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**IEEE Standard for Electrical and
Electronic Control Apparatus
on Rail Vehicles**

IEEE Vehicular Technology Society

Sponsored by the
Rail Transit Vehicle Interface Standards Committee



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IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles

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Rail Transit Vehicle Interface Standards Committee
of the
IEEE Vehicular Technology Society

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Abstract: This standard is intended to provide a set of uniform design, application, and test requirements for electrical and electronic control apparatus on rail vehicles.

Keywords: apparatus, control, design, electrical, electrohydraulic, electronic, electropneumatic, rail, routine test, test, transit, type test

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Introduction

This introduction is not part of IEEE Std 16-2004, IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles.

This standard is intended to apply to rail vehicles that are electrically powered. These vehicles include locomotives, railway electric multiple unit (EMU) cars, Heavy Rail Vehicles, and Light Rail Vehicles, including units that combine powered and unpowered trucks or axles. Fully-automated, driverless implementations of the above vehicle types are sometimes included in the mode of transit referred to as Automated Guideway Transit (AGT), and, to the extent that the vehicle does not have other unique requirements, this standard can be applied. It is not intended that this standard be universally required for all AGT systems.

The classes of railway vehicles (such as those termed “Diesel Multiple Unit” [DMU]) that use a non-electric propulsion system have features of the electrical systems used in these vehicles that are similar to those used in “conventional” electrically-powered vehicles. To the extent that these systems are similar to those used in electrically powered vehicles, this standard can be applied.

NOTE—Self-propelled railway vehicles operating on trackage of the general railroad system are subject to regulations issued by governmental bodies (e.g., federal, state, and local bodies). In selected jurisdictions this is also true for rail transit vehicles. The user of this Standard should recognize that such regulations always take precedence over a consensus standard.

Certain heavy-duty rubber tired vehicles, notably dual-mode, hybrid, and electric trolley buses and large off-highway haulage trucks, utilize electric propulsion systems. Again, to the extent that these systems are similar to those used in rail vehicles, this standard can be applied.

It should be noted that this standard makes extensive use of the phrase, “as agreed to between the supplier and the authority having jurisdiction”, as well as requiring that the “authority having jurisdiction” provide certain significant parameters and/or make important determinations relevant to a specific project and not necessarily able to be anticipated in advance. Annex B lists all such citations within the standard and categorizes them as guidance for users of this standard.

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IEEE Standard for Electrical and Electronic Control Apparatus on Rail Vehicles

1. Overview

1.1 Scope

This standard prescribes design, application, and test requirements for electrical and electronic control apparatus on rail vehicles.

NOTE—This standard covers neither rotating equipment nor the functional aspects of converters.¹

1.2 Purpose

This standard is intended to provide a set of uniform design, application, and test requirements for electrical and electronic control apparatus on rail vehicles. These requirements are the minimum necessary to ensure suitability for use in a rail vehicle environment. Use of this standard should lead to enhanced levels of safety and reliability, and lower acquisition and maintenance costs.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C84.1-1995, Electric Power Systems and Equipment - Voltage Ratings (60 Hz).²

APTA RP-E-009-98, Recommended Practice for Wire Used on Passenger Rolling Stock.³

APTA SS-E-010-98, Standard for the Development of an Electromagnetic Compatibility Plan.

APTA SS-M-011-99, Standard for Compressed Air Quality for Passenger Locomotive and Car Equipment.

¹ Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

² ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³ APTA publications are available from the American Public Transportation Association, (<http://www.apta.com/>).

ASTM B172-2001A, Standard Specification for Rope-Lay-Stranded Copper Conductors Having Bunch-Stranded Members, for Electrical Conductors.⁴

ASTM B174-2002, Standard Specification for Bunch-Stranded Copper Conductors for Electrical Conductors.

EN 50121-3-2:2000, Railway Applications - Electromagnetic Compatibility - Part 3-2: Rolling Stock – Apparatus.⁵

Federal Specification W-C-596G-2001, General Specification for Power Electrical Connector (with amendments).⁶

IEC 61024-1-1:1993, Protection of structures against lightning – Part 1: General principles – Section 1: Guide A: Selection of protection levels for lightning protection systems.⁷

IEC 61287-1:1995, Power convertors installed on board rolling stock – Part 1: Characteristics and test methods.

IEEE Std 1TM-2000, IEEE Recommended Practice: General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.^{8,9}

IEEE Std 11TM-2000, IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles.

IEEE Std 1476TM-2000, IEEE Standard for Passenger Train Auxiliary Power Systems Interfaces.

IEEE Std 1478TM-2001, IEEE Standard for Environmental Conditions for Transit Rail Car Electronic Equipment.

IEEE Std 1482.1TM-1999, IEEE Standard for Rail Transit Vehicle Event Recorders.

IEEE Std C37.20.2TM-1999, IEEE Standard for Metal-Clad Switchgear and Station-Type Cubicle.

IPC-2220, Design Standard Series, Printed Boards.¹⁰

IPC-A-610-2001, Acceptability of Electronic Assemblies.

IPC-CC-830B-2002, Qualification and Performance of Electrical Insulating Compound for Printed Wiring Assemblies.

⁴ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

⁵ EN publications are available from the European Committee for Standardization (CEN), 36, rue de Stassart, B-1050 Brussels, Belgium (<http://www.cenorm.be>).

⁶ Federal specifications are available from the US General Services Administration (<http://www.gsa.gov/>).

⁷ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

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¹⁰ IPC publications are available from the Institute for Interconnecting and Packaging Electronic Circuits (IPC), 2215 Sanders Road, Northbrook, IL 60062-6135 (<http://www.ipc.org/>).

ISO 4406:1999, Hydraulic fluid power - Fluids - Method for coding level of contamination by solid particles.¹¹

MIL-DTL-5015H, General Specification for Connectors, Electrical, Circular Threaded, AN Type.¹²

MIL-M-81531, Notice 1, Marking of Electrical Insulating Materials.

NEMA LI 1-1998, Industrial Laminated Thermosetting Products.¹³

NEMA WD 6-2002, Wiring Devices - Dimensional Requirements.

SAE AS4059 APR01, Aerospace Fluid Power - Cleanliness Classification for Hydraulic Fluids.¹⁴

UL 498-2001, Standard for Attachment Plugs and Receptacles.¹⁵

UL 943-1993, Standard for Ground Fault Circuit Interrupters.

UL 1059-2001, UL Standard for Safety Terminal Blocks.

3. Definitions, abbreviations, and acronyms

3.1 Definitions

For the purposes of this standard, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards, Seventh Edition* [B8],¹⁶ should be referenced for terms not defined in this clause.

3.1.1 short-time operating voltage: A supply voltage, other than the continuous operating voltage range, operation at which for a defined period of time will not damage the apparatus.

3.1.2 declared rating: A rating stated by a supplier for a given piece of equipment, representing the characteristics of the equipment as actually manufactured for a particular application.

3.1.3 published rating: A rating publicly stated by a supplier for a commercially available piece of equipment, independent of the use of that equipment in a particular application; typically, a rating embodied in documents prepared for broad distribution through commercial channels.

3.1.4 specified rating: A rating that a given piece of equipment is required to be capable of achieving for use in a particular application; often, in practice, a rating to which a piece of equipment is specially designed or adapted.

¹¹ ISO publications are available from the ISO Central Secretariat, Case Postale 56, 1 rue de Varembe, CH-1211, Genève 20, Switzerland/ Suisse (<http://www.iso.ch/>). ISO publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

¹² MIL publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

¹³ NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

¹⁴ SAE publications are available from the Society of Automotive Engineers, 400 Commonwealth Drive, Warrendale, PA 15096, USA (<http://www.sae.org/>).

¹⁵ UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA (<http://global.ihs.com/>).

¹⁶ The numbers in brackets correspond to those of the bibliography in Annex A.

3.2 Acronyms and abbreviations

AGT	Automated Guideway Transit
ANSI	American National Standards Institute
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance of Way Association
ASTM	American Society for Testing and Materials
DMU	diesel multiple unit
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMU	electric multiple unit
EN	European Norm
ESD	electrostatic discharge
ICEA	Insulated Cable Engineers Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IPC	Association Connecting Electronics Industries (previously Institute of Interconnecting and Packaging Electronic Circuits)
ISO	International Organization for Standardization
LVPS	low voltage power supply
MIL	military (related to U.S. Department of Defense standards and other documents)
MU	multiple unit
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NRTL	nationally recognized testing laboratory
SAE	Society of Automotive Engineers
UL	Underwriters' Laboratories, Inc.
UNS	Unified Numbering System (for metals and alloys) ¹⁷

¹⁷ This system is managed jointly by the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE).

4. Design requirements

4.1 Service conditions

All apparatus, including but not limited to electronic apparatus, shall be designed for the standard environmental conditions given in IEEE Std 1478-2001,¹⁸ unless otherwise agreed between the supplier and the authority having jurisdiction.

4.2 Supply voltages

4.2.1 General

Equipment shall operate normally or without damage when exposed, for the duration listed in this standard, to any voltage from zero to the maximum value listed in this standard. If necessary, appropriate protection from damage may be provided by other elements of the system in which the equipment is configured (e.g., undervoltage cutout devices). The authority having jurisdiction shall specify the performance expected of the equipment at nominal voltage conditions. At voltages other than nominal, performance shall be as described in this standard unless otherwise agreed to between the supplier and the authority having jurisdiction.

In the absence of a specification or agreement to the contrary, the minimum time duration to be considered for “short time” operation shall be taken as 1.0 second for undervoltage operation and 0.2 second for overvoltage operation. Conditions existing for shorter times shall be considered transient conditions governed by 4.3.1.

4.2.2 DC-powered low-voltage control equipment

Nominal supply voltages for low-voltage control equipment shall be chosen from the preferred values given in 4.4.3 of IEEE Std 1476-2000. The nominal, minimum operating, and maximum continuous values and the required operating characteristics of the equipment within and outside of these voltage ranges shall be as given in 4.4.3 of IEEE Std 1476-2000. Equipment shall not be damaged by continuous application of voltage between zero and minimum operating.

