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IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles

Sponsor

Electric Machinery Committee
of the
IEEE Power Engineering Society

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Abstract: This standard applies to rotating electric machinery which forms part of the propulsion and major auxiliary equipment on internally and externally powered electrically propelled rail and road vehicles and similar large transport and haulage vehicles and their trailers where specified in the contract.

Keywords: armature, electric input, electric output, impedance, load, phase control, propulsion, regeneration, shutdown, ventilation, waveforms, windage

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Introduction

(This introduction is not part of IEEE Std 11-2000, IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles.)

This standard provides for usual conditions. In addition, it provides for special conditions that have been found convenient or necessary at times in the industry, which may be invoked by agreement between the manufacturer and purchaser. The conditions chosen may affect the economics or performance, or both, of machines in a given situation.

Provisions where special agreement between manufacturer and purchaser may be invoked are as follows:

Subclause	Provision
1.3.2	High ambient temperature
1.3.3	Special conditions of environment
1.4.1	Type test quantities
1.4.2	Routine overspeed and single phase or locked rotor test
1.4.2.3	Routine commutation and characteristic test quantities, quality control, and sampling plan
1.5.6	Special conditions of electric input or output
4.2.3	Greatest continuous rating
5.2	Waiver of temperature-rise limits
7.1	Dielectric test
8.2.1	Commutation routine tests
8.2.3	Level of visible sparking
8.3.1	Interruption type tests
9.3.1	Maximum design speed
10.1.1	Routine test tolerances
10.6.4.2	Assumed stray load loss
10.6.5	Assumed harmonic losses
10.7.4	Tolerance from contract curve
10.8.1, 10.8.2, 10.8.3	Routine test tolerances
11.2	Variation of performance with voltage
11.3	Load reduction under condition of low supply voltage
13.1	Commutator trueness measurement
13.2	Vibration measurement
13.3	Sound measurement
13.4	Shaft voltage

This standard parallels the major technical contents of International Electrotechnical Commission (IEC) Recommendation Publication 349, Rules for Rotating Electrical Machines for Rail and Road Vehicles. However, it differs from IEC recommendation 349 in important respects.

These differences have been called to the attention of the U.S. Committee of Experts for IEC Technical Committee 9, the International Mixed Committee on Electric Traction Equipment.

This standard was prepared by a working group under the sponsorship of the DC, PM, and Special Machinery Subcommittee of the Electric Machinery Committee of the IEEE Power Engineering Society. The members of the working group were as follows:

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IEEE Standard for Rotating Electric Machinery for Rail and Road Vehicles

1. Overview

1.1 Scope

This standard applies to rotating electric machinery which forms part of the propulsion and major auxiliary equipment on internally and externally powered electrically propelled rail and road vehicles and similar large transport and haulage vehicles and their trailers where specified in the contract.

Major auxiliary equipment includes equipment such as blower and compressor motors, motor-generator and motor-alternator sets, auxiliary generators, and exciters, usually larger than 3 kW.

1.2 Purpose

The purpose of this standard is to define ratings, tests, and calculation procedures to permit comparison among machines for similar use, and to enable evaluation of the suitability of machines for a given use.

1.3 Service conditions

This standard applies under the following conditions:

1.3.1 Altitude

All temperature tests at the manufacturer's plant shall be made at the sea-level rating. No correction in rating is necessary when normal service altitude does not exceed 1200 m (4000 ft). A reduction in current rating of 1% shall be made for each 300 m (1000 ft) additional elevation or fraction thereof.

1.3.2 Temperature

Whenever the temperature in the shade exceeds 40 °C, special stipulations may be agreed upon by the manufacturer and the purchaser.

1.3.3 Special conditions

The manufacturer shall be informed by the purchaser of any particularly arduous condition such as dust, humidity, temperature, snow, dynamic effects, etc., under which the machines are intended to work.

1.4 Test categories

1.4.1 Type tests

Type tests to establish ratings and characteristics shall be carried out on all new products. The number of type tests shall be one for every order for a new type, up to 100 machines on the order, and one for every additional 300 machines (or part thereof) for larger orders, unless otherwise agreed to between manufacturer and purchaser. Machines given type tests shall also be given routine tests.

1.4.2 Routine tests

Routine tests show that each machine is ready for service and like the type tested machines. Resistance, rotation, vibration, heating-up run, bearing temperature, and dielectric tests shall be carried out on all machines. In no case do routine tests require precise temperature measurement.

For inverter-driven induction motors, no-load phase balance and magnetizing current and kilowatt input tests shall be run, and overspeed and single phase tests may be run by agreement.

For synchronous machines, overspeed test shall be run on each machine.

For dc machines, overspeed test shall be run on each machine, and requirements for commutation and characteristic tests shall be met by one of the methods given below.

1.4.2.1

Load test may be used to demonstrate commutation and characteristics directly.

1.4.2.2

Simulated load test may be used to demonstrate that the factors that affect commutation and characteristics agree with identical tests on machines that have had type test.

1.4.2.3

On machines produced in large quantity and assembled by precision methods, statistical methods may be used to determine the number of machines subject to commutation and characteristic tests. The quality control and sampling plan may be subject to agreement between manufacturer and purchaser.

1.5 Electric inputs or outputs

1.5.1

DC motors supplied from rectified polyphase alternating current with not less than six-pulse rectification without phase control are considered to be operating on smooth current. No correction is needed from tests run on smooth current.

1.5.2

DC motors supplied from rectified single-phase alternating current or from pulse-control devices are considered to be operating on undulating current. Type tests for temperature rise, commutation, characteristics, and efficiency shall be made with undulating current with pulsation frequency and ripple as in service. Tests with smooth current may also be run.

1.5.3

AC machines that operate with essentially sinusoidal waveform should be tested under those conditions.

1.5.4

AC machines producing or fed with nonsinusoidal waveform should have type tests with waveforms as in service. Tests with sinusoidal waveform may also be run.

1.5.5

The effects of load characteristics and supply characteristics (11.3 and 11.4) shall be taken into account in specifying electric inputs or outputs of machines, particularly ac auxiliaries.

1.5.6

Special conditions of electric input or output are subject to agreement between manufacturer and purchaser.

2. References

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

ANSI/NEMA CB 1–1995, Brushes for Electrical Machines.[1]

IEEE Std 1–1986 (Reaff 1992), IEEE Standard General Principles for Temperature Limits in the Rating of Electric Equipment and for the Evaluation of Electrical Insulation.[2]

IEEE Std 112–1996, IEEE Standard Test Procedure for Polyphase Induction Motors and Generators.

3. Definitions

3.1 alternator: An ac generator.

3.2 as built curve: A curve that is found on an individual machine during testing. *Syn*: **manufactured curve**.

3.3 average voltage: The value declared by the user to be the average of the system described, where externally powered.

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[1] NEMA publications are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (http://global.ihs.com/).

[2] IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

3.4 continuous rating: The output that the machine can sustain for an unlimited period under the conditions of Clause 4 without exceeding the limits of temperature rise of Clause 5.

3.5 contract curve: A specified machine characteristic curve that becomes part of the contract.

3.6 current ripple: Current ripple, for the purpose of this standard, is defined as $[I_{max} + I_{min})/(I_{max} + I_{min})] \times 100$ expressed in percent, where I_{max} and I_{min} are the maximum and minimum values of the current waveform, provided that the current is continuous.

3.7 declared curve: A characteristic curve of the machine type, as obtained by averaging the results of testing four to ten machines, of which at least two shall have had a type test.

3.8 electric thermometer: An instrument that utilizes electric means to measure temperature IEEE Std 100-1996). Electric thermometers include thermocouples and resistance temperature detectors.

3.9 heating-up run: A period of operation with current and ventilation designed to bring the machine to approximately its temperature-rise limit.

