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BSI Standards Publication

Electric traction — Rotating electrical machines for rail and road vehicles

Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter

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National foreword

This British Standard is the UK implementation of EN 60349-4:2013. It is identical to IEC 60349-4:2012.

The UK participation in its preparation was entrusted by Technical Committee GEL/9, Railway Electrotechnical Applications, to Subcommittee GEL/9/2, Railway Electrotechnical Applications - Rolling stock.

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Electric traction - Rotating electrical machines for rail and road vehicles - Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter

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(CEI 60349-4:2012)

Elektrische Zugförderung – Drehende elektrische Maschinen für Bahn- und Straßenfahrzeuge - Teil 4: Umrichtergespeiste Synchronmaschinen mit Permanentmagneterregung
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CENELEC

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Foreword

The text of document 9/1734/FDIS, future edition 1 of IEC 60349-4, prepared by IEC/TC 9 "Electrical equipment and systems for railways" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 60349-4:2013.

The following dates are fixed:

• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-10-15
• latest date by which the national standards conflicting with the document have to be withdrawn	(dow)	2016-01-15

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CENELEC [and/or CEN] shall not be held responsible for identifying any or all such patent rights.

Endorsement notice

The text of the International Standard IEC 60349-4:2012 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60034-2-1	NOTE Harmonized as EN 60034-2-1.
IEC/TS 60034-17	NOTE Harmonized as CLC/TS 60034-17.
IEC 61260	
	NOTE Harmonized as EN ISO 3746:2010 (not modified).
ISO 3747	
	NOTE Harmonized as EN ISO 9614-2:1996 (not modified).

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated

		Rotating electrical machines - Part 1: Rating and performance	EN 60034-1	-
IEC 60034-8	-	Rotating electrical machines - Part 8: Terminal markings and direction of rotation	EN 60034-8	-
IEC 60034-9	-	Rotating electrical machines - Part 9: Noise limits	EN 60034-9	-
IEC 60034-14	-	Rotating electrical machines - Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher - Measurement, evaluation and limits of vibration severity	EN 60034-14	-
IEC 60050-131	-	International Electrotechnical Vocabulary (IEV) - Part 131: Circuit theory	-	-
IEC 60050-151	-	International Electrotechnical Vocabulary (IEV) - Part 151: Electrical and magnetic devices	-	-
IEC 60050-221	-	International Electrotechnical Vocabulary (IEV) - Chapter 221: Magnetic materials and components	-	-
IEC 60050-411	-	International Electrotechnical Vocabulary (IEV) - Chapter 411: Rotating machinery	-	-
IEC 60050-811	-	International electrotechnical vocabulary (IEV) - Chapter 811: Electric traction	-	-
IEC 60085	-	Electrical insulation - Thermal evaluation and designation	EN 60085	-
IEC 60850	-	Railway applications - Supply voltages of traction systems	-	-
IEC 62498-1	-	Railway applications - Environmental conditions for equipment - Part 1: Equipment on board rolling stock	-	-

CONTENTS

ELECTRIC TRACTION – ROTATING ELECTRICAL MACHINES FOR RAIL AND ROAD VEHICLES –

Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter

1 Scope and object

This part of IEC 60349 applies to converter-fed permanent magnet synchronous motors or generators (machines) forming part of the equipment of electrically propelled rail and road vehicles.

This standard is derived from IEC 60349-2 changing the subject to permanent magnet synchronous machines.

The object of this part is to enable the performance of a machine to be confirmed by tests and to provide a basis for assessment of its suitability for a specified duty and for comparison with other machines.

Where further testing is to be undertaken in accordance with a combined test, it may be preferable, that some type and investigation tests be carried out on the combined test bed, to avoid duplication.

Particular attention is drawn to the need for collaboration between the designers of the machine and its associated converter as detailed in 5.1.

NOTE 1 This part also applies to machines installed on trailers hauled by powered vehicles.

NOTE 2 The basic requirements of this part may be applied to machines for special purpose vehicles such as mine locomotives but this part does not cover flameproof or other special features that may be required.

NOTE 3 It is not intended that this part should apply to machines on small road vehicles, such as battery-fed delivery vehicles, factory trucks, etc. This part also does not apply to minor machines such as windscreen wiper motors, etc. that may be used on all types of vehicles.