NOTE—These nominal supply voltages correspond to nominal battery voltages of 24, 32, 48, and 64 volts. Refer to IEEE Std 1476-2000 for details.

4.2.3 AC auxiliary apparatus

Nominal supply voltages and required continuous and short-time operating voltage ranges for ac auxiliary apparatus shall be chosen from the preferred values given in ANSI C84.1-1995, Table 1, Low Voltage Class. Unless otherwise agreed between the supplier and the authority having jurisdiction, rated performance shall be obtained at the nominal frequency and within the Utilization Voltage limits of Voltage Range A of ANSI C84.1-1995, Table 1. Operation at other frequencies shall be as specified in NEMA MG 1-2003, section 12.45. Operation outside of Voltage Range A but within the Utilization Voltage limits of Voltage Range B of ANSI C84.1-1995, Table 1, shall be as specified by the authority having jurisdiction.

¹⁸ Information on references can be found in Clause 2.

4.2.4 High-voltage dc-powered traction and auxiliary apparatus

Supply voltages for high-voltage dc-powered traction and auxiliary apparatus powered from a dc source (e.g., overhead contact system or third rail) shall be as shown in Table 1. Unless otherwise agreed between the supplier and the authority having jurisdiction, rated performance shall be obtained at the nominal voltage and above, up to the maximum voltage listed in Table 1 for that nominal voltage case. At other voltages, performance shall be in accordance with the design or inherent characteristics of the apparatus.

NOTE—By agreement between the supplier and the authority having jurisdiction, the minimum performance (e.g., rating) voltage may be taken at a value lower than the nominal system voltage, and the voltage at which the equipment ceases operation may be taken as a value lower than the minimum continuous voltage. This is commonly done for auxiliary apparatus but may also be done for propulsion equipment where circumstances dictate, such as a chronically “soft” power supply.

Table 1—Standard voltages for high-voltage dc-powered traction and auxiliary apparatus powered from a dc source

Nominal system voltage (V)	Operating voltage range (V)		
	Minimum continuous	Maximum continuous	Maximum short-time
600	400	720	800
750	500	900	1000
1500	1000	1800	1950
3000	2000	3600	3900

NOTE—Nominal voltages of 600 Vdc and 3000 Vdc, while widely used, are not recommended for new applications.

For nominal system voltages other than those shown in Table 1, the minimum continuous operating voltage shall be taken as minus 30 percent relative to the nominal system voltage, and the maximum continuous operating voltage shall be taken as plus 20 percent relative to the nominal system voltage. For any nominal voltage, voltages outside the limits given in Table 1 or the percentages given above shall be considered surges or sags, and performance under those conditions shall be governed by 4.3.1.

4.2.5 High-voltage single-phase ac systems

Supply voltages for high-voltage single-phase ac systems shall be as shown in Table 2:

Table 2—Standard voltages for high-voltage single-phase ac systems

Nominal system voltage (V)	Nominal frequency (Hz)	Operating voltage range (V)			
		Minimum short-time	Minimum continuous	Maximum continuous	Maximum short-time
12 000	25	8 400	9 600	13 200	14 400
12 500	60	8 750	10 000	13 750	15 000
25 000	60	17 500	20 000	27 500	30 000
50 000	60	35 000	40 000	55 000	60 000

NOTE—Systems operated at 25 Hz, while widely used, are not recommended for new applications.

The authority having jurisdiction shall specify the time duration of short-time operation and the expected performance under those conditions. Voltages outside these limits shall be considered surges, and performance under those conditions shall be governed by 4.3.1.

4.3 Electrical transient withstand capability

4.3.1 Spikes and surges

The equipment shall operate normally and shall not be damaged when subjected to input voltage variations as defined in the remainder of this subclause.

4.3.1.1 Supply system

Unless otherwise agreed between the supplier and the authority having jurisdiction, input overvoltage and time duration limits shall be in accordance with the followings sections of IEC 61287-1:1995.

- AC system, normal operation: Curve 1 of Figure 3 – AC supply system overvoltage levels
- AC system, no damage: Curve 2 of Figure 3 for guidance
- DC system, normal operation: Curve 1 of Figure 4 – DC supply system overvoltage levels
- DC system, no damage: Curve 2 of Figure 4 for guidance

4.3.1.2 Auxiliary ac systems

Unless otherwise agreed between the supplier and the authority having jurisdiction, equipment connected to the auxiliary ac system shall operate normally when subjected to voltage fluctuations defined in 4.3.1 of IEEE Std 1476-2000.

4.3.1.3 Low voltage system

Equipment connected to the low voltage dc system shall operate normally when subjected to voltage fluctuations defined in 4.4.3.4 of IEEE Std 1476-2000.

The equipment shall not be damaged when subjected to overvoltages as defined in 4.4.3.5 of IEEE Std 1476-2000.

The equipment shall not be damaged when subjected either to a voltage from zero to the minimum operating voltage or to positive or negative voltage steps between minimum and maximum operating voltages.

NOTES

1—It is recommended that equipment be designed not to be damaged when continuously subjected to nominal low voltage power supply (LVPS) output voltage at reverse polarity, combined with voltage fluctuations and transients as defined in this standard.

2—Power supplies within equipment connected to the LVPS are not specifically addressed, but the supply voltage quality and the loads must be coordinated for proper functionality in order to meet the overall requirements of this standard.

3—In some cases, LVPS voltage may rise gradually as a result of float battery charging. This standard requires functionality within certain voltage ranges. Therefore, equipment that requires a fast rate of rise of supply voltage may not ultimately meet the system requirements.

4.3.1.4 Electrostatic discharge

Protection shall be provided against electrostatic discharges (ESDs) in compliance with EN 50121-3-2:2000, Table 9. The discharge is to be delivered to the enclosure in which the equipment is housed (if an enclosure exists), to the enclosure of each line-replaceable unit, and to all surfaces and controls that are accessible to operating staff and passengers (e.g., knobs, switches, fasteners, printed circuit board faceplates, handles). The equipment shall function properly after such testing.

NOTE—This requirement is not intended to apply to the contacts of electrical connectors that are exposed in the course of removing, replacing, and/or handling a line-replaceable unit.

ESD-sensitive equipment shall be labeled. The label shall be affixed in a location that clearly indicates the ESD concern to maintenance personnel.

4.3.1.5 Transients

With respect to immunity to fast transient bursts and immunity to surges, the equipment shall be designed in accordance with the requirements of Tables 7 and 8 of EN 50121-3-2:2000. Power supply inputs sourced from the low voltage system shall also withstand transients of at least 20 joules without damage or misoperation.

4.3.2 Interruptions

Equipment shall not be damaged when exposed to random interruptions in the power supply. The authority having jurisdiction shall specify the nature of the performance to be obtained under such conditions. In the absence of information from the authority having jurisdiction, the supplier shall identify the interruption criteria assumed for the design and resulting system response. High voltage interruptions that occur frequently shall not require a deliberate fault reset action as a prerequisite for resumption of normal operation.

NOTE—Examples of high voltage interruptions include, but are not limited to bouncing of the power collector device (e.g., third rail shoe or pantograph), gaps in the third rail, phase/frequency breaks or supply transition zones in an overhead supply wire, and ice or snow buildup on the third rail or overhead supply wire. Examples of low voltage or auxiliary voltage interruptions include, but are not limited to temporary shutdown of the on-board power supply resulting from interruptions in the high voltage supply, short-term overloads of the low voltage or auxiliary power supply, and undercharged batteries.

4.4 Electromagnetic compatibility

Electromagnetic compatibility shall be ensured by an Electromagnetic Compatibility (EMC) plan created in accordance with the requirements of APTA SS-E-010-98.

NOTE—Ordinarily, the EMC plan is required of the vehicle supplier and contains requirements for the individual suppliers.

4.4.1 Train-wayside system compatibility

The authority having jurisdiction shall define the communication system and the wayside signal system operating frequency bands, coupling modes, and permissible vehicle or train emissions corresponding to those frequencies and coupling modes. Emissions limits shall be defined as a function of time duration if appropriate for a particular wayside system implementation.

The vehicle supplier and/or systems suppliers shall calculate vehicle and train emissions considering normal operation, infrequent operating modes, transient operation modes, environmental conditions, and failure modes, including but not limited to the following:

- Variations in power feed and power return impedances;
- Power feeds configuration including third rail and catenary gaps;
- Ice and rust accumulation on the power collector and return surfaces;
- Degraded wayside power supply capability;
- Variations in supply voltage;
- Substation phase imbalance limits;
- Variations in regenerative current receptivity;
- Variations in train consist configuration;
- Other vehicles of the same or different type operating in the same area;
- Towing and other non-typical and emergency vehicle operating modes;
- Reduced rail adhesion conditions with corresponding equipment responses; and
- Intermittent and variable auxiliary power demand conditions.

Based on total vehicle emissions limits, the vehicle supplier shall allocate emissions limits for individual systems. The vehicle and/or systems with credible failure modes, as determined by a Failure Modes and Effects Criticality Analysis performed under the EMC Plan of 4.4 that create emissions exceeding the limits shall react automatically in a manner to reduce the emissions below the allocated limits within a time period that will prevent adverse effects on system operation.

4.4.2 On-board equipment compatibility

With respect to all emissions, equipment shall be designed in accordance with the requirements of EN 50121-3-2:2000. Equipment shall not be susceptible to any level of emissions meeting the requirements of EN 50121-3-2:2000.

With respect to immunity to disturbances induced by radio-frequency fields, the equipment shall be designed in accordance with the requirements of EN 50121-3-2:2000.

Additional limits on emissions and susceptibility, higher frequency ranges, and corresponding tests shall be as specified by the authority having jurisdiction.

NOTES

1—EN 50121-3-2:2000 imposes requirements over specific frequency ranges. There may be electromagnetic compatibility needs at higher frequencies not addressed by this standard.

