not apply to wiring located in a LVLE circuit.

22.2 The wiring used within the GSE electrical system 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.

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

22.4 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 dielectric strength required by Section 29, Dielectric Strength Test, 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.

22.5 Wiring shall be protected against mechanical damage by:

a) Housing it in enclosures;

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.

Exception: This requirement does not apply to wiring located in a LVLE circuit.

22.6 Protection for insulated leads located within the operator's compartment is not required if:

a) The walls and floor of this compartment are of metal, phenolic composition, or other thermosetting material having equivalent mechanical strength and resistance to impact; and

b) The leads are not likely to be subjected to mechanical damage by the operator.

22.7 Wiring connections to a continuously moving part, or a part for which the degree of movement is appreciable shall be a Type such as S, SJ, SJE, SJO, SEO, SJT, SJTO, SJEO, SO, ST, SE, or STO flexible cord.

Exception No. 1: Individual conductors having flexible stranding, such as Type FFH-2, TFF, or SFF-2, enclosed in flexible tubing are permitted to be used in place of flexible cord. The tubing is not required on exposed moving conductors that are readily visible to the operator and are therefore subject to replacement when damaged.

Exception No. 2: Cords determined to be equivalent to those within UL 62 and CAN/CSA C22.2 No. 49, but with an increased number of conductors, may be acceptable.

22.8 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.

22.9 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.

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

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

Exception: Control wiring and other small conductors which are connected by crimped or soldered special-type lugs or eyelets.

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

23 Printed Wiring Boards

23.1 A printed-wiring board shall comply with UL 796 and CSA C22.2 No. 0.17.

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

23.3 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 21, may be acceptable if it complies with UL 796.

24 Interlocks

24.1 An interlock required to reduce the risk of electric shock or injury to persons shall comply with 24.2 – 24.8.

24.2 The interlock device shall not be defeated readily without:

a) Damaging the equipment;

b) Making wiring connections or alterations;

c) Using other than ordinary tools; or

d) Using materials other than those readily available. Adhesive tape, string, or conventional extension cord sets are identified as readily available.

24.3 The interlock device shall be such that during normal operation and user servicing:

a) The interlock is not defeated by improper disassembly, for example, removal of the wrong screws during removal of the cover;

b) The cover in which the interlock is mounted shall not be rotated by its own weight about the interlock axis perpendicular to the cover during any stage of its removal or replacement, if such rotation gives access to a live part, or damages the interlock or cover;

c) The act of removal or replacement of the interlocked cover shall not subject the user to unintentional contact with live parts; and

d) The interlocked cover is not capable of being readily misapplied to result in a risk of electric shock.

24.4 With reference to 24.3(c), parts that are recessed more than 64 mm (2-1/2 in) from the edge of the opening, normally in the plane of the cover, are excluded when determining that the act of removal or replacement of a cover will subject the user to unintentional contact with live parts.

24.5 An interlock switch shall be suitable for a minimum of 10,000 operations without failed functionality.

24.6 An actuator of an interlock switch shall be so located so as to reduce the risk of unintentional operation.

24.7 Operation of an interlock in normal use shall not inconvenience the operator so as to encourage deliberate defeat of the interlock.

24.8 If an interlock is actuated by movement of a guard, the arrangement shall be such that the guard is in place when the interlock is in the open position that permits operation of the parts being guarded. With the guard removed, the interlock shall comply with the requirements in 24.6.

25 Adhesives

25.1 An adhesive that is relied upon to reduce the risk of fire, electric shock, or injury to persons, shall comply with the requirements for adhesives in UL 746C and CAN/CSA C22.2 No. 0.17.

26 Lasers

26.1 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).

PERFORMANCE

27 General

27.1 Unless otherwise stated, compliance with the performance requirements shall be determined by testing a representative model of the GSE electrical system. The performance of the electrical system shall be investigated by subjecting a representative sample or samples to the tests described in Sections 28 – 38, 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.

27.2 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 h at room ambient.

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

27.4 Temperature shall be measured using thermocouples. Thermocouples are to consist of wires not larger than 0.21 mm^2 (24 AWG) and not smaller than 0.05 mm^2 (30 AWG). Whenever reference temperature measurements by thermocouples are necessary, thermocouples consisting of 0.05 mm^2 (30 AWG) iron and constantan wire and a potentiometer-type instrument are to be used. The thermocouple wire is to conform with the requirements specified in the Tolerances on Initial Values of EMF versus Temperature tables in ANSI/ASTM E230/E230M. For those tests that require the sample to reach thermal equilibrium (also referred to as steady state conditions), thermal equilibrium is considered to be achieved after three successive readings taken at intervals of 10 % of the previously elapsed test duration, but not less than 5 min intervals, indicate no change in temperature greater than ±2 °C (±3.6 °F).