NOTE 4 Industrial type machines complying with IEC 60034 may be suitable for some auxiliary drives, provided that it is demonstrated that operation on a converter supply will meet the requirements of the particular application.

The electrical input to motors covered by this part is be from an electronic converter. Generators may be connected to a rectifier or a converter.

The machines covered by this part are classified as follows:

a) Traction motors

   Motors for propelling rail or road vehicles.

b) Main generators

   Generators for supplying power to traction motors on the same vehicle or train.

c) Auxiliary motors not covered by IEC 60034

   Motors for driving compressors, fans, auxiliary generators or other auxiliary machines.

d) Auxiliary generators not covered by IEC 60034

   Generators for supplying power for auxiliary services such as air conditioning, heating, lighting and battery charging, etc.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60034-1, *Rotating electrical machines – Part 1: Rating and performance*

IEC 60034-8, *Rotating electrical machines – Part 8: Terminal markings and direction of rotation*

IEC 60034-9, *Rotating electrical machines – Part 9: Noise limits*

IEC 60034-14, *Rotating electrical machines – Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of vibration severity*

IEC 60050-131, *International Electrotechnical Vocabulary (IEV) – Chapter 131: Circuit theory*

IEC 60050-151, *International Electrotechnical Vocabulary (IEV) – Chapter 151: Electrical and magnetic devices*

IEC 60050-221, *International Electrotechnical Vocabulary (IEV) – Chapter 221: Magnetic materials and components*

IEC 60050-411, *International Electrotechnical Vocabulary (IEV) – Chapter 411: Rotating machines*

IEC 60050-811, *International Electrotechnical Vocabulary (IEV) – Chapter 811: Electric traction*

IEC 60085, *Thermal evaluation and classification of electrical insulation*

IEC 60850, *Railway applications – Supply voltages of traction systems*

IEC 62498-1, *Railway applications – Environmental conditions for equipment – Part 1: Equipment on board rolling stock*

3 Terms and definitions

For the purposes of this document the terms and definitions given in IEC 60050-131, IEC 60050-151, IEC 60050-221, IEC 60050-411, and IEC 60050-811 as well as the following, apply.

3.1
rating of a machine
combination of simultaneous values of electrical and mechanical quantities, with their duration and sequence, assigned to the machine by the manufacturer

3.1.1
rated value
numerical value of any quantity included in a rating

3.1.2
continuous rating
mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for an unlimited time under the conditions specified in 8.1 without exceeding the limits of

temperature rise given in Table 2, all other appropriate requirements in this part also being satisfied

Note 1 to entry: Several continuous ratings may be specified.

3.1.3
short-time rating
(for example, 1 h)
mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for the stated time without exceeding the limits of temperature rise given in Table 2. The test being carried out as specified in 8.1 starting with the machine cold, all other appropriate requirements in this part being also satisfied

3.1.4
short-time overload rating
mechanical output that the motor (or electrical output that the generator) can deliver on the test bed for the stated time without exceeding the agreed limits of temperature

Note 1 to entry: Short-time overload ratings are of value in determining the suitability of machines for duties which involve relatively long periods of operation below the continuous rating followed by a period above it. These are most likely to occur in locomotive applications. They are not relevant to the repeated short load cycles of rapid transit and similar duties, and should not be specified for such applications.

3.1.5
intermittent duty rating
duty cycle in which the machine may be operated without the temperature rises exceeding the limits given in Table 2 at any point

3.1.6
equivalent rating
continuous rating with constant values of voltage, current and speed that, as far as temperature rise is concerned, is equivalent to the intermittent duty cycle which the machine has to withstand in service

Note 1 to entry: This rating should be agreed between user and manufacturer.