2—Specific entities for which electromagnetic compatibility may be required include cab signals, track signals, communications-based train control radios, legal intentional radio frequency emitters (e.g. cell phones and train crew radios), medical life support devices (e.g. pacemakers), global positioning system receivers, and fare cards.

4.5 Breaking and making capacity

The published ratings cover all of the application requirements including, for example, load circuit inductance, except as agreed below. The supplier shall state the breaking and making capacity (ratings) of the apparatus. Apparatus shall be applied within these ratings. By agreement between the supplier and the authority having jurisdiction, apparatus may be applied outside its published or declared ratings subject to test as specified in 5.7.

4.6 Temperature rise limits

4.6.1 Allowable limits

For equipment cooled by natural convection, the ambient temperature is the average temperature of the air outside the enclosure in the immediate vicinity of the equipment. For equipment that is force-cooled or with a heat exchanger that is not integral with the equipment, the ambient temperature is that of the cooling medium. Further criteria are listed in IEEE Std 1-2000.

The temperature rise or total temperature, whichever is more limiting, of the equipment items measured during testing in accordance with 5.9 shall not exceed the limits in Table 3, Table 4, and Table 5. In addition, the temperature rise and total temperature shall not exceed the actual limits of the materials used in the equipment.

NOTES

1—As can be observed in the following tables, the temperature rise assumes a 40°C ambient temperature. Nevertheless, the temperature rise limit is restricted at lower temperatures to mitigate extremes of thermal cycling.

2—The user is advised that for many applications, the authority having jurisdiction may require lower values of temperature and temperature rise.

Table 3—Allowable temperature rise and limits by insulation class

Insulation class	Limit of hottest spot temperature rise (°C)	Limit of hottest spot total temperature (°C)
90	50	90
105	65	105
130	90	130
155	115	155
180	140	180
220	180	220
240	200	240

NOTE—For additional information on temperature limits, see IEEE Std 1-2000 and IEEE Std C37.20.2-1999.

Table 4—Allowable temperature rise and limits for buses and connections

Type of bus or connection	Limit of hottest spot temperature rise (°C)	Limit of hottest spot total temperature (°C)
Buses and connections with silver surfaced, tin surfaced, or equivalent connecting joints	65	105
Connection to insulated cables, silver surfaced, tin surfaced, or equivalent	45	85

NOTE—For additional information on temperature limits, see IEEE Std C37.20.2-1999 and IEEE Std C37.23-2003.

Table 5—Allowable temperature rise and limits for selected electromagnetic devices and their connections

Component	Temperature rise limit (°C)
Bare wire coils	105
Contacts in Air	
Pure Copper in the form of a spring	35
Brass or bronze in the form of a spring	65
Pure copper or copper alloy not forming a spring	75
Solid silver or silver plate	100
Flexible Connections in Air	90
Accelerating and/or Braking Resistors	
Imbedded, outside of imbedding material	250
Open type, of strap, ribbon wound, formed, or similar configuration	600 (RMS) 800 (peak)

NOTE—For additional information on temperature limits, see IEC-60077 [B7].

4.6.2 Effects of altitude

Altitude shall be considered in the design of equipment. Derating factors for altitudes greater than 1000 m shall be as provided in Part III, Clause 4 of IEEE Std 1-2000.

4.7 Clearance and creepage distance

NOTE—The term “gap,” which is widely used in the rail industry, is synonymous in this context with “clearance” and with “striking distance,” both as defined in IEEE 100, *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition*. The term “clearance” will be used in this standard.

CAUTION

Electrical circuits and associated cabling shall be designed with clearance and creepage distance between voltage potentials and vehicle body ground that consider the environmental conditions to which the circuits and cabling will be subject. Situations in which ionized gas may be present may require special treatment. If adequate enclosure ventilation is provided, ionized gas will not have an effect on these calculations; in the absence of adequate enclosure ventilation, buildup of ionized gas may result in arc-over even at clearance and creepage distance values calculated in accordance with this standard.

CAUTION

Do not use the methods described in this standard when nominal potentials to ground exceed 3000 volts or when corona effects are expected as they may lead to insufficient creepage and clearance distances.

Clearance and creepage requirements of 4.7 do not apply to power semiconductor devices or immediate connections to them.

NOTE—Clearance and creepage distances of power semiconductor devices are beyond the control of rail equipment suppliers. Suppliers should package the devices in a manner that considers the low clearance and creepage distances. EN 50124-1:2001, while not as conservative as the requirements of this standard, may provide guidance regarding these distances.

4.7.1 Clearance

For ordinary environmental conditions in which rail vehicles operate, minimum clearance distances shall be calculated in accordance with the equation given below.

$$\text{Clearance (mm)} = 3.2 + (0.0127 \times \text{nominal voltage})$$

4.7.2 Creepage distance

Table 6 shall be used to determine minimum creepage distances. This table covers many standard passenger rail vehicle electrical system applications.

For voltages other than those included in Table 6, utilize the equation given below to calculate creepage distances under ordinary environmental conditions. Voltages that exceed 1500 volts must consider the effects of corona, as the creepage distances are not necessarily linear functions of voltage.

$$\text{Creepage distance (mm)} = 3.2 + (0.0476 \times \text{nominal voltage})$$

Table 6—Creepage distance

Nominal voltage (V)	Surface	Class			
		Low Energy	Ordinary (Enclosed environment with breathing)	Underfloor exposed	Highly exposed (No external protection)
		Electronic and protected electrical devices (0.5 A maximum)	Control and power devices mounted in control group enclosures (short circuit limits)	Power resistors Open disconnect devices mounted outside protective enclosures	Third rail shoe beams and current collection devices (short circuit current unlimited by onboard devices)
37.5 See 4.2.2 Note	Horizontal	1.5 mm	4.5 mm	19 mm	N/A
	Vertical	1.5 mm	4.5 mm	13 mm	N/A
74 See 4.2.2 Note	Horizontal	3.5 mm	6.5 mm	40 mm	N/A
	Vertical			25 mm	N/A
230	Horizontal	10 mm	16 mm	75 mm	100 mm
	Vertical	10 mm	16 mm	50 mm	55 mm
600	Horizontal	19 mm	32 mm	180 mm	255 mm
	Vertical	19 mm	32 mm	120 mm	150 mm
750	Horizontal	See Note 3 below	40 mm	See Note 3 below	See Note 3 below
	Vertical				
1500	Horizontal	See Note 3 below	75 mm	See Note 3 below	See Note 3 below
	Vertical				

NOTES

1—The formulas in Clause 4.7.1, the formula in Clause 4.7.2, and Table 6 are adapted from NFPA 130-2003, Table F-1 [B16]. Within NFPA-130-2003, Table F-1 is not part of the requirements, but is included for informational purposes only. Within IEEE Std 16-1955 [B10], Table 6 is normative. NFPA does not include the table rows for 74, 750, and 1500 volts. IEEE Std 16 uses fewer significant digits in the conversion to metric units, relative to NFPA-130.

2—Material as noted is reprinted with permission from NFPA 130-2003, *Fixed Guideway and Passenger Rail Systems*, Copyright © 2003, National Fire Protection Association, Quincy, MA 02269 [B16]. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

3—This standard is not offering guidance in areas where Table 6 does not include distance values. Where no value is given or for non-standard values, the creepage distance shall be agreed between the supplier and the authority having jurisdiction. EN 50124-1:2001, while not as conservative as the requirements of this standard, provides a basis for discussion of alternate requirements.

4—11.5.1 of the AREMA 2005 Communications and Signals Manual of Recommended Practices [B1] recommends higher dielectric strength withstand voltages for signaling equipment. Creepage distances greater than those listed may be required to meet these recommendations.

4.8 Apparatus internal wiring requirements

4.8.1 Conductor rating

Cables and wiring shall be rated in accordance with IEEE Std 1478-2001 and for the expected design ambient temperature inside the enclosure. Conductors shall be sized based on the current-carrying capacity, mechanical strength, temperature, flexibility, and voltage drop. Derating factors shall be applied to accommodate for grouping and ambient temperatures greater than supplier's design value in accordance with criteria specified by the authority having jurisdiction. In the absence of specified cable and wire rating criteria, the criteria contained in APTA RP-E-009-98 should be utilized.

4.8.2 Wiring

NOTE—While the effects of environmental contaminants such as those described in IEEE Std 1478-2001 will be adequately accommodated by the clearance and creepage considerations of 4.7, suppliers and users of rail vehicles should be aware that other aspects of wiring practices may also be affected by environmental contaminants.

4.8.2.1 Circuit separation and electromagnetic compatibility

Wires of circuits that operate at potentials differing by 50 volts or more shall not be cabled or bundled together and should not be placed in the same routing enclosure (e.g., conduit, raceway or junction box), however, each area of an enclosure distinctly divided by metallic partitions may be considered separately in the application of this rule. Where it is impracticable to avoid having wires of circuits differing by more than 50 volts in the same enclosure, the wires shall be physically separated and bundled separately. Each wire (i.e., physically distinct conductor) connected to a device shall be insulated for the highest voltage connected to that device.

Wiring connected to transient-generating devices, such as unsuppressed contactor coils, shall not be cabled together with wiring carrying signals to, from, or between semiconductor, logic, cab signal or communications circuits. In cases where physical separation is impracticable, shielded wire of an approved design shall be used for all such conductors. All wires connected to a circuit breaker or any other protective devices shall permit that device to operate and remove power without suffering thermal damage to the wire.

As an aid to achieving the electromagnetic compatibility of 4.4, the following circuits shall not be intermixed in common wire and cable bundles:

- Traction power circuits;
- DC control circuits;
- AC power circuits;
- Unprotected wiring (e.g., battery or power trainline to circuit breaker);
- Different trainline types (e.g., MU control, car control, communications, power, etc.);
- Safety control circuits (e.g., cab signal, automatic train stop, etc.);
- Communication circuits;
- Low-level signals not in shielded cables;
- Wires connected to different sources of energy unless all wires are insulated for the highest rated voltage present; and
- Wires connected to electronic control apparatus and wires connected to a higher voltage source of energy than control voltage.