27.5 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 GSE 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.

27.6 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.

27.7 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.

27.8 Unless noted otherwise in the individual test methods, the tests shall be followed by a 1-h observation time prior to concluding the test and temperatures are to be monitored in accordance with 27.6.

27.9 A GSE's electrical systems that are operational after 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.

28 Power Input/Output Verification

28.1 The input rating to the GSE, and the output rating of an off board charger, shall not exceed the manufacturer's specified rating by more than 10 %.

28.2 GSEs where the battery is charged while the battery remains on the GSE shall be tested in accordance with 28.3. GSEs where the battery is removed and charged off board the GSE shall be tested in accordance with 28.4.

28.3 A GSE with a fully discharged battery is connected to its off board charger as intended. The connection is made through a meter that can measure the input current to the GSE. This measured value is recorded and compared to the manufacturer's specified input rating for the GSE during charging and the charger's specified output rating.

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

29 Dielectric Strength Test

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

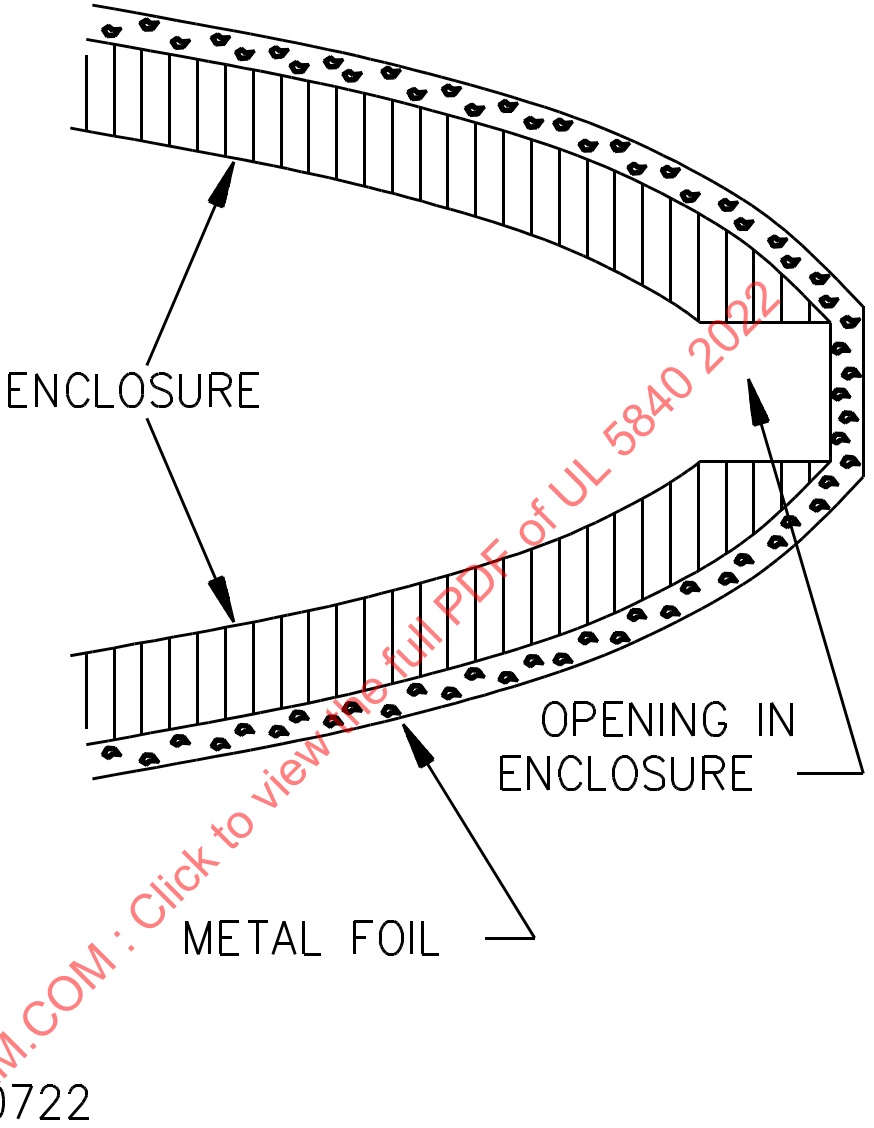
29.2 Circuits at 60 Vdc or higher shall be subjected to a dielectric withstand voltage consisting of a dc potential of twice the rated voltage.