3.1.7
guaranteed rating
rating assigned by the manufacturer for test purposes

3.1.8
guaranteed rating of a machine
normally the continuous rating but in special cases the user and manufacturer may agree that it be a short-time or intermittent rating

3.1.9
guaranteed rating of an auxiliary machine
continuous rating unless otherwise specified

3.1.10
rated voltage
root-mean-square value of the fundamental component of the line-to-line voltage of a machine when it is operating at a guaranteed rating

3.1.11
rated speed
speed at a guaranteed rating

3.2
maximum service voltage
highest root-mean-square value of the fundamental component of the line-to-line voltage of the machine in service

3.3
maximum voltage
highest root-mean-square value of the fundamental component of the line-to-line voltage of the machine in any possible condition

Note 1 to entry: motor **operated** at high speed with **open circuit** may have a higher **maximum** voltage than the maximum service voltage.

3.4
repetitive peak voltage
peak value of the waveform of the converter output voltage, any random transient peaks arising from line voltage transients or other causes being disregarded

3.5
EMF
electromotive force in the machine winding caused by the flux of the permanent magnets

3.6
induced voltage
open circuit line-to-line root-mean-square value of the fundamental component of the EMF of the machine at a defined speed and a defined magnet temperature

3.7
maximum current
maximum current shown on the specified characteristic as defined in 5.4

3.8
maximum working speed

3.8.1
maximum working speed of a traction motor
highest rotational speed assigned to the motor by the manufacturer

Note 1 to entry: When the characteristics of the vehicle for which a motor is intended are specified, this speed is not less than that corresponding to the maximum service speed of the vehicle assuming fully worn metallic wheels or the minimum rolling diameter of rubber tyres.

3.8.2
maximum working speed of generator or auxiliary generator
generator speed corresponding to the maximum governed speed of the engine for the particular application

Note 1 to entry: This will normally be the maximum governed speed on “no–load”. Transient speed variations during load changes should be disregarded.

3.8.3
maximum working speed of an auxiliary machine
highest rotational speed assigned to the machine by the manufacturer

Note 1 to entry: For specific applications, when assigning this speed, the most unfavourable conditions of voltage, frequency, loading, etc., that can occur in service should be taken in account.

3.9
user
normally the end customer, but can be delegated to an other organization

3.10
manufacturer
producer of machines

3.11
system manufacturer
organization which has the technical responsibility for the supply of the combined system

Note 1 to entry: The system manufacturer as defined above may also be the manufacturer of the motor, of the inverter, of the control, or of all of them, or of none of them.

3.12
cogging torque
torque at the disconnected motor, caused by variations of the reluctance in function of the rotor angle

4 Environmental conditions

Unless otherwise specified by the user, the following environmental conditions are assumed:

a) Altitude

Height above sea level not exceeding Class A3 according IEC 62498-1.

b) Temperature

Air temperature in the shade Class T1 according IEC 62498-1.

Whenever machines are intended to operate where one or both of these limits will be exceeded, special requirements may be agreed between user and manufacturer. For more information refer to IEC 60034-1.

Furthermore, the user shall inform the manufacturer of any particularly severe environmental condition such as dust, humidity, temperature, snow, dynamic effects, etc., to which the machines will be subjected.

5 Characteristics

5.1 Exchange of information

The machine and converter designers shall collaborate to produce all the technical information necessary to ensure that the combined unit will meet the requirements of this part of IEC 60349.

To fulfill this requirement, the machine designer shall provide the converter designer with all the information necessary to fully evaluate the interaction between the machine and the converter.

The converter designer shall also provide the machine designer with the characteristics showing, for example, the converter line-to-line output voltage (including the repetitive voltage peaks), current, fundamental frequency, harmonics and power over the whole range of the application, including operation at the maximum and minimum values of the contact-system voltage.

The machine designer shall provide the converter designer with the characteristics showing induced voltage due to the permanent magnets by 20 °C as a function of speed over the whole

range of application of the machine. To calculate the induced voltage for other temperatures the machine designer shall also provide the temperature coefficient of the induced voltage.

The documents recording this exchange of information shall form an integral part of the specification of the machine and of the converter.

NOTE 1 For more information refer to IEC 61287-1, 5.3.1.1, Interfaces between motor and convertor (inverter).

NOTE 2 The length of cable run between machine and converter and the effect on peak voltages seen at the machine terminals should be considered. Responsible for this issue is the system manufacturer.

NOTE 3 For information about wave fronts and the impact to the machine see IEC 60034-17.

5.2 Special characteristic of a driven permanent magnet machine

The EMF of a driven permanent magnet synchronous machine cannot be switched off. This effect shall be taken into account.