3.10 manufacturer: The organization supplying the electric machinery to the purchaser. For the purpose of this standard it may include a repair contractor.

3.11 nominal system voltage: A number used to denote the general level of voltage of the system described and, in the case of an externally powered system, selected from the list of preferred values in Clause 11.

3.12 one hour rating: The output that the machine can sustain for 1 h starting cold under the conditions of Clause 4 without exceeding the limits of temperature rise of Clause 5.

3.13 purchaser: The organization placing the contract for the machinery or its repair; often called the "user."

3.14 pulse control: Means by which the voltage applied to a machine circuit departs from being essentially constant if unidirectional, or from being essentially sinusoidal if alternating. Pulse control devices include, but are not limited to, choppers, inverters, and rectifiers.

3.15 rated voltage: The voltage specified at the terminals of a machine.

3.16 rating: The output at the shaft if a motor, or at the terminals if a generator, assigned to a machine under specified conditions of speed, voltage, temperature rise, etc.

3.17 routine test: A test showing that each machine has been run and found to be sound electrically and mechanically, and is essentially identical with those that have been type tested.

3.18 short-time overload rating: The output that the machine can sustain for a specified time starting hot under the conditions of Clause 4, without exceeding the limits of temperature rise of Clause 5.

3.19 smooth current: Current that remains unidirectional and the ripple of which does not exceed 3%.

3.20 type test: A test made by the manufacturer on a machine that is identical in all essential respects with those supplied on an order, to demonstrate that it complies with this standard.

3.21 undulating current: Current that remains unidirectional, but the ripple of which exceeds that defined for smooth current.

4. Ratings and temperature-rise tests

4.1 Classes of ratings

This standard recognizes three classes of ratings: continuous rating, 1 h rating, and short time overload rating.

4.2 Continuous ratings and temperature-rise tests

4.2.1

The continuous rating of a machine applied in duty that is long compared to the thermal time constant of the machine generally will be the point of greatest continuous tractive effort with the highest continuous flux level. The test shall be performed with inputs as in service unless 4.6.1 applies. It shall be ascertained that no other point is limiting.

4.2.2

The continuous rating of a machine applied in duty that has short cycles compared to the thermal time constant of the machine will be the steady rating that produces the same heating with the same ventilation in the same time as the duty cycle. This continuous rating is calculated from speed, time, distance, rms current, etc., over the duty cycle. Ripple in dc or harmonics in ac change during the duty cycle so it may not be possible to provide the continuous rating point with waveforms as in service. Subclause 4.6.1 may apply.

A duty cycle test shall be performed with the pulse control to be used in service to demonstrate that the temperature rises are comparable to those at the calculated continuous rating. The machine shall be operated in simulation of the actual duty cycle, including dwell time, as realistically as possible. The cycle shall be repeated until temperature rises have leveled. The test shall end at a temperature rise peak, if appreciable.

4.2.3

Where agreed, a machine may be tested to find the greatest continuous rating that will meet temperature rise limits with assurance. Such a rating must be used with care that other conditions have not changed to render the rating inapplicable.

4.2.4

A continuous temperature test shall be continued until the temperature rises that can be observed during the test have attained steady final values. See Table 1 in 5.1. In order to abridge the long time required to attain steady temperatures, reasonable overload or reduction of ventilation during the preliminary heating period is permissible.

4.3 Initial temperature of machine for temperature-rise test to determine 1 h rating

The temperature-rise test to determine the 1 h rating shall commence only when the windings and other parts of the machine are within 4 °C of the cooling-air temperature at the time of starting the test.

4.4 Making of short-time overload test

The short-time overload capacity of the machine shall be determined by one or more temperature-rise tests following the continuous rating test at the highest continuous current. The cooling curve of the earlier rating test shall be plotted as taken, and the overload shall be applied when the extrapolation of this curve indicates that the proper initial armature temperature rise has been reached. The overload shall then be applied under normal ventilation conditions and at the voltage that corresponds to the test current on the machine characteristic and shall be maintained constant for a period estimated to reach the final temperature rise given in Table 2 in 5.1. The short-time overload rating of the machine may be calculated from a test that does not differ in final temperature rise from that in Table 2 by more than ±10 °C.

4.5 Ventilation during temperature-rise test

The test shall be carried out with the machine arranged as in service, with all those parts that would affect the temperature rise of the machine in place, but without any ventilation corresponding to that produced by the motion of the vehicle itself.

4.6 Waveforms during temperature-rise tests

4.6.1

Smooth current or sine wave power may be used rather than pulse-controlled if the ripple or harmonic content would be so low that the added losses may be neglected or accounted for.

4.6.2

Rating test(s) shall be repeated with smooth current or sine wave supply to establish reference for further type tests. If type test equipment can not reach the rating point, another point at the same flux level may have to be used.

4.6.3

Heat run(s) on waveforms as in service are required on one machine deemed typical. Other type tests are compared to the reference test(s).

4.7 Voltage during temperature-rise test

The voltage applied to a machine during the temperature-rise test shall be the rated voltage as defined in 4.8.

4.8 Rated voltage

4.8.1 Motors on externally powered vehicles

The rated voltage of a motor is the same as the nominal supply voltage of the traction network (see Table 4, Clause 11) in all cases where the motor is fed directly from the line.

4.8.2 Motors in series

For motors connected permanently in series the rated voltage of the motor is designated by the ratio E/n, E being the nominal supply voltage and n the number of motors in series.

4.8.3 Motors on internally powered vehicles

The rated voltage of a traction motor fed from a generator carried on the vehicle shall be at least equal to its share of the generator output voltage at the continuous rating of the motor.

4.8.4 Traction generator or alternator

A traction generator or alternator which is part of a motor-generator set carried on the vehicle or is driven from a prime mover on the vehicle usually will have a variable-voltage, variable-current characteristic. High voltage is of interest since it will stress the commutator, or rectifiers in the case of an alternator where the rectifiers form an integral part of the generator, and since the exciting field windings are operated at high current. High current is of interest from the standpoint of heating of the armature and other windings and rectifiers which carry main current. Such a generator or alternator has two continuous ratings on its characteristic curve which are as follows:

4.8.4.1

The continuous current rating of a generator or alternator is the continuous rating that corresponds to the higher output current. The continuous current rating for an alternator with rectifiers is the value of the rectified dc at the output of the rectifiers.

4.8.4.2

The continuous voltage rating is the continuous rating that corresponds to the higher output voltage.

4.8.5 Exciting supply

The rated voltage of the exciting supply shall be sufficient to provide this continuous voltage rating of the main generator.

4.8.6 Regulated supply

The rated voltage of a machine generating electricity under the control of a regulator or of a machine fed from such a generator shall be the nominal value of the regulated voltage.

4.8.7 Fixed excitation

The rated voltage of a machine on a car or locomotive generating electricity under a fixed value of excitation shall be that occurring at the rated speed and current of the machine.

4.8.8 Pulse control

The rated voltage of a motor fed by pulse control shall be the average value (if unidirectional current) or the effective value of the fundamental frequency component (if alternating current) of the motor voltage over the recurring waveform with the motor delivering rated output.

4.9 Contract ratings

Each rating specified in the contract is to be confirmed by test.

5. Temperature rises and temperature-rise tests

5.1 Limits of temperature rise

This standard utilizes the concept of temperature measurements for insulation systems as detailed in IEEE Std 1-1986. The temperature-rise limits for machine components are listed in Tables 1 and 2. For totally enclosed machines the temperature rise may be 10 °C higher.