4.8.2.2 Physical arrangement

Where physical separation of circuits of different voltages is not possible, then where wire bundles cross, the wires in each bundle shall be insulated for the highest rated voltage present.

All wire and cable shall be handled to be free of kinks and insulation abrasions. All wire and cable shall be fully protected against any contact with any surface other than that designed specifically to support or protect the wire. Protective edging or similar material shall be applied to any surface where a possibility exists for a wire to contact a sharp edge.

Wire and cable dress shall allow sufficient slack for removal and reapplication of the wire terminations at least twice (three times on 10 AWG and smaller wire) without excess tension. All wiring shall terminate at terminal blocks, terminals of apparatus, or at connectors as specified. Wire splices shall not be used unless otherwise agreed between the supplier and the authority having jurisdiction.

Wire and cable ties shall be snug but not so tight as to cause indentation and cold flow damage to the insulation. Adhesive mounting bases shall not be used for cable support.

All wire bundles and cables within an enclosure shall be supported (e.g., by the use of tape rails), shall be free from the enclosure structure, metal edges, bolt heads and other interference points, and shall have electrical clearance from the covers regardless of the insulation properties of the covers. Wire bundles shall be located above or alongside the device rather than at the bottom of the enclosure wherever practicable. Except where allowed by the authority having jurisdiction, wire shall be a minimum of 25 mm above the bottom of the box.

NOTE—Certain situations (e.g., electric coupler enclosures) may not allow compliance with this criterion.

Wires shall not enter into environmentally exposed under-floor control boxes through the bottom of the box. Wires shall not be exposed to contactor arcs. All similar equipment boxes shall have identical wire routing, location and termination.

Wire supports shall be arranged such that motion of the wire bundle (e.g., wiring around hinged panels) neither damages the wire bundle nor transmits damaging forces to connected devices.

4.8.2.3 Terminals and connectors

Terminal blocks shall be of the molded unit type and shall comply with the requirements of UL 1059-2001. Terminals at stud-type terminations shall be fastened by a locking mechanism suitable for the operating environment. Modular terminal blocks shall be secured to the mounting rail by end clamps having metallic hardware.

No soldering or solder-type terminals shall be permitted on wiring connected to terminal blocks or pieces of apparatus.

NOTE—The use of soldered connections is not recommended except for printed circuit applications within subsystems or components.

All connections shall be crimp-type including connector contacts. All terminations shall be of the vibration resistant, compression (crimp) type and shall be provided with a properly fitting insulation grip where feasible. All crimp terminations shall be performed in accordance with the appropriate manufacturer's recommended procedure. Crimps shall be made using certified, properly calibrated, manufacturer's suggested tools and dies that are operator independent.

Multi-pin connectors shall have a positive retention coupling independent of the extraction force of the contacts. The coupling mechanism shall provide extended coupling life of a minimum of 500 operations. Visual, tactile, and, to the extent feasible, audible indications of full coupling shall be given. Material selection for the shells (e.g., metal or plastic), shell finish, connector pins (e.g., gold, silver or other

plating), and use of waterproof seals shall be a function of the application. Connectors shall meet the ambient temperature requirements of IEEE Std 1478-2001 and be rated higher than the temperature of the conductors to which they are exposed. Circular connectors shall have a quarter turn bayonet coupling. Circular connectors in environmentally exposed applications should be similar in requirements to MIL-DTL-5015.

Wherever wire is expected to be exposed to high temperatures, such as near grid resistors, high-temperature insulated wiring (or equivalent protection or preparation) shall be provided. Hardware and terminations used in such locations should be nickel-plated or stainless steel.

4.8.3 Wire and identification marking

Each physically distinct conductor within an enclosure shall have a unique alphanumeric identifier. Physically distinct conductors that are electrically connected shall have identifiers that reflect this connection in a recognizable way.

Each physically distinct conductor within an enclosure shall be permanently marked with its identifier at each termination point.

The following three wire marking rules shall be applicable unless otherwise agreed between the supplier and the authority having jurisdiction:

- a) The conductor identification within the enclosure need not correspond to conductor identification outside the enclosure.
- b) Within an enclosure, the identifier need not be marked along the entire length of the conductor.
- c) Electronic racks are not considered "enclosures" for purposes of wire marking. Nevertheless, all wiring should be traceable using equipment drawings, and the application of some wire markers is consistent with good wiring practice.

Individual conductors of multi-conductor cables shall additionally be identifiable by means of a color code or equivalent means. Shields of multi-conductor cables need not be individually marked if their identities are evident from their association with marked conductors.

The wire markers shall have a consistent character height at least 3 mm high and shall be read from left to right. The letters "I", "O", and "Q" should be avoided. In the absence of agreement between the supplier and the authority having jurisdiction, wire markers shall use black text on a light colored background with characters in a sans serif font.

Wire marking shall meet the durability requirements of MIL-M-81531, paragraph 3.6, when tested according to the procedure defined in MIL-M-81531, paragraph 4.6.2.

NOTE—For optimum durability, the use of a clear protective overlay or a marking technique that intelligibly deforms the surface to which the marking is applied is recommended, provided that the integrity of the wire insulation is not affected.

Wire markers shall be non-conductive.

4.9 Bus bar application

Bus bars shall be fabricated from copper per UNS C10100 or C11000, except that by agreement between the supplier and the authority having jurisdiction, bus bars may be fabricated from other copper alloys, aluminum or composites of copper and aluminum. Bus bar electrical connections shall be silver- or tin-plated. Refer to Table 3 and Table 4 for bus bar temperature rise limits.

NOTES

1—It is not uncommon to see current density requirements for busbars. This standard, however, only places requirements on temperature rise, allowing designers to consider the busbar material, shape, thermal conductivity, convection and radiation. This standard retains current density requirements for joints, as shown below.

2—See 3.2 for additional information on UNS (Unified Numbering System).

3—If tin plating is used, it should be correctly alloyed to insure that the transition from white tin to gray tin, commonly known as “tin pest” or “tin disease”, does not occur within either the operating temperature range or the storage temperature range.

For circuits operating at greater than 50 volts, bus bars shall be arranged to prevent accidental contact by maintenance or other personnel working in the area of the bus bars. This requirement shall be met using a method appropriate for the voltage level. Typical methods include insulating coatings on the bus bars and bus bar area covers.

Where bolted connections are used, there shall be a flat washer on each side of the bus bar assembly for load distribution and a Belleville washer on one side for constant load. The conducting area shall be considered to be the annular ring of the flat washer. The pressure in the conducting area shall be at least 10 MPa for copper and 7.5 MPa for aluminum, but no greater than that which would cause cold flow of the bus bar material. For copper bus bars, the current density in the conducting area shall not exceed 0.75 A/mm², except that by agreement between the supplier and the authority having jurisdiction the current density shall not exceed 1.4 A/mm².

NOTE—It is common to use standard design tables that specify torque levels and maximum currents as a function of bolt size and material. Where supporting calculations show that such design tables are consistent with the pressure, current density and/or temperature rise requirements of this standard for the maximum continuous current level of the connection, these design tables may be used.

4.10 Printed circuit board design and construction

NOTE—Some authorities having jurisdiction have historically maintained vehicle electronic equipment. Advances in electronic design have resulted in the need for more sophisticated troubleshooting and repair equipment. The definitions of the categories of printed circuit boards are given below to assist authorities having jurisdiction in the development of contractual requirements. Typically, Category 1 boards are readily repairable, Category 2 boards are repairable only in sophisticated repair facilities (and unit replacement may be preferable), and Category 3 boards are not repairable.

Printed circuit boards will be considered to belong to one of three categories:

- Category 1 boards are those that have a density of components, component types, and component mounting, which allows manual probing of the board when troubleshooting to identify the defective component (i.e., resistor, capacitor, integrated circuit, etc.).
- Category 2 boards are high-density boards that utilize multi-layer construction, surface mount components, large integrated circuits (such as processor chips, programmable logic devices and other custom components), which may preclude effective manual troubleshooting.
- Category 3 boards are commercial off-the-shelf printed circuit boards purchased from commercial industrial equipment manufacturers, where these are non-repairable, or where the design information is not available from the manufacturer to support troubleshooting and repair.

These categories are descriptive and are not prescriptive as to what is to be provided. These categories are used to define the capability of test equipment and repair facilities with respect to each printed circuit board.

Printed circuit boards shall be designed to IPC-2220 Design Standards Series, Printed Boards, Class 2 or better.

Printed circuit board material shall be NEMA LI 1-1998, Type FR4 or better.

Printed circuit board connectors shall be two-part type meeting the environmental requirements of IEEE Std 1478-2001 and specifically designed to be inserted and removed many times.

NOTE—Connectors meeting EN 60303 Quality Level 2 are representative of connectors meeting the intent of this standard. "Edge" connectors do not meet the intent of this standard.

Printed circuit board assemblies shall be constructed and inspected to IPC-A-610-2001, Class 2 or better.

The design of printed circuit board assemblies shall inherently protect against insertion into the wrong socket by "keying", physical pin arrangement, or other means.

The supplier shall, as a minimum, provide test points as needed to maintain the board according to the supplier's maintenance procedures, including both fault isolation and troubleshooting, and should also provide a means for monitoring signals of interest for the interface of the printed circuit board with other printed circuit boards, modules, and systems.

Both sides of the assembled printed circuit board shall be coated with an insulating and protecting conformal coating that can be removed with a brush applied solvent when required or penetrated by a hot soldering iron when a component must be unsoldered. The coating solvent shall not adversely affect board-mounted components. Conformal coating shall be in accordance with IPC-CC-830B-2002, Class 2 or better, except that all coatings shall include fluorescent indicators.

Boards that are deemed non-repairable shall be coated with an insulating and protecting conformal coating as required above, except that the conformal coating need not be removable or penetrable.

NOTE—Conformal coatings meeting the requirements of MIL-I-46058C are considered to meet the requirements of IPC-CC-830B-2002 plus fluorescent indicators.