EXAMPLES (informative only):

– An internal winding short circuit induces a short circuit current as soon as the machine is rotating.
– There is a voltage present on the open terminals as soon as the machine is rotating.
– A permanent magnet machine may show a cogging torque.

5.3 Reference temperature

All characteristics, irrespective of the thermal class of insulation system used on the machine to which they apply, shall be drawn for a winding reference temperature of 150 °C and a permanent magnets temperature of 100 °C which shall be stated in the characteristics.

5.4 Specified characteristics

Machine specifications shall, as a general rule, include characteristic curves in accordance with the relevant clauses of this part. These curves, defined as the "specified characteristics", shall be plotted to the designed operating limits of each variable. Unless otherwise agreed between user and manufacturer, the characteristics shall show the performance at the nominal voltage of the intermediate circuit, and shall be submitted to the user before the order for the machines is placed.

5.5 Declared characteristics

Declared characteristics are derived from the results of type tests carried out in accordance with 8.2.1 and shall meet the requirements of 8.2.2.

Unless previously agreed, the declared characteristics of machines electromagnetically identical with any previously manufactured for the same user or application shall be those of the existing machines. In which case, compliance with the characteristics shall be demonstrated by reduced type tests.

5.6 Efficiency characteristics

Efficiency characteristics shall take into account losses arising from the harmonics in the supply from the converter.

5.7 Traction motor characteristics

The specified and declared characteristics of a traction motor shall be the converter-fed variable frequency characteristics, which shall show motor line-to-line voltage, current, induced voltage, mean torque and efficiency as a function of speed over the whole range of application of the motor. Voltage curves shall show the root-mean-square value of the fundamental

component. Current curves shall show the root-mean-square value of the fundamental component and the total root-mean-square value. For motor used in the braking mode, similar characteristics shall be produced showing the torque input and the electrical output as a function of motor speed.

NOTE Subclause 5.1 refers to the need for the exchange of information between the designers of the machine and of the converter.

As an alternative to motor torque and speed, the characteristics may show tractive effort at the rail and vehicle speed, in which case the gear ratio, wheel diameter and transmission losses shall be stated. If conventional values are used for the latter, they shall be in accordance with Figure B.1.

5.8 Main generator characteristics

The characteristic curves shall show voltage and efficiency as a function of load current at defined speeds.

Characteristic curves shall be drawn corresponding to the generator input power available for traction at (or between) maximum, average and minimum engine speeds, and if the engine has a number of predetermined intermediate speed notches, additional curves shall be drawn for a sufficient number of these speeds to adequately show the performance of the generator.

Alternatively, the characteristics may be plotted as a function of speed.

If the generator is used as starter for the main engine, use the same as in 5.7.

5.9 Auxiliary motor characteristics

The specified and declared characteristics of auxiliary motors shall be the converter-fed characteristics, which shall show the motor line-to-line voltage, current, speed and mean torque as a function of motor output for each operating frequency over the whole range of application of the machine. The characteristics of motors which operate at continuously variable frequency shall be plotted for the maximum and minimum frequencies only.

Voltage curves shall show the root-mean-square value of the fundamental component. Current curves shall show the root-mean-square value of the fundamental component and the total root-mean-square value. The characteristics shall take account of the additional losses arising from the supply harmonics and the efficiency at the guaranteed rating shall be stated.

Alternatively, the characteristics may be plotted as a function of speed.

NOTE Subclause 5.1 refers to the need for the exchange of information between the designers of the machine and of the converter.

5.10 Auxiliary generator characteristics

The characteristic curves of output voltage, power and efficiency shall be plotted as a function of output current at the rated speed and, for variable speed machines, at the minimum and maximum speeds for the application. The frequency of the a.c. outputs shall be stated.

If the generator is used as starter for an engine, use the same as in 5.9.

6 Marking

6.1 Nameplate

All machines covered by this part of IEC 60349 shall carry a nameplate including at least the following information:

a) manufacturer's name;

b) machine type designation;

c) remark that indicates this is a permanent magnet machine;

d) machine serial number;

e) year of manufacture;

f) indication of final assembly location.