Table 1—Observable 1 h or continuous temperature rise

Temperature-rise class designation	Component or winding	Method of temperature measurement	Temperature rise (°C)
B	Rotating armature winding	Resistance	120
	Stationary armature winding	Resistance	120
		Embedded detector	130
	Stationary field winding	Resistance	130
	Rotating field winding	Resistance	120
	Commutator and/or collector	Electric thermometer	120
F	Rotating armature winding	Resistance	140
	Stationary armature winding	Resistance	140
		Embedded detector	155
	Stationary field winding	Resistance	155
	Rotating field winding	Resistance	140
	Commutator and/or collector	Electric thermometer	120
H	Rotating armature winding	Resistance	160
	Stationary armature winding	Resistance	160
		Embedded detector	180
	Stationary field winding	Resistance	180
	Rotating field winding	Resistance	160
	Commutator and/or collector	Electric thermometer	120
C	Rotating armature winding	Resistance	180
	Stationary armature winding	Resistance	180
		Embedded detector	200
	Stationary field winding	Resistance	200
	Rotating field winding	Resistance	180
	Commutator and/or collector	Electric thermometer	120

NOTE—No correction shall be made for cooling-air temperature during test bewteen the limits of 10 °C and 40 °C.

Table 2—Overload test, starting hot observable short-time temperature rise

Temperature-rise class designation	Rise by resistance (°C)	
	Initial	Final
B	75	135
F	85	155
H	100	180
C	120	220

NOTE—Although armature windings are generally limiting, the overload shall not result in injurious temperatures in any other parts of the machine.

5.2 Waiver of temperature-rise limits

When agreed to by manufacturer and purchaser, the temperature limits listed may be altered or made optional.

5.3 Separability

If the manufacturer so desires, different parts of the same machine may have different classes of insulation, and each may be rated for its corresponding temperature rise.

5.4 Rotor cage windings

Temperatures of rotor cages and end rings shall not cause injury to themselves or other parts.

6. Temperature measurements

6.1 Measurement of the cooling-air temperature during tests

6.1.1 Placing of thermometers

6.1.1.1 Totally enclosed machines

The cooling-air temperature shall be measured by means of several thermometers placed at different points around and halfway up the machines at a distance of 1 m to 2 m (3 ft to 6 ft) and protected from drafts and abnormal heat radiation as specified in 6.1.2.

6.1.1.2 Self-ventilated machines (except those equipped with inlet ducts)

The cooling-air temperature shall be measured by thermometers placed as close as possible to each intake opening, but protected from radiated or conducted heat in such a way as to measure the actual temperature of the air entering the machine.

6.1.1.3 Ventilated machines equipped with inlet pipes or ducts

For determining the temperature rises of the enclosed parts when the cooling air is supplied through ducts or pipes, the temperature of the cooling air shall be measured in the test machine inlet duct system at a distance not less than 1 m (3 ft) from the machine itself.

6.1.2 Use of oil cup

In order to avoid errors due to the time lag between the temperature of large machines and the variation in the cooling-air temperature, all reasonable precautions shall be taken to reduce these variations and the errors arising therefrom. Thus the thermometer for determining the cooling-air temperature should be immersed in a suitable liquid, such as oil, in a suitably heavy metal cup when the cooling-air temperature is subject to such variations that an error in the temperature rise might result.

A convenient form for such an oil cup consists of a metal cylinder with a hole drilled partly through it. This hole is filled with oil, and the thermometer is placed therein with its bulb well immersed. The response of the thermometer to various rates of temperature change will depend largely upon the size, kind of material, and mass of the containing cup and may be further regulated by adjusting the amount of oil in the cup. The larger the machine under test, the larger should be the metal cylinder employed as an oil cup in the determination of the cooling-air temperature. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm (1 in) in diameter and 50 mm (2 in) high.

6.1.3 Mean temperature

The value to be adopted for the cooling-air temperature during a test is the mean of the readings of the thermometers (placed as in 6.1.1) taken at equal intervals of time during the last quarter of the duration of the test.

6.2 Method of measuring the temperature of parts

Two methods of determining temperatures of respective parts are recognized, 1) for commutators or collectors, by electric thermometer, and 2) for windings, by resistance or embedded detector.

6.2.1 Electric-thermometer method

In this method the temperature is determined by means of electric thermometers, applied immediately after the machine has stopped, on the accessible parts of the commutator, collector, or end rings at the spots presumed to be the hottest.

6.2.2 Resistance method

In this method the temperature rise of the windings is determined by their increased resistance as measured by a Kelvin double bridge or equivalent method.

Determination of the Mean Temperature Rise of a Copper Winding by Variation of its Electrical Resistance. For copper windings the temperature rise at the end of the test is determined by the following formula:

$$t_2 - t_\mathrm{a} = t_1 + \left(\frac{R_2 - R_1}{R_1}\right)(234.5 + t_1) - t_\mathrm{a}$$

where

t_a is mean cooling-air temperature as defined in 6.1.1 during the last quarter of the duration of the test
t_2 is temperature of the winding at the end of the test, °C
t_1 is temperature of the winding when cold at the moment of the initial resistance measurement, °C
R_2 is resistance of the winding at the end of the test, ohm
R_1 is initial resistance of the winding when cold, ohm

6.3 Shutting down machine

Separate ventilation shall cease at the instant power is cut off from the machine being tested. This is the instant of shutdown. Means shall be used to limit the stopping period to a value not exceeding 1 min for machines rated up to and including 100 kW continuous rating and 2 min for machines rated above 100 kW continuous rating.

6.4 Rules for correcting to time of shutdown

A series of resistance measurements shall be taken beginning within 45 s after shutdown, continued for a minimum of 5 min, and plotted in terms of time intervals after shutdown. The use of semilog paper with time on the linear axis is suggested. A curve shall be drawn through these points and extrapolated back to the instant of shutdown. The temperature so derived shall be taken as the temperature at the instant of shutdown. The temperature of stationary windings operating on smooth dc may be measured by the volt-ampere resistance method just prior to shutdown. In the case of the short-time overload test these readings shall be taken not more than 10 s before shutdown.

7. High-potential tests

7.1 Selection of test method

The nature of dielectric stresses due to ac and dc high-potential tests differs for numerically equal test voltages. Alternating high-potential tests shall be used after completion of new machines, unless otherwise agreed to between manufacturer and purchaser. The ac test is a proof test, and failure to pass will cause damage. The direct high-potential test is a diagnostic test which may be terminated if leakage current indicates impending failure. The dc test is recommended for use on machines in service condition. The dc test may be used with or in place of the ac test by agreement between manufacturer and purchaser.

7.2 AC test procedure

The test voltage shall be as nearly as possible of the sine-wave form, at utility frequency. The effective value of the wave shall be the test voltage. The test shall begin at a voltage of less than one third the test voltage and shall be increased gradually to the full test voltage. The full test voltage shall be maintained for 60 s and then gradually reduced.

7.3 DC test procedure

Beginning from zero, the voltage shall be applied in increments of approximately 20% of final voltage, allowing time at each increment for leakage current to stabilize. Leakage current shall be observed carefully for sharp rising fluctuations which indicate impending breakdown of insulation. The final full test voltage shall be maintained for 60 s. The purchaser may require a record of the leakage current for each machine. After application of a high direct potential, the grounding of windings is important for safety as well as for the accuracy of subsequent tests. The grounding time should be a minimum of four times the charge time.

7.4 Test voltage

The test voltage is based on the operating voltage, according to the applicable provision below. The voltage E is taken as the root-mean-square value if the supply voltage is alternating, or as the average value for operation with undulating current. The test voltage given is for ac tests; for dc tests the test voltage shall be multiplied by 1.75. In measuring the voltage with a voltmeter, the instrument should derive its voltage from the high-voltage circuit either directly or through an auxiliary ratio transformer, or by means of a voltmeter coil placed in the testing transformer.

7.5 Test voltage for machines operating on circuits with power ground

The test voltage for machines operating on circuits with power ground shall be at least $2E$ plus 1500 (except with a minimum of 2500 V on the main traction machines), where E equals:

7.5.1 External line

The nominal system voltage where motors are connected directly to the line or fed from pulse-control apparatus, or the highest motor voltage to ground if greater than line voltage.