4.11 Protective functions

All systems shall incorporate protective functions to prevent, if feasible, or minimize damage to apparatus resulting from the imposition of abnormal service conditions. Examples include, but are not limited to, temperature extremes, voltages, currents or duty cycles, which are beyond the operational design limits of the apparatus. A list of representative protective functions is given in Annex C. The use of fuses or so-called "crowbar circuits" for overload or overcurrent protection is not recommended except where it can be demonstrated that there is no other practicable means to provide the required protection.

Protective functions for supply overvoltage or supply undervoltage conditions shall automatically reset and restore normal operation when the supply voltage comes within specified limits. All other protective functions shall automatically reset unless to do so would result in damage to the apparatus. If necessary, a limit to the number of automatic resets within a given time period may be imposed.

Overload and fault protective devices within a system or subsystem shall be selective in their operation to localize isolation of the faulted equipment. The devices shall be coordinated to allow the device nearest the fault on its source side to operate first and shall be coordinated to minimize nuisance fault indications but still prevent damage to equipment. The protection coordination shall be done as part of the overall vehicle system protection.

The design of protective functions shall include:

- Identification of the fault parameter for which a protective function is required, including where and how it is measured,
- Threshold level for declaring a fault,
- Time duration in excess of the threshold level before activating the protective function,
- Time duration at acceptable level after a fault before an automatic reset can occur,
- Number of fault protective function reset(s) allowed before corrective action,
- System response to the fault occurrence,
- Annunciation of the fault event and how the annunciation is reset,
- Inclusion into a group error message, if appropriate,
- Operator or maintenance response to the fault occurrence.

Where protective functions are logged and reported to a vehicle level event recorder, the system shall be consistent with the requirements of IEEE Std 1482.1-1999.

NOTE—There are related protective function and annunciation requirements in IEEE Std 1475-1999.

4.12 Grounding and bonding

All electrical equipment or enclosures shall be grounded using a ground cable or strap or by a bond between a vehicle body grounding surface and the equipment's grounding surface. An acceptable grounding surface is a ground pad in accordance with 4.12.1 or a prepared surface that meets the functional requirements of this section. All shock-mounted electrical equipment shall be grounded using ground cables or straps. The ground termination method shall allow the connection to carry the maximum fault current of the application without damage or degradation over time.

Interior mounted, low voltage equipment shall be grounded according to the needs of the design.

All circuits shall be electrically isolated from the mechanical structure of the equipment except for power returns where permitted by the authority having jurisdiction, and circuit to structure components for the purpose of transient absorption and EMI protection where applicable.

All grounding connections shall be visible and accessible for inspection and troubleshooting. The bonding method employed shall not produce a dc resistance in excess of 0.0025 Ω across any bond, or more than 0.025 Ω at 150 kilohertz for any applied ac voltage.

WARNING

Equipment grounding and bonding designed to this standard shall be done as part of an overall vehicle grounding system wherein ground paths, including vehicle-body-to-rail-ground, are defined. This overall system shall be designed with personnel safety and equipment protection considered, including prevention of current flow through bearings.

CAUTION

Where running rails are used for return current, the vehicle structure can be a parallel path for return current, resulting in a voltage drop along the vehicle/train length, additional current in ground cables and connections, and potential control malfunctions.

NOTE—The bonding requirements for apparatus covers vary greatly and are not addressed in this standard. Designers should consider exposure, failure modes, and EMI in determining whether covers should be bonded to enclosures.

4.12.1 Grounding pads

Grounding pads shall be made of copper or copper alloys, sized for the application, and brazed to the respective vehicle body and piece of equipment. The use of nickel or tin plating is recommended to ensure that the bonding requirements are maintained over time. Transition (base) plates, if used, shall be made from the same alloy group as the respective vehicle body or equipment. The transition plate shall be welded to the vehicle body or equipment. By agreement between the supplier and the authority having jurisdiction, welded steel grounding pads may be used. If so used, steel pads shall be either nickel- or tin-plated carbon steel, or stainless steel.

NOTE—This standard does not address variations in ground pad arrangements that may be required for aluminum enclosures. It is noted that zinc plated steel studs, with anti-corrosive paste, have been used in the industry for attachment to aluminum enclosures.

Truck ground pads must be applied in low stress areas and in a manner to preclude base metal hardening.

Pads shall include one or more tapped holes for securing connections. Pads using a stud arrangement may be used by agreement between the supplier and the authority having jurisdiction. Anti-corrosive paste may be applied over connections.

NOTE—The supplier should specify the kind of anti-corrosive/anti-oxidant paste to be used for connections, if needed. The use of such paste is not a requirement of this standard.

4.12.2 Grounding connections

All grounding connections shall be sized to handle the available fault current without failure. Ground brush and truck grounding jumpers shall be sized to handle lightning discharge current according to IEC 61024-1-1:1993, for all but the worst 5 percent strikes repeatedly and the worst strike once, without failure. Where applicable, stranding should be according to ASTM B174-2002 for wire sizes 14 AWG and smaller and according to ASTM B172-2001A for wire sizes larger than 14 AWG.

4.12.3 Convenience receptacles

On new or rebuilt equipment, each convenience receptacle supplying 60 Hz type power shall be on a circuit supplied through a Nationally Recognized Testing Laboratory (NRTL) labeled five milliamperere rated Ground Fault Circuit Interrupter (GFCI) as specified in UL 943-1993. Test and reset functions of the GFCI shall not be accessible to vehicle passengers.

Each receptacle shall be NRTL labeled as conforming to Federal Specification W-C-596G and shall be of the suitable NEMA WD 6-2002 configuration for the circuit's voltage and ampere rating, along with the correct number of insulated/grounded current carrying and equipment grounding conductors/poles/contacts.

Each 15 or 20 ampere 120 volt single-phase straight blade convenience receptacle accessible to vehicle passengers shall be of the:

- NRTL labeled “Hospital Grade” and “Tamper Resistant” construction as specified in ANSI/UL 498-2001; and,
- respective NEMA WD 6-2002 5-15R or 5-20R configuration.

Each convenience receptacle shall have its wiring device strap and equipment grounding contact bonded to the vehicle body. Convenience receptacles shall be mounted so that fluids will not drain into the receptacle.

NOTE—Subclause 4.3.2 of IEEE Std 1476-2000 requires systems supplying convenience receptacles to be galvanically isolated from the line-side power source.

4.13 Electro-pneumatic devices

The following requirements apply to electro-pneumatic devices. Air supply sources are not addressed in these requirements.

The characteristics of pneumatic power used for operating electro-pneumatic devices shall be specified as nominal, minimum, and maximum air pressure values by the authority having jurisdiction. In the absence of specified values, the ratio of maximum to minimum pressure shall be 1.8 or greater and the maximum pressure shall not exceed 1.04 MPa.

Maximum test pressure and duration values that will not result in loss of functionality at specified operating pressures shall be as mutually agreed between the supplier and the authority having jurisdiction.

Maximum test pressure and duration values that will not result in failure of the device when applied at specified operating pressures shall be as mutually agreed between the supplier and the authority having jurisdiction.

Pressures shall be specified as gage values rather than absolute.

Devices shall function with compressed air quality in accordance with APTA SS-M-011-99.

NOTE—Durability of the device may be specified by number of operations, duty cycle, or other relevant parameters.

4.14 Electro-hydraulic devices

The following requirements apply to electro-hydraulic devices. Hydraulic power sources are not addressed in these requirements.

The characteristics of hydraulic power used for operating electro hydraulic devices shall be specified as nominal, minimum, and maximum fluid pressure values by the authority having jurisdiction. In the absence of requirements from the authority having jurisdiction, the maximum pressure shall not exceed 16.0 MPa. Maximum test pressure and duration values that shall not result in loss of functionality at specified operating pressures shall be as mutually agreed to by the supplier and the authority having jurisdiction.

Maximum test pressure and duration values that shall not result in failure of the device when applied at specified operating pressures shall be as mutually agreed to by the supplier and the authority having jurisdiction.

Pressures shall be specified as gage values rather than absolute.

The hydraulic fluid specifications shall be mutually agreed by the supplier and the authority having jurisdiction. The cleanliness of the fluid shall be in accordance with ISO 4406:1999 or SAE AS4059. The supplier shall establish or specify the filtering required for a hydraulic system by maximum particle size allowed and efficiency. The supplier shall also specify the requirements for storing, handling, and filling hydraulic fluid to minimize contamination, including but not limited to moisture and air.

NOTE—Durability of the device may be specified by number of operations, duty cycle, or other relevant parameters.

5. Testing requirements

5.1 General test requirements

Type and routine tests shall be performed on all equipment.

NOTES

1—"Type tests" as used in this standard and defined in IEEE 100™ [B8], shall be considered synonymous with the term "qualification tests" as defined in IEEE 100.

2—"Routine tests" as used in this standard and defined in IEEE 100-2000, shall be considered synonymous with the terms "acceptance tests" and "production tests" as they are defined in IEEE 100.

Type tests shall be performed on at least one system or apparatus, in its production configuration, to demonstrate that the design is qualified for use in the intended application. The supplier shall perform type tests listed in Table 7. If design changes occur subsequent to type test, elements of the type test shall be repeated as agreed between the supplier and the authority having jurisdiction.

NOTE—The authority having jurisdiction may accept prior test results or service history for the same or similar device.

Routine tests shall be performed on each production system or apparatus to verify that the system or apparatus has been manufactured such that it is equivalent to the particular system or apparatus that underwent type testing. The supplier shall perform routine tests listed in Table 7 on all systems or apparatus.

Tests required by this standard are listed in Table 7 but may not necessarily include all tests that may be appropriate for a particular system or apparatus. Where the tests in Table 7 are not sufficient for particular equipment or applications, the supplier shall identify and perform additional tests as necessary for type and routine testing. By agreement between the supplier and the authority having jurisdiction, additional tests may be defined by the authority having jurisdiction.