Furthermore, a serial number shall be punched on both the stator and rotor of every machine, and machines designed for unidirectional rotation shall carry an arrow indicating the direction of rotation.

NOTE 1 f) may be integrated in a), d) or e).

NOTE 2 The machine name plate and, if applicable, the rotation arrow should be easily readable when the machine is installed in the vehicle.

6.2 Terminal and lead marking

Terminal and lead markings shall be in accordance with IEC 60034-8 unless otherwise agreed.

7 Test categories

7.1 General

There are four categories of tests:

– type tests;

– reduced type test;

– routine tests;

– investigation tests.

NOTE See Clause 1 on duplication of tests.

7.2 Type tests

7.2.1 General

Type tests are intended to prove the ratings, characteristics and performance of new types of machines. They shall be carried out on one machine of every new design. Unless otherwise agreed, the machine shall be one of the first ten manufactured. Where there is a change in place and/or method of manufacture, refer to 7.3.

The type test motor shall also be routine tested (see Clause 9).

Before testing commences, the manufacturer shall provide the user with a test specification outlining the tests to be undertaken to demonstrate compliance with this standard. Following completion of the type tests, the manufacturer shall supply the user with a full test report.

7.2.2 Type tests on converter supply

The type test shall be carried out using the converter and control to be applied in service, but, as an alternative, a supply which closely resembles the supply from the vehicle converter in control principle, waveform and harmonics may be employed.

NOTE

a) Many working points of a permanent magnet synchronous machine can be operated stable only with the converter and its control.

b) In case of a permanent magnet generator with rectifier a similar diode bridge can be used instead of a converter.

If agreed, the manufacturer shall demonstrate the similarity of the test and service supplies, and shall state the likely effect on the performance of the machine of any difference between them.

Unless otherwise agreed, the type test may be repeated if the electrical output characteristics of the converter are changed.

7.3 Reduced type test

7.3.1 General

The reduced type test consists of the routine test and one temperature rise test out of 7.3.2 to 7.3.5. This reduced type test is applicable to demonstrate the similarity in repeat orders or change of place and/or method of manufacture or for machines of the same electromagnetic and cooling design at the same or higher rating. If a reduced type test is planned, this additional temperature rise test shall be performed as part of the full type test.

The test parameters shall be maintained for any subsequent test on that design of machine.

The temperature rise measurements shall be carried out as detailed in 8.1.

If all of the following conditions are fulfilled, the full type test can be replaced by this reduced type test.

a) The agreement between the user and the manufacturer is made.

b) The results of the reduced type test are within the tolerances established on the previous machines.

c) The manufacturer provides a full type test report for a previous machine of the same electromagnetic and cooling design at the same or higher rating.

NOTE This reduced type test was named “repeated type test” in IEC 60349-2.

7.3.2 Repeat the type test temperature rise test with converter

Use the same setup, voltage, frequency, torque, cooling and test duration of the type test again.

7.3.3 Repeat a temperature rise test with converter with different load

The machine is fed by a converter and connected to a mechanical load. Voltage, frequency, torque, cooling and test duration can be at the manufacturer’s discretion, but the duration of the test shall be at least 1 h and at values that do not over-stress the machine.

7.3.4 Repeat a temperature rise test with sinusoidal supply

The machine is connected to a sinusoidal supply and connected to a mechanical load.

Voltage, frequency, torque, cooling and test duration can be at the manufacturer's discretion, but the duration of the test shall be at least 1 h and at values that do not over-stress the machine.

7.3.5 Repeat a temperature rise test in generating mode with a passive load

The machine is driven by a motor and is in generating mode. The load can be resistive or RL (resistance and inductance in series). The frequency, power, cooling and test duration can be at the manufacturer's discretion, but the duration of the test shall be at least 1 h and at values that do not over-stress the machine.

7.4 Routine tests

Routine tests are intended to demonstrate that a machine has been assembled correctly, is able to withstand the appropriate dielectric tests, and is in sound working order both mechanically and electrically.

The routine tests specified in Clause 9 shall normally be carried out on all machines but, before placing an order, the user and manufacturer may agree to adopt an alternative test procedure (e.g. in the case of machines produced in large quantities under a strict quality assurance procedure). This may permit reduced routine testing of all machines or may require the full tests on a proportion of machines chosen at random from those produced on the order. Any such agreement shall require the dielectric tests specified in 9.4 to be carried out on all machines.