7.5.2 External line through transformer

The highest voltage from transformer traction windings to ground with nominal system voltage on the primary, where motors are connected to a transformer directly or through pulse-control apparatus.

7.5.3 Internal power

The highest machine voltage to ground in operation.

7.6 Test voltage for machines operating on ungrounded circuits

The test voltage for machines operating on ungrounded circuits shall be at least 2*E* plus 1000 (except with a minimum of 2000 V on main traction machines), where *E* equals:

7.6.1 External line through transformer

The highest voltage applied to one or more permanently interconnected motors with nominal system voltage on the primary, where motors are connected to a transformer directly or through pulse-control apparatus.

7.6.2 Internal power

The highest voltage of the source in operation.

7.7 Test voltage for machines operating on circuits with high-impedance ground-fault detection

High-impedance ground-fault detection here means a connection that establishes ground potential and provides for the detection of ground current at a value too low to cause serious damage. The test voltage for machines operating on circuits with high-impedance ground shall be at least 2*E* plus 1000 (except with a minimum of 2000 V on main traction machines), where *E* equals:

7.7.1 External line through transformer

The highest voltage to ground at the machine terminals with nominal system voltage on the primary, where motors are connected to a transformer directly or through pulse-control apparatus.

7.7.2 Internal power

The highest machine voltage to ground in operation.

7.8 New completed machines

High-potential tests are routine tests which shall be carried out on each machine in the manufacturer’s plant. The test shall be made while the machine is hot after the heating-up run, and overspeed test, if required. The test voltage specified above shall be applied in turn between each winding and the frame The windings not being tested shall be connected to the frame as ground. For dc tests the leakage current shall not exceed 10 microA after 60 s at the full test voltage.

7.9 Repaired machines

Completely rewound and treated machines shall be tested in the same manner as newly completed machines. If a rotor is tested separately, the shaft shall be used as ground.

7.10 Machines in service condition

7.10.1 DC high-potential test

DC high-potential tests may be used to evaluate the machine condition. The test voltage should be 80% of that required if the machine were new; the recommended limit on leakage current is 1 mA.

7.10.2 AC high-potential test

High-potential tests should be preceded by a dc insulation resistance test. The insulation resistance test voltage should be 500 V on machines that would have alternating high-potential tests of less than 2000 V when new, and up to 1000 V for other machines. Alternating high-potential tests should not be carried out on a machine having less than 2 MΩ insulation resistance. If a high-potential test is made, the test voltage should be half that required if the machine were new.

7.11 Connected apparatus

When units of apparatus are electrically connected and tested as an electrical system, the system shall be tested at 85% of the lowest required test voltage of any of the individual units of apparatus.

8. Commutation tests (dc machines only)

8.1 Commutation type tests

8.1.1

Commutation type tests shall be carried out in the manufacturer’s plant, with care being taken to avoid exceeding normal operating temperatures or speeds.

8.1.2

In general, commutation type tests shall be carried out at various points over the entire operating range of the machine, in both directions of rotation if the machine normally operates in both directions.

8.1.3

Commutation type tests on regulated machines shall be carried out at various operating points within the full range of operation of the regulator.

8.1.4

Commutation type tests shall be carried out on motors fed directly or through a transformer from the line at various values of current and corresponding field strength shown on the motoring characteristic curve and at a voltage corresponding to the maximum voltage given in Clause 11, Tables 4 and 5.

8.1.5

For motors which operate regeneratively, commutation type tests shall be carried out at various values of current and speed shown on the regenerative characteristic curve, the machine running as a generator at a voltage corresponding to the maximum voltage given in Clause 11, Tables 4 and 5.

8.1.6

For motors which operate with rheostatic braking, commutation type tests shall be carried out at various values of current, field strength, and corresponding speed shown on the rheostatic braking characteristic curves.

8.1.7

Where motors are connected permanently in series without mechanical coupling, the motor shall in addition be type tested as a motor at a current corresponding to 75% of the current at the continuous rating and at a voltage of 1.5 times the rated voltage of the motor and with the fields connected for full excitation.

8.1.8

For traction motors fed from a generator carried on the vehicle, type tests shall be carried out at various values of voltage per motor and current per motor corresponding to points on the generator characteristic curves.

8.1.9

Where the motor is arranged for field control, it shall be run at various field strengths at which it may be called upon to operate in service.

8.1.10

Where motors fed from a generator carried on the vehicle are connected permanently in series without mechanical coupling, the motor shall in addition be type tested with maximum field strength at 1.5 times the voltage per motor, corresponding to the maximum voltage shown on the maximum generator characteristic curve with the current adjusted so that the motor runs at maximum design speed.

8.1.11

Where pulse control is used, the motor shall be tested under the applicable conditions given above, with ripple frequency and waveform as in service.

8.1.12

Where machines operate on other than smooth current, tests shall be carried out with waveforms as in service. Additional tests may be carried out on smooth dc to provide correlation for routine tests.

8.1.13

The machine shall withstand each of the commutation tests without mechanical deterioration, flashing or permanent damage; permanent damage being that which would prevent successful operation of the machine after completion of the tests. The presence of some visible sparking is not necessarily evidence of unsatisfactory commutation.

8.2 Commutation routine tests

8.2.1

On machines given commutation routine tests, commutation shall be observed under conditions agreed upon between manufacturer and purchaser, generally at not more than six points per machine which type tests have shown to be significant. One of these points shall be after the overspeed test.

8.2.2

On machines produced in quantity where precision methods are used to assure proper commutating pole flux in the assembled machine, the fitting of brushes and the observation of commutation may be omitted.

8.2.3

The machine shall withstand each commutation routine test without mechanical deterioration, flashing or permanent damage; permanent damage being that which would prevent successful operation of the machine after the test. The presence of some visible sparking is not necessarily evidence of unsatisfactory commutation. The level of visible sparking permitted may be subject to agreement between manufacturer and purchaser.

8.3 Interruption type tests

8.3.1

Interruption type tests may be carried out by agreement between manufacturer and user. These tests shall be made on any motor fed directly or through a transformer from the line at 1.1 times rated voltage and at significant values of current and corresponding field strength as shown on the characteristic curve.

8.3.2

The tests may be carried out by means of either hand operation or automatic control in such a manner that the circuit will be opened when carrying steady load and the circuit remade after an interval of between 0.5 and 1 s.

8.3.3

The speed of the machine shall be kept as constant as possible, for example, by mechanically coupling a motor to a dc generator of suitable size and simultaneously interrupting the load circuit.

8.3.4

A total of six interruptions shall be made at intervals of a few minutes, three with full excitation and three with minimum excitation.

8.3.5

During the transient following the interruption, the voltage at the motor terminals shall not be less than 0.9 times the rated voltage at any time and shall be not less than 1.1 times the rated voltage under steady state. This shall be verified by means of a recording if requested by the user.

8.3.6

In making the tests the motor shall have connected with it the field control equipment designed for the purpose.

8.3.7

If the motor forms part of an equipment in which there is always an automatic arrangement providing, in case of interruption, complete protection during an interval that is less than 1 s', the exact value of the interval may be used for the test. (In such a case the interruption test may not necessarily prove the ability to withstand other line transients.)

8.3.8

With pulse control of the motor or motors the combination shall be tested for its ability to withstand interruptions and other line transients.

8.3.9

The machine shall withstand each test without mechanical deterioration, flashing, or permanent damage; permanent damage being that which would prevent successful operation of the machine after the test.