Table 7—Outline of test requirements

Description of test	Corresponding design requirements subclause	Applicable test section	
		Type test	Routine test
Operational	—	5.2.1	5.2.2
Environmental conditions	4.1	5.3.1	5.3.2
Supply voltage variation	4.2	5.4.1	5.4.2
Transient voltage and interruption	4.3	5.5.1	—
Electromagnetic compatibility	4.4	5.6	—
Breaking and making capacity	4.5	5.7	—
Temperature rise	4.6	5.8	—
Insulation	4.7	5.9	5.9
Environmental stress	—	—	5.10
Protective devices	4.11	—	5.11
Air tightness	4.13	5.12.1	5.12.3
Pneumatic overpressure	4.13	5.12.2	—
Pneumatic device functionality	4.13	5.12.4	5.12.4
Hydraulic	4.14	5.13.1	5.13.2
Resistance and impedance	—	5.14	5.14

5.2 Operational test

5.2.1 Operational type testing

The system or apparatus under test shall be tested for conformance to all aspects of the required functionality. All input/output relationships and internal diagnostic functions shall be included as part of the operational test. In addition to tests under nominal operating conditions, tests shall be conducted at the minimum and maximum temperature, voltages, and pressure, as well as the combination of those parameters that subject the system or apparatus to the greatest stress. Functions that are independent of temperature, voltage, and pressure (e.g., certain software functions) are not required to be tested under more than one condition. In the event that other environmental parameters affect the operation of the system or apparatus, tests shall include the full range of those parameters, both individually and in concert with other environmental parameters.

5.2.2 Operational routine testing

The system or apparatus under test shall be tested to verify that the system or apparatus has been manufactured such that it is equivalent to the particular system or apparatus that underwent type testing. This test includes verification that each input and output is functional, at minimum, nominal, and maximum voltage and pressure for the application.

5.3 Environmental conditions testing

5.3.1 Environmental conditions type test

The system or apparatus under test shall be tested for conformance with IEEE Std 1478-2001.

5.3.2 Environmental routine test

If exterior mounted, the system or apparatus under test shall be tested for watertightness in accordance with 4.2.1 of IEEE Std 1478-2001.

NOTE—Watertightness tests conducted as part of a vehicle level watertightness test meet the intent of this requirement.

5.4 Supply voltage testing

5.4.1 Type tests over the range of supply voltage variations

The system or apparatus under test shall be tested for conformance to the required functionality over the specified range of input voltages and frequencies. Under the declared or specified rating conditions of input or output voltage, a test for conformance to the declared or specified rating capability shall be performed. This may be a continuous or duty cycle test as agreed between the supplier and the authority having jurisdiction.

5.4.2 Routine tests over the range of supply voltage variations

The system or apparatus under test shall be tested for conformance to the required functionality over the specified range of input voltages. Where supplied by an ac voltage, the system or apparatus under test may be tested at a single frequency in the allowable frequency range.

For devices where operation is also affected by temperature, routine tests shall include modifications to the supply voltage to simulate the simultaneous effects of voltage and temperature variations.

NOTE—An example is the impact of coil temperature rise (and thus coil resistance) on electro-mechanical devices. The “minimum voltage” test shall be performed at a test voltage lower than the actual minimum operating voltage, calculated as follows:

- a) Determine or calculate the coil resistance under maximum ambient conditions when energized at maximum continuous operating voltage
- b) Determine the coil resistance under test conditions (typically at room temperature)
- c) Calculate the coil current that would flow under such maximum ambient/maximum operating voltage conditions
- d) Reduce the test voltage to a level that results in the calculated coil current

5.5 Electrical transient test

5.5.1 Type tests under transient voltage and interruption conditions

The system or apparatus under test shall be tested for conformance to the required functionality under the transient input voltage conditions of 4.3. If a precise duplication of the specified transient voltage

conditions is not practicable, the test procedure representative of the specified conditions shall be as agreed to by the supplier and the authority having jurisdiction.

5.6 Electromagnetic compatibility test

5.6.1 Train-wayside electromagnetic compatibility type tests

The system or apparatus under test shall be tested for conformance to the requirements developed in the EMC Plan of 4.4 and the requirements of 4.4.1.

5.6.2 On-board electromagnetic compatibility type tests

The system or apparatus under test shall be tested for conformance to the requirements developed in the EMC Plan of 4.4 and the requirements of 4.4.2.

5.7 Breaking and making capacity tests

If the supplier and the authority having jurisdiction have agreed to apply the apparatus outside of its published ratings, or have agreed to apply the apparatus subject to additional performance requirements not contemplated in the published ratings, per 4.5, the apparatus shall be tested at the agreed application rating.

5.8 Temperature rise tests

5.8.1 General

Type tests shall be applied to the following kinds of equipment, whether individually or as part of a system:

- Buses and connections
- Insulated windings
- Bare wire coils
- Contacts in air
- Flexible connections in air (e.g., braided shunts)
- Accelerating and braking resistors
- Heat sinks
- Devices or assemblies whose life is a function of operating temperature
- Other heat sensitive devices or assemblies

5.8.2 Temperature measurement

Temperature measurements shall be taken during the operational portion of the test if practicable. If not practical, temperatures shall be measured beginning as soon after the completion of the test as practicable, using measurements to project the temperature at the time of the conclusion of the test using a method such as 6.4 of IEEE Std 11-2000. When the temperature of a part is measured during the test, the temperature shall also be measured immediately after the completion of the test and the highest measurement shall be adopted.

Temperature sensors shall be placed near cooling air inlets and outlets. Measurements shall also be taken at intermediate locations and those considered worst case based on equipment orientation.

NOTE—Users are reminded that it is total temperature that affects service life. For convenience, temperature measurements are made of rise over the ambient temperature existing under test conditions. When combined with any correction factors from 5.8.4.4, a value for the maximum expected total temperature under limiting application conditions is derived.

5.8.2.1 Acceptable methods of measurement

Temperatures shall be estimated and/or measured using one of the five fundamental methods described in Part III, Clause 3 of IEEE 1-2000:

- Thermometers
- Applied thermocouple
- Contact thermocouple
- Resistance
- Embedded detector

For the resistance method, the experimentally determined relation between temperature and resistance is given by:

$$\frac{R}{r} = \frac{C + T}{C + t}$$

Then,

$$T = \frac{R(C+t)}{r} - C$$

where

- r is the resistance at the reference temperature
- t is the reference temperature in °C
- R is the measured resistance
- T is the temperature sought in °C
- C is the experimentally determined coefficient relating resistance to temperature for the metal (e.g., $C = 234.5$ for copper)

NOTES

- 1—These equations do not apply for alloys that are nonlinear with temperature.
- 2—Resistance measurements and improper location of temperature measuring devices can mask hot-spot temperatures.

5.8.2.2 Determination of ambient temperature

As a guideline, cooling air temperature shall be measured as close as possible to air intake, but protected from radiated or conducted heat. The value to be adopted for cooling air temperature shall be the mean of measurements taken at equal intervals during the last quarter of the duration of the test.

5.8.3 Test duration

The temperature rise limits of 4.6.1 shall not be exceeded when tested according to any of the tests of this section.

5.8.3.1 Apparatus with continuous rating

For apparatus with continuous rating, the temperature test shall be continued until the temperature rises observed during the test have attained a steady state value. If this is not practical, testing shall continue until sufficient evidence is available to show that the temperature rises would not exceed the requirements of this standard, should the test be prolonged until the attainment of steady state values.

5.8.3.2 Apparatus with short-time rating

For apparatus with short-time rating, the duration of the temperature test shall be the time required by the rating. The test shall commence only when the windings or other parts of the apparatus are within 2 °C of the cooling medium temperature at the time of starting the test or one percent of expected equipment temperature rise, whichever is greater.

5.8.3.3 Apparatus with duty cycle rating

For apparatus with duty cycle rating, the duration of the temperature test shall be for the times of load and rest specified by the rating and shall continue for the total time required by the rating or until temperature rises have leveled. The test shall end at a temperature rise peak, if appreciable. Alternatively, the temperature test may be performed at the calculated rms current levels, until the temperature rises observed during the test have attained a final steady state value. The test shall commence only when the windings or other parts of the apparatus are within 2 °C of the cooling medium temperature at the time of starting the test or one percent of expected equipment temperature rise, whichever is greater.

5.8.3.4 Short-term overload rating

Tests for short-term overload shall be conducted after the apparatus reaches temperature stabilization by either method in 5.8.3.3.

5.8.4 Test conditions

5.8.4.1 Mounting

The apparatus shall be mounted so as to accurately reproduce the normal service conditions on the vehicle.

5.8.4.2 Ventilation

Ventilation shall reproduce conditions similar to that encountered in service, including but not limited to the effects of filtration devices, air ducting, and car motion.

5.8.4.3 Enclosed apparatus

Temperature tests shall be made with enclosures in position and simulating mounting on the vehicle, if enclosures are provided as part of the apparatus.

If the enclosure is not provided by the supplier, a simulated enclosure as close as possible to the actual enclosure shall be used. By agreement between the supplier and the authority having jurisdiction, an upward adjustment to temperature measurements without an enclosure may be used. Adjusted temperatures should be substantiated by actual tests on similar equipment with and without enclosure.

5.8.4.4 Air temperature

The test may be made at any cooling air temperature, but preferably not below 10 °C. It shall be assumed that the temperature rise is the same for all cooling air temperatures between 10 °C and 40 °C. Outside these limits, a correction applied to the maximum temperature rises observed shall be decided by agreement between the supplier and the authority having jurisdiction.

5.8.4.5 Effect of altitude

For apparatus to be operated at an altitude of 1000m or less, a test at any altitude within this range is suitable, and the anticipated increase in temperature rise with altitude neglected. For equipment operating above 1000 m, test results shall be de-rated as discussed in Part III, Clause 4 of IEEE Std 1-2000.

5.8.4.6 Effect of heating by adjacent apparatus

If considered necessary by agreement between supplier and the authority having jurisdiction, tests shall be made considering the effect of heating by adjacent apparatus. Effects due to any combination of convection, induction, or radiation shall be replicated based on agreement between supplier and the authority having jurisdiction.