7.5 Investigation tests

Investigation tests are optional special tests performed to obtain additional information. They shall be carried out only if an agreement between user and manufacturer has been reached before placing the order for manufacture of the machines. The results of these tests shall not influence acceptance of a machine unless similarly agreed.

7.6 Summary of tests

Table 1 lists the tests required for compliance with this part of IEC 60349.

Table 1 – Summary of tests

Test category	Clause									
	Tempera-ture rise with converter	Temperature rise test for reduced type test Converter or sinusoidal	Charac-teristics	No-load test	Current load test	Over speed	Dielectric	Vibration	Noise	Investi gation
Type	8.1	7.3.1 to 7.3.5[a]	8.2	9.2.2	9.2.3	8.3	9.4	8.4	8.5 [a]	–
Reduced type test [a]	–	7.3.1 to 7.3.5	–	9.2.2	9.2.3	9.3[a]	9.4	9.5[a]	–	–
Routine	–	–	–	9.2.2	9.2.3	9.3[a]	9.4	9.5[a]	–	–
Investi-gation [a]										10

NOTE All machines, including those type tested, shall be routine tested.

[a] Optional tests, subject to agreement between user and manufacturer.

8 Type tests

8.1 Temperature-rise tests

8.1.1 General

The tests shall be carried out at the guaranteed ratings of the machine.

The rated mechanical output may be measured directly or indirectly at the machine shaft, or be obtained without measurement by supplying the machine at the voltage, current and frequency shown on the declared characteristics as producing the rated mechanical output.

In the case of continuous rating tests, the time to reach a steady temperature may be shortened by commencing the test at an increased load or reduced ventilation provided that the rated conditions are subsequently maintained for at least 2 h or until it is demonstrated by appropriate means that steady temperatures have been reached.

NOTE Steady temperature is defined as a change in temperature of less than 2 K during the final hour of the test.

8.1.2 Cooling during rating tests

Machines shall be tested with the cooling arranged as in service with all those parts which would affect the temperature rise, including any ducting and filters regarded as part of the vehicle in place, or with an arrangement giving equivalent conditions. Cooling corresponding to that produced by air movement on the vehicle shall be subject to agreement between user and manufacturer.

If cooling is by forced ventilation, the static pressure and the airflow shall be measured at the inlet to the machine so that a table giving the relationship between these two quantities may be drawn up.

If cooling is by self-ventilation with ducts, the air quantity has to be measured in function of the motor speed.

In case of liquid cooling, the static pressure and the liquid flow shall be measured at the inlet to the machine so that a table giving the relationship between these two quantities may be drawn up.

8.1.3 Measurement of temperature

The temperature shall be measured in accordance with annex A.

8.1.4 Judgement of results

The temperature rises of the windings at the “commencement of cooling” as defined in Clause A.4 shall not exceed the values given in Table 2.

8.1.5 Limits of temperature rise

The different thermal classes of insulation systems are defined in IEC 60085.

Table 2 gives the permissible limits of temperature rise above the temperature of the cooling medium, measured on the test bed, for windings, permanent magnets and other parts insulated with materials of the thermal classes presently used in the construction of machines to which this standard applies.

If different parts of the same machine have different thermal classes of insulation systems, the temperature-rise limit of each part shall be that of its individual class.

Table 2 – Limits of temperature rise for continuous and other ratings

Part	Method of measurement	Thermal class of insulation system					
		130(B)	155(F)	180(H)	200	220	250
Stator windings	Resistance	130 K	155 K	180 K	200 K	220 K	250 K
Permanent magnet temperature	Thermometer or another suitable method	The temperature rise shall not be sufficient to endanger the permanent magnets properties.					
Other parts		The temperature rise of any part shall not endanger other parts of the machine.					

For totally enclosed machines, the limits above are increased by 10 K on the winding.

Where the machines are directly or indirectly exposed to the heat from an engine or from any other source, the adoption of temperature rises lower than those specified in Table 2 may be agreed between the user and manufacturer.