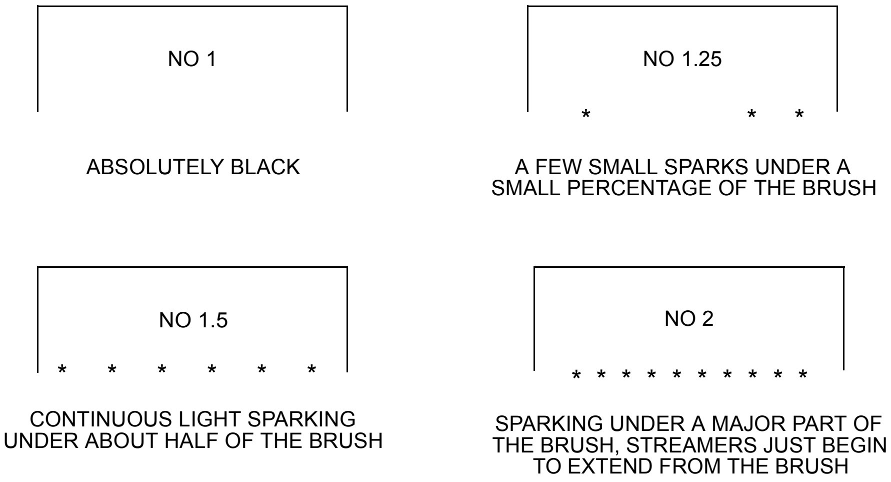
8.4 Evaluation of the degree of sparking

8.4.1

Figure 1 should be used to standardize the evaluation of the degree of sparking.

8.4.2

For consistent evaluation of sparking all brushes, including those not being observed, shall have good surface contact, and stable commutator film shall have been developed. Under these conditions sparking of degree 2 or greater on smooth current usually results in the removal of metal from the commutator and is unsatisfactory for continuous operation. The presence of some visible sparking is not necessarily evidence of unsatisfactory commutation.



ABSOLUTELY BLACK

A FEW SMALL SPARKS UNDER A SMALL PERCENTAGE OF THE BRUSH

CONTINUOUS LIGHT SPARKING UNDER ABOUT HALF OF THE BRUSH

SPARKING UNDER A MAJOR PART OF THE BRUSH, STREAMERS JUST BEGIN TO EXTEND FROM THE BRUSH

NOTE—Each diagram represents the trailing edge of one brush. If brushes are different, record condition of each, identifying them 1, 2, 3, etc., from riser end. (See NEMA CB 1-1995.) For the degrees of sparking involved here, spitting, glowing spots, and leading edge sparking are not normal.

Figure 1—Sparking chart

9. Overspeed requirements and test

9.1 Overspeed test

The machine shall withstand for 2 min after the heating-up run a rotation speed 1.20 times its maximum design speed.

9.2 Results of overspeed test

After the overspeed test the machine shall show no permanent deformation and shall successfully pass the specified dielectric test. Where a commutation test is specified it shall include a point after the overspeed test.

9.3 Relation to vehicle speed

9.3.1

The maximum design speed of a traction motor shall not be less than that which corresponds to the vehicle maximum service speed with new wheels. This recognizes that an increase in motor speed with wheel wear is considered in motor design. The relation between motor maximum design speed and vehicle maximum service speed, considering gear ratio and wheel size, may be subject to further limitation by special agreement between manufacturer and purchaser.

9.3.2

The normal maximum operating speed of the vehicle shall be sufficiently less than the vehicle maximum service speed to allow for the tolerances and operation of vehicle overspeed control devices, where applicable.

10. Characteristic curves and tests

10.1 Characteristic curves

10.1.1

Inverter-driven induction motor inherent characteristics do not represent vehicle characteristics in electric traction. Vehicle characteristics at rated supply voltage (externally powered vehicles) or power (internally powered vehicles) shall be provided by the system supplier per 10.1.5 as a minimum. Motor tests are required to provide information to the system supplier, and to assure that motors are like the type test motors. Consequently, 10.7 and 10.8 below do not apply. The tolerances on routine tests shall be agreed between manufacturer and purchaser to verify that proper functioning of the system will in fact be attained.

10.1.2

The manufacturer’s specifications of generators and dc traction motors shall include characteristic curves at rated voltages (see 4.8) or voltage schedules of interest.

10.1.3

The curve for a dc motor alone shall give the values of armature rotational speed, efficiency, and output torque at the shaft plotted against armature current.

10.1.4

Alternatively, when curves representing vehicle characteristics are required, the curve shall give vehicle speed, efficiency, and tractive effort plotted against motor current, taking wheel diameter, gear ratio, and gear losses into account. The wheel diameter and gear ratio used shall be stated on the curve.

10.1.5

Alternatively, characteristics of vehicle equipment shall show the vehicle tractive effort and propulsion system efficiency plotted against vehicle speed.

10.1.6

The various field strengths of a dc motor shall be designated, beginning with full field, as FS-1, FS-2, FS-3, etc., by actual field strengths, or a maximum and minimum, as appropriate.

10.1.7

Where traction motors are used for braking, braking effort curves shall be included.

10.1.8

For a traction generator or alternator the characteristic shall show efficiency and output voltage plotted against current over the entire operating range and shall state input rotational speed and power for traction.

10.1.9

The maximum values shown on the characteristic curves shall be significant, such as maximum speed, maximum field weakening, maximum armature current for corresponding field strength, maximum torque.

10.1.10

Temperatures of all windings, including inductive shunt if applicable, shall be taken as 110 °C.

10.2 Methods of determining efficiency

10.2.1

For machines operating on essentially smooth dc or sinusoidal ac, the loss method should be used in determining conventional efficiency. The efficiency may be obtained from the component losses, most of which are accurately determinable by type tests and the remainder of which are assigned conventional values (in accordance with 10.3 and 10.4, or 10.5 and 10.6). The efficiency determined in this way shall be the ratio of the output to the sum of output and losses, or of input minus losses to the input.

10.2.2

For dc series motors operated from a rectified and filtered single-phase commercial-frequency ac supply, the loss method above may be used in determining conventional efficiency. The total power input is the sum of the dc and the ac components of input power. The total motor losses are then taken as the sum of the dc losses determined as in 10.2.1 plus the measured ac component of input power. Motor speed is based upon average (dc) values. The actual ohmic heating of windings is due to the total root-mean-square current; the remainder of the loss due to ac input power occurs in iron parts.

For inverter driven induction motors, the loss method above should be used in determining conventional efficiency. The total power input is the sum of the fundamental frequency and harmonic components; all harmonic input is taken as added loss. The actual ohmic heating of stator windings is due to the total root-mean-square current; the remainder of the loss due to harmonics occurs primarily in the rotor cage.

10.2.3

Efficiency may be determined by direct measurement of total losses in an appropriate pump-back configuration, the appropriate supply waveforms being provided. Instrumentation must be several times as accurate as that required for the method of 10.2.1 for results of comparable accuracy.

10.2.4

Efficiency may be determined by direct measurement of input and output as with a dynamometer, the appropriate waveforms being provided. Instrumentation must be an order of magnitude more accurate than that required for the method of 10.2.1 for results of comparable accuracy.

10.2.5

Particular attention shall be given to the accurate measurement of power where waveforms depart from smooth dc or sinusoidal ac.

10.2.6

Sufficient test points shall be taken to provide for accurate characteristic curves over the operating range.

10.3 Losses to be considered for direct-current machines

Conventional efficiencies of dc machines within the scope of this standard shall be based upon the following losses:

a) I^2R losses in armature and field windings
b) Brush friction, armature-bearing friction, and windage losses
c) No-load core losses
d) Brush-contact losses
e) Stray-load losses
f) Excitation losses, if any

10.4 Determination of losses in direct-current machines

Losses shall be measured, calculated, or taken conventionally as specified in the following paragraphs.

10.4.1 I^2R losses

The I^2R losses shall be based upon the current and the measured resistance, corrected to the temperature of 10.1.10.