5.8.5 Insulated windings

Temperature tests on windings (e.g., circuit breaker holding coils, magnet valve coils, electro-magnetic contactor operating coils, relay coils, transformers, etc.) shall be made at the voltage that produces the maximum continuous losses in the winding. If this voltage cannot be determined, tests shall be made at a voltage equal to the upper limit of voltage in the circuit in which the windings are to be connected.

For windings fed through additional resistances, the voltage to be applied to the terminals of the windings shall be equal to the actual voltage at the terminals when the voltage applied to the winding-resistance assembly is equal to the maximum rated continuous circuit voltage.

For apparatus or devices operating from a source that includes harmonic currents, temperature rise testing shall be conducted with the actual waveform or test conditions that result in equivalent heating.

For wound components operating in conjunction with regulated constant power converters, tests shall be done at the voltage that results in the highest continuous current in the wound component.

For special items operating infrequently, enabling cool-down between two successive operations, the temperature rise shall be agreed upon between the supplier and the authority having jurisdiction.

The temperature rise shall not exceed the limiting values given in Table 3.

5.8.6 Bare windings, contacts in air, flexible connections, and bus bars

Temperature tests shall be carried out with continuous rated current. If this cannot be determined, they are to be carried out at the rated current of the apparatus.

The temperature rise for bus bars shall not exceed the limiting values given in Table 4.

The temperature rise for bare windings, contacts in air, and flexible connections shall not exceed the limiting values given in Table 5.

5.8.7 Accelerating and braking resistors

Temperature rise tests shall be based on the material employed. The temperature rise shall not exceed the limiting values given in Table 5.

NOTE—As a result of the variation in thermal time constants and local hot spots, duty cycle is the recommended method of testing.

5.8.8 Electronic assemblies

Temperature tests on electronic assemblies (e.g., circuit boards, modules, etc.) shall be made at the supply voltage that results in the maximum temperature rise. Tests shall also include dissipative loads, along with their respective duty cycles (see 5.8.3.3), as seen by the electronic assembly.

Test conditions shall comply with those specified in 5.8.4.

Unless otherwise agreed upon between the supplier and the authority having jurisdiction, temperature tests shall be continued until the temperature rises observed during the test have attained a steady state value. If this is not practical, testing shall continue until sufficient evidence is available to show that the temperature rises would not exceed the maximum component rating.

In no case shall the temperature rise over the limits of IEEE Std 1478-2001 exceed the limiting values imposed by suppliers of any components on the electronic assembly including potential effects on adjacent components. For electronic assemblies operating infrequently, enabling cool-down between two successive operations, the temperature rise shall be agreed upon between supplier and the authority having jurisdiction.

5.8.9 Electro-pneumatic devices

Temperature tests on electro-pneumatic devices shall be performed in accordance with test conditions specified in 5.8.4 and air quality conditions in 4.13. Electrical portions of the electro-pneumatic device assembly (e.g., insulated windings, contacts in air, and flexible connections) shall be tested in accordance with the appropriate sections in this standard.

5.8.10 Electro-hydraulic devices

Temperature tests on electro-hydraulic devices shall be performed in accordance with test conditions specified in 5.9.4 and hydraulic fluid quality conditions in 4.14. Electrical portions of the electro-hydraulic device assembly (e.g., insulated windings, contacts in air, and flexible connections) shall be tested in accordance with the appropriate sections in this standard.

5.9 Insulation testing

WARNING

High potential testing involves potentially lethal voltages and must be done in strict accordance with all applicable safety precautions.

Insulation tests are both type tests and routine tests, with differing requirements as indicted herein.

5.9.1 Insulation test purposes

Insulation testing is conducted to validate the design, application and installation of:

- wire insulation
- components and assemblies
- packaging

for electrical integrity.

5.9.2 Insulation test sequences

After all cable, wiring and equipment installation on the vehicle, with the allowable exception of electrical connection of previously tested equipment, the insulation integrity of all vehicle circuits shall be tested according to 5.9.3 and 5.9.4, at the full test voltage. On items with double insulation, such as grid resistors mounted by insulators to a frame insulated from vehicle body, each set of insulation shall be individually tested (i.e., resistors to frame and frame to vehicle body connection points).

Where assemblies have been previously tested for insulation integrity and are not connected during the vehicle tests, additional vehicle tests shall be conducted after all equipment has been connected, as follows:

- An insulation resistance test shall be conducted according to 5.9.3.
- For circuits with a nominal voltage above 300, a dielectric test shall be conducted according to 5.9.4, using the re-test voltage.

Where assemblies are being tested for insulation integrity prior to installation on the vehicle, the interface circuits of each separately assembled and wired package shall be tested for insulation integrity, according to 5.9.3 and 5.9.4, including individual tests of double insulation.

All circuits of each separately assembled and wired package shall be tested for insulation integrity, according to 5.9.3 and 5.9.4, except that the test shall be considered only a type test, unless otherwise agreed between the supplier and the authority having jurisdiction.

Replacement apparatus, equipment, cables and wiring shall be tested for insulation integrity. A final insulation resistance test should be conducted after all replacement equipment has been connected.

5.9.3 Insulation resistance test

Wiring continuity tests should be performed prior to conducting insulation resistance tests. Insulation resistance tests shall be performed using a dc insulation resistance tester, consisting of a generator producing either 500 or 1000 volts and an ammeter scaled in megohms. Any batteries shall be isolated during this test. Insulation resistance tests shall be conducted on all circuits within a device, system, or vehicle. Tests shall be conducted to verify the state of insulation on all circuits of each voltage class to the following, where applicable;

- the equipment case
- wiring of different voltage classes
- input and output circuit of high voltage line switches and circuit breakers
- vehicle chassis

Semiconductor devices may be protected against electrical stress if they are not inherently protected by the circuit in which they are used. Such protection may include short circuiting or disconnecting some parts of the equipment, as agreed between the supplier and the authority having jurisdiction.

On items with double insulation, such as grid resistors mounted by insulators to a frame insulated from car body, each set of insulation shall be individually tested (i.e., resistors to frame and frame to vehicle body).

The vehicle-level insulation resistance limits of Table 8 shall apply when all circuits on the vehicle of a given voltage class are connected in parallel under all environmental conditions including non-condensing high humidity, for new equipment:

Table 8—Vehicle-level insulation resistance limits

Nominal Circuit Voltage (Volts dc or ac rms)	Minimum Insulation Resistance
Below 90 volts	2 megohms at 500 Vdc
90 to 300 volts	4 megohms at 1000 Vdc
Above 300 volts	5 megohms at 1000 Vdc

The test limits for individual devices or apparatus shall be higher than those of Table 8, as is appropriate for that hardware, so that the limits for the completed vehicle can be met.

Insulation resistance tests on equipment in service shall not be expected to exhibit the same insulation resistance as new equipment. (One megohm, under all humidity conditions, is the recommended minimum.) The nature of the equipment that is connected during the test and the humidity will cause variations in the readings.

5.9.4 Dielectric test

5.9.4.1 Basic dielectric testing

The dielectric test shall be conducted after the insulation resistance test is completed and passed. Tests shall be conducted to verify the state of the insulation to the case or vehicle body, between wiring of different voltage classes, and between the input and output circuit of traction high voltage line switches and circuit breakers.

Semiconductor devices may be protected against electrical stress if they are not inherently protected by the circuit in which they are used. Such protection may include short circuiting or disconnecting some parts of the equipment, as agreed between the supplier and the authority having jurisdiction. The various wires in a system shall be shorted to ensure that all parts of a system are tested, and to prevent capacitive or fault currents from passing through and damaging low voltage devices.

The test shall be conducted by applying the test voltage, as listed in Table 9, for a period of one minute, across the insulation being tested. The test is passed if there is no insulation breakdown. The test voltage shall be at a frequency of 50/60 Hz with a sinusoidal waveform. V , in the equations in Table 9, shall be the nominal system voltage for a circuit.

Table 9—Dielectric test voltage

Nominal circuit voltage, dc or ac rms	Test voltage, ac rms
Below 300 volts	$2V + 1000 \text{ Vac}$
Above 300 volts	$2.25V + 2000 \text{ Vac}$

Repeated high potential dielectric tests should be avoided. For repeated tests, the test voltage shall be 0.85 times the value defined in Table 9.

NOTES

1—11.5.1 of the AREMA 2005 Communications & Signals Manual of Recommended Practices recommends higher dielectric test voltages for signal equipment. This recommendation should be considered in each application of signals equipment, based on the wire insulation used.

2—The method or methods used to determine insulation breakdown may need to be adapted to the equipment under test. Methods include disruptive discharge (visual by flashover and acoustic by arcing), leakage current (absolute limit and/or stabilization) and change in insulation resistance after dielectric testing.

5.9.4.2 Variations in dielectric testing

Standard apparatus may be production tested for one second at a test voltage 20 percent higher than the above listed one-minute test voltage. Pass/fail criteria shall be determined by agreement between the supplier and the authority having jurisdiction.

High potential test using a dc voltage shall only be used by agreement between the supplier and the authority having jurisdiction. A design incorporating capacitance to ground is an example of a case where dc dielectric testing is appropriate. Where a dc test voltage is used, the voltage shall be equal to the peak of the corresponding required ac test voltage.

WARNING

Any dc dielectric test procedure shall conclude with the discharging of capacitance of the equipment under test.

NOTE—For sensor circuits and for electronic racks with electrical connections that are galvanically isolated from the vehicle power sources, routine dielectric testing at 500 volts dc may be considered.