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

29.4 If the accessible parts of the GSE 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 29.1.

Figure 29.1

Method of Covering Enclosures With Foil for Measurement and Tests



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

29.6 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.

29.7 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).

30 Humidity Conditioning

30.1 GSE electrical systems shall comply with the Dielectric Strength Test, Section 29, following this exposure. The test is performed with each sample subjected to an exposure for 48 h to air having a relative humidity of 92.5 ±2.5 % relative humidity at a temperature of 42 ±2 °C (107.6 ±4 °F).

30.2 To determine if equipment complies with the requirement in 30.1, the equipment is to be heated to a temperature just above 34 °C (93 °F) to reduce condensation of moisture during conditioning. The heated equipment is to be placed in the humidity chamber and conditioned for 48 h under the conditions specified in 30.1. Following the conditioning, the equipment is to be subjected to the Dielectric Strength Test, Section 29.

31 Temperature Test

31.1 General

31.1.1 This test is conducted to determine whether or not temperature sensitive safety critical components and temperature sensitive materials in the GSE 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.

31.1.2 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 27.4.

31.1.3 With reference to 31.1.2, 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.

31.1.4 A GSE with a non-removable battery is tested in accordance with 31.2, GSEs with non-removable batteries. A GSE with a battery that is inherently required to be removed for charging, shall be tested in accordance with 31.3, GSEs with removable batteries. For a GSE that provides the user with an option and allows for charging both on board or off board the GSE, the test shall be in accordance with both 31.2 and 31.3.

31.1.5 Temperatures measured on components shall not exceed their specifications. See Table 31.1 and Table 31.2 for surface and component temperature limits.

Table 31.1
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 in)		
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 in) 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 in)		
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 in) or less		
a. In an open motor:		
Thermocouple or resistance method	120	(248)
b. In a totally enclosed motor:		
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. Reserved		
3. Field wiring terminals	75	(167)
4. Vulcanized fiber employed as electric insulation	90	(194)
5. Plated bus bar	90	(194)
6. Unplated bus bar and a joint	75	(167)
7. Relays, solenoids, and similar devices		
a. Class 105 coil insulation systems:		

Table 31.1 Continued on Next Page

Table 31.1 Continued

Materials and components	Temperature limit	
	°C	(°F)
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)
8. 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)
9. Phenolic composition employed as electrical insulation or as a part the deterioration of which results in a risk of fire or electric shock	150[c]	(302)[c]
10. Wood and other combustible material	90	(194)
11. Rubber- or thermoplastic-insulated wire and cord	60[c,d]	(140)[c,d]
12. Other types of insulated wires	e	e
13. A surface upon which a portable unit is mounted in service, and surfaces that are adjacent to the unit when so mounted	90	(194)
14. Any point on or within a terminal box or compartment of a fixed unit on which field-installed conductors rests	60	(140)
15. Thermoplastic sealing compound	f	f
16. Selenium rectifier	75[c,g]	(167)
17. Power semiconductor	g	g
18. Printed-wiring board	h	h

[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.

Table 31.1 Continued on Next Page

Table 31.1 Continued

Materials and components	Temperature limit	
	°C	(°F)
[c] 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 CAN/CSA C22.2 No. 0.17.		
[d] 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 and UL 746B and CAN/CSA C22.2 No. 0.17.		
[e] The temperature is not to exceed the temperature limit of the wire except as noted in note d.		
[f] 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.		
[g] For a power-switching semiconductor and similar components the temperature limit on the case is the maximum case temperature specified by the semiconductor manufacturer.		
[h] For a printed wiring board, the temperature limit is the specified limit of the board.		

Table 31.2
Temperatures on User Accessible Surfaces

Accessible surfaces	Maximum surface temperatures		
	Metal	Glass, porcelain and vitreous materials	Plastic and rubber[a]
	°C (°F)	°C (°F)	°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 in), and which are not likely to be touched in normal use, temperatures up to 100 °C (212 °F) are permitted.			
[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.			

31.2 GSEs with non-removable batteries

31.2.1 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.

31.2.2 During this test, the GSE is tested under conditions of normal operation. If the GSE is intended to carry a load, the maximum load as specified by the manufacturer is to be applied.