10.4.2 Brush friction, armature-bearing friction, and windage losses

The brush friction, armature-bearing friction, and windage losses shall be determined by type tests as a total under the following conditions. In making the test, the machine shall be run without gears. The kind of brushes and the brush pressure shall be the same as in service. The machine shall be run idle as a motor on low voltage with low excitation. The product of armature counter-electromotive force and current at any speed shall be taken as the sum of the above losses at that speed.

10.4.3 No-load core losses, brush friction, armature-bearing friction and windage losses

The no-load core loss, brush friction, armature-bearing friction, and windage losses shall be determined by type tests as a total under the following conditions: The machine shall be run without gears. The kind of brushes, the brush pressure, and lubrication shall be the same as in service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for a given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above mentioned is equal to the product of the counter-electromotive force and the armature current.

The no-load core losses are obtained by deducting from the total losses thus obtained the power required to drive the machine at the corresponding speeds (see 10.4.2).

Alternatively the number of brushes and the windage may be reduced to improve the accuracy of no-load core loss readings, the no-load core loss being obtained as the difference in the power required to drive the machine with and without excitation under otherwise identical conditions.

10.4.4 Brush-contact losses

The brush-contact losses shall be taken as the product of the current and the total brush-contact drop, taken as follows where no brush shunts are provided:

$$2.5 + \frac{\begin{array}{c}\text{amperes per square meter}\\ \text{of brush contact area}\end{array}}{77\,500}\text{volts}$$

$$\left(2.5 + \frac{\begin{array}{c}\text{amperes per square inch}\\ \text{of brush contact area}\end{array}}{50}\text{volts}\right)$$

Where brush shunts are provided attached to brushes and holders, the total brush contact drop shall be taken as follows:

$$1.5 + \frac{\begin{array}{c}\text{amperes per square meter}\\ \text{of brush contact area}\end{array}}{77\,500}\text{volts}$$

$$\left(1.5 + \frac{\begin{array}{c}\text{amperes per square inch}\\ \text{of brush contact area}\end{array}}{50}\text{volts}\right)$$

10.4.5 Stray-load losses

The stray-load losses for dc machines with compensating windings shall be taken equal to the test short-circuit losses. The stray-load losses for dc machines without compensating windings shall be taken as a percentage of the test short-circuit losses in accordance with the following tabulation.

Ratio = $\frac{\text{Exciting field ampere turns}}{\text{Armature ampere turns between brush centers}}$	**Stray-load losses as a percent of short-circuit losses**
0	100
0.5	81
1.0	64
1.5	50
2.0	40
2.5	35

The type test for short-circuit losses shall be made with an ammeter connected with as little resistance as possible across the armature terminals of the machine. The desired values of revolutions per minute shall be obtained by driving the machine with a small motor of known efficiency and about 25% or less of the capacity of the machine being tested. Only enough field excitation shall be used to cause the desired values of armature current in the short circuit. Interspersed readings of armature circuit resistance shall be taken. I^2R losses, friction, and windage losses shall be subtracted point by point from the input to the shaft of the machine, the short-circuit losses being the remainder.

10.4.6 Excitation losses

The gross power used for excitation shall be taken as a machine loss. Absorbed shaft power shall be taken in the case of a rotating exciter. Field voltage times armature current shall be taken in the case of series motors, whether the field is shunted or not. In the case of static excitation supply the true power shall be taken as input to the static exciter.

10.5 Losses to be considered for inverter-driven induction motors

Conventional efficiencies of inverter-driven induction motors within the scope of this standard shall be based on the following losses:

a) I^2R losses in stator and rotor windings
b) Friction and windage losses
c) No-load core losses
d) Stray-load losses
e) Harmonic losses

10.6 Determination of losses in inverter-driven induction motors

Losses shall be measured, calculated, or taken conventionally as specified in the following paragraphs. Because of the wide speed and flux range in electric traction, it is important to know how each loss varies with speed (frequency) and flux over the operating range. The tests of 10.6.1, 10.6.2, 10.6.3 and 10.6.4 are run with sine wave power. The tests of 10.6.1, 10.6.2 and 10.6.3 are type tests. The tests of 10.6.4 and 10.6.5 shall be run on one machine deemed typical.

10.6.1 I^2R losses

Stator I^2R loss shall be based on fundamental current and the measured resistance. Rotor I^2R loss shall be taken as in 5.2 of IEEE Std 112–1996. Both shall be corrected to the temperature of 10.1.10.

10.6.2 Friction and windage losses

Friction and windage losses shall be taken as in 5.3 of IEEE Std 112–1996, corrected to speed at each point.

10.6.3 No-load core losses

No-load core losses shall be taken as in 5.3 of IEEE Std 112–1996, corrected to frequency and flux at each point.

10.6.4 Stray-load losses

Stray-load losses shall be taken from Test (10.6.4.1) or Assumed (10.6.4.2) Load Loss, corrected to frequency and approximate rotor current (as defined in 10.6.4.1) at each point.

10.6.4.1 Test for stray-load loss

Using either the indirect (5.4.1) or the direct (5.4.2) methods from IEEE Std 112–1996 (or applicable subclauses from latest revision) determine the Stray-Load Loss (W_{LLR}) at the approximate rated rotor current (I_{2R}) and rated frequency (F_R). If desired F_R can be selected to be some other frequency than rated frequency for purposes of establishing W_{LLR}. Stray-Load Loss (W_{LL}) at fundamental current I and fundamental frequency F will then be taken as:

$$W_{LL} = W_{LLR}\left(\frac{I^2 - I_0^2}{I_{2R}^{\ 2}}\right)(F/F_R)^{1.5}$$

where

I_0 is no load current at frequency F and the fundamental voltage used at F.

For the indirect method:

$$I_{2R} = \sqrt{I_R^{\ 2} - I_{0R}^{\ 2}}$$

where

I_R is current corresponding to W_{LLR} and at fundamental frequency F_R rated voltage.
I_{0R} is no load current at frequency F_R and at the voltage level used for the test.

For the direct method:

$I_{2R} = I_{tR}$ is Test current corresponding to W_{LLR} at fundamental frequency F_R.

10.6.4.2 Assumed stray-load loss

If the stray-load loss is not measured and it is acceptable by application standards and contract specification, the value of W_{LL60} can be taken as given in Table 3 as a percentage of the equivalent 60 Hz output power. The equivalent 60 Hz output power is based on the product of torque, which would be obtained with rated flux (V/Hz) at the approximate rated rotor current (I_{2R} as defined for the indirect method in 10.6.4.1), and the equivalent rated speed = speed(F_R) * (60/F_R) where speed(F_R) is the rotational speed at frequency F_R.

Table 3—Assumed values for stray-load loss

Machine rating		Stray-load loss percent of rated output
1–125 hp	1–90 kW	1.8%
126–500 hp	91–375 kW	1.5%
501–2499 hp	376–1850 kW	1.2%
2500 hp and greater	1851 kW and greater	0.9%

Stray-Load Loss (W_{LL}) at fundamental current I and fundamental frequency F will be taken as follows:

$$W_{LL} = W_{LL60}\left(\frac{I^2 - I_0^2}{I_{2R}^2}\right)(F/60)^{1.5}$$

10.6.5 Harmonic losses

The losses due to harmonic content of the input are the difference between the total input power and the fundamental frequency input power to the motor with stator winding temperature corrected to the temperature of 10.1.10.

This test shall be run in system test. Sufficient data shall be taken to show how harmonic loss varies over the range of operation in each inverter operating mode.

If the inverter is a voltage source type and its modulation pattern is independent of load, the difference may be measured at no load.

This test may be omitted by agreement, but harmonic losses are to be included in calculation of efficiency.

10.7 Declared curve type tests and tolerances

Type tests shall establish declared curves, correction being made to the winding temperature of 10.1.10.

10.7.1

Where the component loss method is used to determine efficiency, declared curves shall be established by calculation.