5.10 Environmental stress screening

Environmental stress screening is not a mandatory requirement of this standard. Where agreed between the supplier and the authority having jurisdiction, all electronic assemblies shall undergo temperature environmental stress screening as part of routine testing. Unless otherwise agreed between the supplier and the authority having jurisdiction, the following stress screen regimen shall be used:

- a) The test shall be performed with the equipment operational, powered, and oriented as per the specified application. Input signals and output loads to simulate the maximum power dissipating condition in the equipment shall be applied during rising temperature and maximum temperature portions of the temperature cycle

- b) Test ambient temperature shall be repetitively cycled between -25°C and $+70^{\circ}\text{C}$. The rate of change of temperature shall be no less than 5°C per minute. Temperature shall be maintained at the temperature extremes for at least 5 minutes or until the unit under test reaches temperature stability. There shall be a minimum of 20 complete temperature cycles.
- c) The unit under test shall be given a full functional test before and after the stress screening, and shall be monitored for failure throughout the stress screening.

In the event of failure, the repaired assembly shall be given another stress screen, completing the unfinished temperature cycles, but no less than two complete temperature cycles.

NOTE—Bibliographical references [B13] and [B17] provide additional references to environmental stress screening processes.

5.11 Settings and operation of protective apparatus, relays, and static circuits

Routine tests shall be performed on protective apparatus, relays, and static circuits to verify that they operate within tolerances given below.

Unless otherwise agreed between the supplier and the authority having jurisdiction, all such apparatus, components or circuits shall operate with the following tolerance on their nominal setting:

- ± 3 percent for protective functions utilizing solid state sensors, active electronic circuitry or microprocessor computation
- ± 5 percent for passive electronic circuitry or electromechanical components not equipped with mechanical latches
- ± 7.5 percent for components with mechanical latches

For apparatus having a time delay feature, the tolerance on the operating time shall be fixed by agreement between the supplier and the authority having jurisdiction. In the absence of such agreement, for apparatus, components or circuits having a specified value of time delay, the following tolerance of this value shall be accepted:

- ± 5 percent for protective functions utilizing solid state sensors, active electronic circuitry or microprocessor computation
- ± 10 percent for all other protective functions

Any calibration markings on protective apparatus and components shall be correct to plus/minus five percent, this tolerance being added to the setting tolerance previously mentioned.

5.12 Tests for pneumatically operated equipment

5.12.1 Air tightness type test

The device shall be tested at its maximum or minimum operating pressure, whichever is more severe. The test air supply shall conform to the requirements of 4.13.

The device shall be connected to an air reservoir of at least one liter.

If the device tested includes a magnet valve and it is checked with the valve energized, the coil shall be energized with a current equal to that obtained with the winding hot at the minimum allowed operating voltage.

Unless otherwise specified, air tightness is acceptable if the pressure decrease is less than three percent of the test pressure after ten minutes.

5.12.2 Over-pressure type test

The over-pressure test shall be made at the pressure and for the duration agreed upon between the supplier and the authority having jurisdiction. If functionality is required after the test, it may be demonstrated by repeating the routine test for the tested device. If functionality is not required after the test, verify that no disruptive air leaks or discharges occurred during the test.

5.12.3 Air tightness routine test

The leak test shall be performed using a method as agreed between the supplier and the authority having jurisdiction.

Acceptance criteria shall be not more than ten percent of the maximum pressure loss over a ten minute duration.

5.12.4 Functional type and routine test

The device shall be functionally tested at either the maximum or minimum rated pressure for the device, whichever is more severe.

Devices with set-points shall verify that the switch point is within $\pm 0.21 \text{ kg/cm}^2$ or plus/minus five percent, whichever is less, of the specified value.

Requirements to verify calibration of the device with proportional electrical or pneumatic functions shall be as agreed between the supplier and the authority having jurisdiction.

5.13 Tests for hydraulically operated equipment

5.13.1 Leakage type tests for hydraulically operated equipment

These tests apply to electromagnetic valves, pressure switches, and transducers, hereafter referred to as electrohydraulic devices, in which hydraulic pressure must be maintained. These tests shall be performed by the supplier.

An endurance test of three months duration shall be made on a complete hydraulic apparatus operating on a load cycle agreed between the supplier and the authority having jurisdiction to verify that no leaks exist that would either jeopardize the functioning of the apparatus or necessitate replenishing the hydraulic fluid. There shall be no loss of fluid from the system as a whole.

The duration of the test may be established for a period other than three months by mutual agreement between the supplier and the authority having jurisdiction.

5.13.2 Leakage routine tests for hydraulically operated equipment

Each device to be delivered shall be tested, unless sample tests are mutually agreed with the authority having jurisdiction.

With pistons having packing, rings, or gaskets, there shall be no significant leakage from cylinders with the maximum or minimum load applied externally to the piston rod, whichever is more severe. Allowable leakage shall be as agreed between the supplier and the authority having jurisdiction.

Valves shall be tested at the maximum flow rate and maximum rated pressure. The leakage under these conditions shall not exceed 0.35 percent per minute of the maximum rated flow per 10MPa.

Pressure switches and pressure transducers shall be tested at maximum rated pressure. There shall be no visible fluid after two minutes at the test pressure.

5.14 Measurement of resistance and impedance

Routine tests of measurements of resistance shall be made on all electromagnetic control or other devices that include windings, the resistance of which may affect operation of the device.

The measurement obtained for any given winding, when corrected to a temperature of 20 °C, shall not vary by more than plus/minus ten percent from the specified value or, alternatively, from the mean of the values measured on at least the first ten units which successfully pass the operational test of 5.2.1.

If the ac resistance is specified to account for skin effect, the required value shall be corrected to an equivalent dc resistance value for test purposes.

For apparatus in ac circuits, or in dc circuits where correct operation depends on the impedance, measurements of resistance shall be accompanied by measurements of impedance carried out with ac at the specified frequency, superimposed on dc as required for the application. For other than air core devices, the test shall specify the current levels at which the impedance test is to be performed.

If the tested device contains multiple windings and coupling between the various windings may affect operation of the device, measurement of the winding coupling shall be performed.

Annex A

(informative)

Bibliography

- [B1] AREMA 2005 Communications & Signals Manual of Recommended Practices.¹⁹
- [B2] APTA SS-E-001-98, Standard for Insulation Integrity.
- [B3] APTA SS-E-005-98, Standard for Grounding and Bonding.
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- [B8] IEEE 100-2000, *The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition*.
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- [B15] NEMA MGI-1998, Motors and Generators.
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¹⁹ AREMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112, USA ([http:// global.ihs.com/](http://global.ihs.com/)).

Annex B

(informative)

Uses of “authority having jurisdiction”

At various points throughout this standard, the text refers to the authority having jurisdiction. There are three distinct ways in which this phrase is used, as shown in the following lists:

First, for certain default design requirements, this standard allows variation from the default requirements if mutually agreed by the supplier and the authority having jurisdiction. In these cases, the language in the standard typically uses the phrase, “unless otherwise agreed between the supplier and the authority having jurisdiction.” Examples are as follows:

- 4.1, service conditions
- 4.2.1, performance at other than nominal voltage
- 4.2.1, short time duration of voltage excursions
- 4.2.3, voltage range and frequency for ac auxiliary apparatus
- 4.2.4, voltage range for nominal performance when powered from high voltage dc
- 4.3.1.1, input overvoltage and duration
- 4.3.1.2, auxiliary ac system input fluctuations
- 4.6.1, special temperature requirements
- 4.8.2.2, wire splices
- 4.8.3, wire marking
- 4.9, bus bar material
- 4.9, bus bar current density
- 4.12, return current in the vehicle body
- 4.12.1, steel ground pads
- 4.12.1, ground pad connection
- 5.8.4.3, temperature test without enclosure
- 5.8.4.4, test temperature range excursions
- 5.11, protective circuit tolerances (2 places)
- 5.12.1, allowable air leak

Second, for certain requirements, the authority having jurisdiction, and sometimes the supplier, must approve the design and/or test parameters. Examples are as follows:

- 4.5, breaking and making outside of published ratings
- 4.7.2, special creepage distance
- 4.9, aluminum or composite bus bars
- 4.13, pneumatic test pressure and duration values for functionality and failure (2 places)

- 4.14, hydraulic test pressure and duration values for functionality and failure (2 places)
- 4.14, hydraulic fluid specifications
- 5.1, repeating type test when the design changes
- 5.4.1, supply voltage type tests for rating capability
- 5.5.1, transient conditions
- 5.8.4.6, effect of heating by adjacent apparatus
- 5.9.3, protecting components during insulation resistance test
- 5.9.4, protecting components during dielectric test
- 5.9.4.2, variations in dielectric testing (2 places)
- 5.10, environmental stress screening
- 5.12.2, 5.12.3, 5.12.4, pneumatic tests (3 places)
- 5.13.1, 5.13.2, hydraulic leakage (3 places)

Third, some parameters are not quantitatively defined in this standard. In those cases, the authority having jurisdiction is given the responsibility of providing appropriate values, typically in the technical specification. Examples are as follows:

- 4.2.1, nominal equipment performance
- 4.2.4, performance as a function of high voltage dc
- 4.2.5, performance as a function of high voltage ac
- 4.3.2, voltage interruptions
- 4.4.1, wayside signal and communication system parameters
- 4.4.2, special EMC requirements
- 4.5, making and breaking capacity of apparatus
- 4.8.1, special wiring current ratings
- 4.13, electropneumatic pressures
- 4.14, electrohydraulic pressures
- 5.1, additional tests to be performed

Annex C

(informative)

Recommended protective functions

The following is a list of conditions for which it is recommended that protective functions be considered. This list is neither mandatory nor exhaustive. It is the mutual responsibility of the supplier and the authority having jurisdiction to determine the protective functions appropriate for the system and apparatus in question and the application in which it is expected to perform reliably.

Environmental:

- Over or under temperature (ambient or internal)
- Excessive sustained vibration
- Insufficient cooling medium flow
- Clogged filter or excessive pressure drops

Electrical:

- Over or under voltage (supply or output)
- Overcurrent (input or output)
- Over or under frequency (supply or output)
- Excessive harmonic content
- Excessive phase imbalance
- Undercharged or depleted battery
- Overcharging battery

Functional:

- Computer shutdown
- Misoperation
- Non-responsive human operator