31.2.3 At the conclusion of the test, the GSE and battery shall be subjected to an observation period in accordance with 27.8. A GSE that contains hazardous operating voltages shall be subjected to a Dielectric Strength Test, Section 29.

31.3 GSEs with removable batteries

31.3.1 For this test, the complete test cycle is defined to represent the worst case possible use. This would include operation of the GSE 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 GSE is to continue until the temperatures stabilize in accordance with 27.4. This continuous operation until temperatures stabilize is one complete test cycle and only one cycle is needed for this test.

31.3.2 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 GSE 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 GSE.

31.3.3 The loading parameters and use parameters for this test shall be as specified in 31.2.2.

31.3.4 At the conclusion of the test, the GSE and battery, as well as all other batteries used in the test, shall be subjected to an observation period in accordance with 27.8. A GSE that contains hazardous operating voltages shall be subjected to a Dielectric Strength Test, Section 29.

32 Abnormal Operation

32.1 General

32.1.1 A GSE 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 32.2 – 32.7. Separate samples are to be used for conducting each test, unless using a sample for more than one test is agreeable to all concerned.

32.1.2 Following each test for GSEs with hazardous voltage circuits, a Dielectric Strength Test, Section 29, is to be conducted.

32.1.3 During these tests, the GSE is to be placed on a softwood surface covered with a white tissue paper and a single layer of cheesecloth is to be draped loosely over the entire enclosure. If it is impractical to drape cheesecloth over the entire enclosure, only the ventilation openings are required to be covered. The white tissue paper is to be soft and strong, lightweight wrapping paper of a weight generally between 12 g/m^2 and 30 g/m^2, primarily intended for protective packaging of delicate articles and for gift wrapping.

32.1.4 The GSE 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 GSE battery is not charging, the inherent protective components associated with the supply of battery power are to remain in place.

32.1.5 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 min. 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.

32.2 Component faults

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

time, during any condition of operation including start-up. This test is not required where circuit analysis indicates that no other component or portion of the circuit is overloaded. At the end of each component fault condition, the GSE electrical system shall comply with the requirement in 32.1.1.

32.2.2 The components chosen for the test shall take into consideration fault testing that is coordinated with the risk assessment and functional safety in Sections 11, Risk Assessment, and 12, Functional Safety. Not all components need be faulted but components shall be selected that are anticipated to provide a potentially hazardous condition which includes the deactivation of protective systems.

32.3 Relay or solenoid burnout

32.3.1 An electromagnetic relay or a solenoid having an open coil construction is to be tested by blocking the armature or the plunger in the de-energized position. The test shall be continued until constant temperatures are obtained or for 7 h maximum. The test results shall comply with 32.1.1.

32.4 Disconnected fan and blocked ventilation

32.4.1 A GSE provided with forced ventilation for the electrical circuits is to be operated with the fan disconnected. For a GSE having more than one fan, the test is to be conducted with each fan disconnected, one at a time, or with two or more fans disconnected, if they are controlled or powered by the same connection. If part of the circuitry senses a disconnected fan and shuts down the unit, the circuitry shall be bypassed to allow operation with the fans disconnected or the circuitry shall be evaluated for suitability of this protective function in accordance with Functional Safety, Section 12.

32.4.2 The test shall also be performed by blocking ventilation openings for allowing air flow to cool internal components, and the unit shall be operated at maximum normal load. If fans are provided for forced ventilation, the fans shall remain operational with the vents blocked. The test shall be continued until constant temperatures are obtained or for 7 h maximum. During and after the test, the GSE shall comply with 32.1.1.

32.5 Motor overload test

32.5.1 This test is intended to evaluate a motor's ability to safely withstand an overload condition, which may occur in the end use application.

Exception: This test is not required if the motor and its overload protection have already been evaluated as part of a motor and motor protector combination evaluation.

32.5.2 The motor can be tested while in the GSE or it can be removed and tested outside the GSE. Temperatures on windings are to be monitored. If the windings are not accessible for small motors, case temperatures can be monitored as an alternative.

32.5.3 For hazardous voltage motors, the motor is first operated under maximum normal load conditions. The load is then increased so that the current is increased in appropriate gradual steps with the motor supply voltage being maintained at its original value. When steady state temperature conditions are established the load is again increased. The load is thus progressively increased in appropriate steps until either the overload protection device operates or the motor winding becomes an open circuit. The motor winding temperatures are determined during each steady period and the maximum temperature recorded. The maximum temperature shall not exceed the value in Table 32.1.