10.7.2

Where direct measurement of total losses is used to determine efficiency, the same tests shall establish declared curves. Where pulse control is used in service, the conditions of waveform, etc., shall be as in service.

10.7.3

Where direct measurement of input and output is used to determine efficiency, the same test shall establish declared curves. Where pulse control is used in service, the conditions of waveform, etc., shall be as in service.

10.7.4

No declared curve shall vary more than 5% from the corresponding contract curve for current values between 0.75 and 1.5 times the continuous rated current, unless otherwise specified in the contract.

10.8 Routine characteristic tests and tolerances

10.8.1

Load tests under operating conditions may be used to establish characteristics directly. Characteristics shall be taken toward the end of the routine heating-up run.

No commutator-type traction motor at its continuous rating shall vary from the declared speed characteristic in either direction of rotation by more than ±3% for dc motors with full field or by ±4% for reduced-field motors. At its continuous rating the difference in speed between the two directions of rotation shall not exceed 3% for dc motors with full field, or 4% for reduced-field motors.

No commutator-type traction motor shall vary from the declared characteristic between 0.75 and 1.5 times the continuous rated current for excitation values used for type tests by more than ±5%.

No traction generator or alternator shall vary from the declared "voltage-current" characteristic established by type tests, between 0.75 and 1.5 times the continuous rated current, and for excitation values used for type tests, by more than ±5%.

For commutator-type machines other than traction motors and generators, no machine shall vary from the declared characteristic established by type tests by more than ±5% at its continuous rating. The total losses of a motor or generator shall not vary more than 10% from the contract curve.

For motor-generator sets or other multiple-machine sets where it is not important to measure the characteristics of the individual components separately, the overall characteristics shall be sufficient. The overall characteristics shall not vary from the declared characteristics by more than ±5% at the continuous rating of the output machine, or the sum of the continuous ratings of the output machines if more than one. A tolerance of 10% is allowed on the total losses of the complete set.

Other kinds of machines that are load tested under operating conditions shall be tested and appropriate tolerances agreed upon between manufacturer and purchaser to verify that proper functioning of the system will in fact be attained.

10.8.2

Load tests under other than operating conditions may be used to verify characteristics by comparison with identical tests on machines that have been used to establish the declared characteristics. This is applicable to machines that operate with pulse control in service but do not have identical supply in routine tests. The test used and tolerances shall be agreed between manufacturer and purchaser to verify that proper functioning of the system will in fact be attained.

10.8.3

Testing other than load testing may be used to verify characteristics by comparison with identical tests on machines that have been used to establish declared characteristics. This is applicable to machines manufactured in large quantity where precision methods have been developed to determine characteristics. The test used and the tolerances shall be agreed between manufacturer and purchaser to verify that proper functioning of the system will in fact be attained.

10.9 Gear losses

10.9.1

When characteristics and efficiency of a traction motor or propulsion system are given in terms of speed and tractive effort, gear losses shall be taken into account. Actual gear unit losses are preferred; they should be taken from tests at operating temperature. When actual losses are not available, the conventional losses given below may be used. The source of gear loss data should be given in the caption for the curves.

10.9.2

For single-reduction gears and axle-hung motors, the conventional gear and axle-bearing losses are as follows:

Input to gearing, in percent of that at nominal motor rating	Losses, in percent of input to gearing
75 and over	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

10.9.3

For oil-lubricated gear units having anti-friction bearings throughout, used with motors rated 30–300 kW output, which are not axle hung, conventional gear unit losses may be taken as the sum of mesh losses and no-load losses given in 10.9.4 through 10.9.7, as applicable.

10.9.4

For gears with parallel shafts and helical tooth form, mesh losses shall be taken as 1.5% of motor shaft output for each mesh for use in 10.9.3.

10.9.5

For gears with offset shafts at right angles and hypoid tooth form, mesh losses shall be taken as 4.5% of motor shaft output for each mesh for use in 10.9.3.

10.9.6

Where the axle gear which dips in the oil has helical tooth form, no-load losses shall be taken as follows for use in 10.9.3:

Axle speed (rpm)	Loss (kw)
0	0
300	0.6
600	1.5
900	2.8
1200	4.4
1500	6.0

10.9.7

Where the axle gear which dips in the oil has hypoid tooth form, no-load losses shall be taken as follows for use in 10.9.3:

Axle speed (rpm)	Loss (kw)
0	0
300	1.8
600	5.0
900	9.25

11. External power systems

11.1 Supply voltage

The standard values for supply voltage at the vehicle power collector are shown in Tables 4 and 5 and are limited in number for standardization purposes.

Table 4—Supply voltages for dc systems

Minimum operating voltage (V)	Nominal system voltage (V)	Maximum operating voltage (V)
400	600	720
500	750	900
1000	1500	1800
2000	3000	3600

Table 5—Supply voltages for single-phase ac systems

Frequency (Hz)	Minimum operating voltage (V)	Normal lower operating voltage (V)	Nominal system voltage (V)	Normal upper operating voltage (V)
25	8 000	9 500	11 000	12 100
50 or 60	8 750	10 000	12 500	13 750
50 or 60	17 500	20 000	25 000	27 500
50 or 60	35 000	40 000	50 000	55 000

The maximum operating voltage on single-phase ac systems is the same as the normal upper operating voltage, except for 25 Hz systems. For 25 Hz systems the maximum operating voltage may somewhat exceed the normal upper operating voltage.

11.2 Propulsion performance voltage

Each user may specify a voltage for the calculation of characteristics and performance. This voltage will usually be the average voltage to be expected at the vehicle power collector on that user's system. This voltage may differ from the nominal system voltage. Above and below this voltage, propulsion performance may vary inherently, or it may be controlled in a manner subject to agreement between manufacturer and user. Alternatively, propulsion performance may be regulated over a range of collector voltages such as ±10% from the nominal system voltage. Regulation of constant propulsion performance over wide supply voltage range generally is not desirable.

11.3 Supply characteristics

Because of the adverse effect on equipment size and system efficiency, the overall range of operating voltage specified by the purchaser should not exceed the range of the standard voltages of Tables 4 and 5, nor should the propulsion performance voltage be made unreasonably low. Operation at or near the minimum operating voltage is assumed to be of limited duration and extent. Under conditions of low supply voltage, the power that can be supplied by the line is limited, and a priority of needs should be established. Any vital auxiliary machine shall have adequate output to permit operation of the vehicle at any value of supply voltage within the range specified in the contract. Reduced performance may be expected at low line voltage. The means of reducing nonvital loads under adverse supply conditions will depend on their characteristics and control, and is subject to agreement between manufacturer and purchaser.

11.4 DC systems using regeneration

Regenerative braking of vehicles on dc systems may be expected to increase the line voltage locally. The designed output voltage of the supply substations should be selected so as to permit adequate receptivity for regenerated power within the range of Table 4 where regenerative equipment is expected to be used. The design and application of auxiliary machines should take into account the frequency and duration of high-voltage conditions. The propulsion and other loads should not use voltage-limiting devices that might defeat the line receptivity foreseen with regeneration.

12. Terminal marking

12.1 Traction motors

12.1.1 General

Terminal marking for apparatus to which this standard applies distinguishes between traction motors and machines other than traction motors. The use of suffix numbers for traction motors is reserved for vehicle use to indicate axle driven or motor location.

12.1.2 Commutator-type traction motors

Armature (connected to a brush holder)	A
Armature (connected to a brush holder or through commutating or compensating field	AA
Series exciting field	F, FF
When commutating field windings are not permanently connected to the armature, the external leads shall be marked	C, CC
When compensating field windings are not permanently connected to the armature, the external leads shall be marked	D, DD
Shunt or separate exciting field	S, SS

When a compensating winding or commutating winding has no significance outside the machine, the AA marking may be applied to the free end of this field winding.

When two field windings are connected together inside a machine and a tap is brought out, the tap will carry the letter of the field having the greater significance outside of the machine.

When no internal connections are made to the armature, or internally connected fields are divided on each side of the armature, the A and AA markings will be arbitrary. When fields are internally connected to one side of the armature, the A lead shall be connected directly to the brush holder.

The correct polarity of the commutating and compensating field is given by lettering sequence A-AA, C-CC, D-DD.

If more than one field of any type is present, the first shall have no suffix, the second X, the third Y, and the fourth Z.

Midtaps shall be marked with the associated field markings (single letter) and the suffix M for the first, MM for the second, etc.

For a traction motor with armature and field polarities A-AA and F-FF (S-SS), rotation will be counterclockwise when looking at the commutator end of the machine.

12.1.3 Noncommutator-type traction motors

Stator windings line leads	TA, TB, TC
Stator winding neutral	TO
Exciting winding	F, FF

The standard line vector rotation is counterclockwise.

The standard phase sequence is A-B-C.

For a traction motor with counterclockwise line vector rotation and phase sequence A-B-C, rotation will be counterclockwise when looking at the end opposite the drive end of the machine.

12.2 Rotating machines other than traction motors

12.2.1 Commutator-type machines other than traction motors

Armature (connected to a brush holder)	A1
Armature (connected to a brush holder or through commutating or compensating field)	A2
Series exciting field	S1, S2
When commutating field windings are not permanently connected to the armature, the external leads shall be marked	C1, C2
When compensating field windings are not permanently connected to the armature, the external leads shall be marked	D1, D2
Shunt or separate exciting field	F1, F2, F3
Cranking field	K1, K2

When a compensating winding or commutating winding has no significance outside the machine, the A1 or A2 marking may be applied to the free end of this field winding.

When two field windings are connected together inside a machine and a tap is brought out, the tap will carry the letter of the field having the greater significance outside of the machine.

When no internal connections are made to the armature or internally connected fields are divided on each side of the armature, the A1 and A2 markings will be arbitrary. When fields are internally connected to one side of armature, the A1 lead shall go directly to the brush holder.

The correct polarity of the commutating and compensating field is given by lettering sequence A1–A2, C1–C2, D1–D2.

If more than one field of any type is present, the first shall have suffixes 1 and 2, the second 3 and 4, the third 5 and 6, etc.

Midtaps shall be marked with the associated field marking letter and the suffix M1 for the first, M2 for the second, etc.

For a motor with armature and field polarities A1–A2 and F1–F2 (S1–S2), rotation will be counterclockwise when looking at the commutator end of the machine.

The sequence of armature and field polarities of A1–A2 and S1–S2 indicates a cumulative series field for a motor and a differential series field for a generator with counterclockwise rotation.

12.2.2 Noncommutator-type machines other than traction motors

Stator winding line leads (polyphase)	T1, T2, T3
Dual winding, if used (polyphase)	T4, T5, T6
Stator winding neutral	T0
Run winding (singlephase)	T1, T2
Start winding (singlephase)	T5, T6
Output terminals of alternator having integral rectifiers	+, –
Exciting winding	F1, F2

The standard line vector rotation is counterclockwise.

The standard phase sequence is 1–2–3.

For a polyphase machine with counterclockwise line vector rotation and phase sequence 1–2–3, rotation will be counterclockwise when looking at the end opposite the drive and of the machine.

For a single-phase machine, rotation will be counterclockwise when looking at the end opposite the drive end when even-numbered main winding leads and odd-numbered start winding leads go to the same side of the line.

12.3 Reactors

12.3.1 Inductive shunts S, SS

Current going in single-lettered terminals gives cumulative magnetization.

12.3.2 Reactors other than inductive shunts T1, T2,…

Current going in odd-numbered terminals gives cumulative magnetization.

12.4 Connection diagrams

In addition to terminal markings, connection diagrams for machines shall show, as applicable, a direction of rotation and the corresponding brush holder polarities (+, –), field polarities (N, S), direction of current, and phase sequence.

Rotation shall be counterclockwise if a two-rotation machine or if normal rotation is counterclockwise. If normal rotation is clockwise, this rotation should be shown. Rotation is as observed from the commutator end, or other than the drive end if noncommutator machine.

12.5 Additional terminals

Terminals for added control windings, auxiliary windings, sensors, etc., shall be marked with a nomenclature that will not be confused with main windings as identified above.

13. Mechanical measurements

13.1 Commutator trueness

By special agreement between manufacturer and purchaser, measurement of the commutator surface may be made part of the routine test. Measurement is to be made at very low speed and at ambient temperature. One of the following options must be agreed on for the measurement:

13.1.1

In the assembled machine.

13.1.2

On the armature with its own bearings and bearing housings.

13.1.3

On the armature supported on its shaft bearing fits.

13.1.4

On the armature supported on its shaft centers.

Single bearing machines require special consideration of support. The recommended limits of total indicator runout (TIR), referred to the commutator peripheral velocity at the maximum design speed (Clause 9), are as follows:

Maximum design speed	**Maximum TIR**
Below 44 m/s (8500 ft/min)	0.05 mm (0.002 in)
44 m/s (8500 ft/min) and over	0.025 mm (0.001 in)

Only gradual changes in commutator surface are permitted. Due to practical limitations, measurement of the bar-by-bar profile is not recommended on a routine basis.

13.2 Vibration

13.2.1 General

Vibration may be measured by special agreement between manufacturer and purchaser. Measurement is to be made on the assembled machine, running light, less any gearing, blowers, etc. Single bearing machines require special consideration of support.

13.2.2 Vibration type test

The machine shall be supported on resilient material having a low natural frequency. The recommended limit of the velocity of vibration in any axis at any speed within the maximum design speed (Clause 9) is 7.6 mm/s (0.3 in/s).

13.2.3 Vibration routine test

Supported in the test stand, the machine shall be run at a speed that avoids stand resonance. The limits of vibration shall be based on that of machines having had type tests, as run under routine test conditions.

13.3 Sound

By special agreement between manufacturer and purchaser, audible sound measurement may be required. The principles of IEEE Std 85-1973 [B2] or ANSI S12.12-1992 [B1], are recommended.

Using IEEE Std 85–1973 [B2], the recommended limits of mean sound pressure level for a machine of 150 kW continuous rated output or less, at a distance of 4.5 m (15 ft), are 78 dBA for a separately ventilated machine and 105 dBA for a self-ventilated machine at or below the maximum design speed (Clause 9). Essentially unidirectional self-ventilated machines may be expected to produce significantly lower sound levels. These values are to be reduced by 3 dBA if significant pure tones exist in the range from 300 Hz to 4000 Hz. For this purpose pure tones are considered significant if any one-third-octave-band sound pressure level is 5 dB or more above the average of the two adjacent one-third-octave bands. These values are for machines without gears. For inverter driven induction motors, test shall be made with inverter drive at multiple speeds.

Separate ventilation blowers are to be sufficiently isolated not to influence the results. A no-load test is recommended. If loading is specified, two identical machines may be directly coupled and the limiting values for the two machines together increased by 3 dBA. If limits lower than those recommended are specified, machine size, weight, and enclosure may be expected to increase.

13.4 Shaft voltage

By special agreement between manufacturer and purchaser, shaft voltage or current may be measured. This is an investigative test.

Annex A

(informative)

Bibliography

[B1] ANSI S12.12–1992 (Reaff 1997), Engineering method for the determination of sound power levels of noise sources using sound intensity.[3]

[B2] IEEE Std 85–1973 (Reaff 1986), IEEE Test procedure for airborne sound measurements on rotating electric machinery.

[B3] IEEE Std 100–1996, IEEE Standard Dictionary of Electrical and Electronics Terms.

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[3] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).