To confirm the induced voltage in hot condition, a no-load measurement in hot condition (e.g. just after finishing the temperature rise test) has to be performed. To confirm no demagnetisation, the no-load test has to be repeated at the same conditions after the heat run. The voltage shall not vary more than 3 % from the measurement before the temperature rise test.

8.1.6 Short-time overload test

If short-time overload ratings are specified, they shall be verified by one or more tests carried out as follows.

The following items shall be specified and agreed between user and manufacturer:

– Cooling conditions
– Start temperature and load
– Either a time or a temperature limit

8.2 Characteristic tests and tolerances

8.2.1 General

Tests to demonstrate compliance with the specified characteristics shall be carried out by measuring the electrical input/output to/from the machine and the mechanical output/input from/to it. The mechanical output/input may either be measured directly or be calculated from the measured output of a driven electrical machine of known efficiency.

Alternatively, and if agreed between user and manufacturer, either the output or input of the machine being tested may be derived by summation of the losses.

Load tests shall be carried out with the machine at approximately the winding reference temperature to which the results shall be corrected if the correction is significant. Sufficient test readings shall be taken to enable the declared characteristics of the machine to be plotted.

The electrical input/output to/from the machine may be modified from that shown in the specified characteristics by agreement between the manufacturers of the machine and its associated converter, subject to the temperature rises of all parts of the machine and converter being within their respective limits when operating at the guaranteed rating and the machine losses being within the tolerance specified in 8.2.2.

The tests shall be carried out in only one direction of rotation.

The instruments used to measure the complex waveforms of the input/output to/from the machine shall indicate the value of the current, voltage and power with sufficient accuracy to enable compliance with the specified tolerances to be demonstrated.

8.2.2 Tolerances

8.2.2.1 Traction motors

The declared torque at any electrical input in the specified characteristics between the values corresponding to the maximum torque and to the maximum working speed shall be not less than 95 % of the specified value.

The motor losses at the guaranteed rating shall not exceed the value derived from the specified characteristic by more than 1 % of the rated output power. This tolerance applies only to the guaranteed rating.

The temperature rise of the stator winding from the reduced type test (see 7.3) where applicable, shall not vary by more than ± 8 % or ± 10 K, whichever is the highest, from the original type test.

At rated speed the induced voltage shall not vary from the corresponding specified value by more than ± 10 %.

8.2.2.2 Main generators

The generator losses at the guaranteed rating shall not exceed the value derived from the specified characteristic by more than 1 % of the rated output power. The temperature rise from the reduced type test (see 7.3) where applicable, shall not vary by more than ± 8 % or ± 10 K, whichever is the highest, from the original type test.

At rated speed, the declared maximum current, the voltage at the rated current and the induced voltage (Points Ch1, Ch2, Ch3 in Figure 1) shall not vary from the corresponding values on the specified curve by more than ± 10 %.

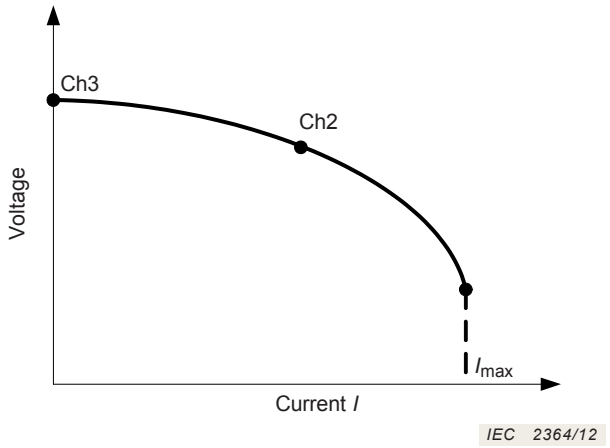


Figure 1 – Inherent characteristic generator

8.2.2.3 Auxiliary motors

The torque shown in the declared characteristics at the guaranteed rating shall be not less than the specified value. The current at the guaranteed rating shall not exceed the specified value.

The current to produce the specified starting torque shall not exceed the value specified to the converter manufacturer in accordance with 5.1.

8.2.2.4 Auxiliary generator

The generator losses at the guaranteed rating shall not exceed the value derived from the specified characteristic by more than 1 % of the rated output power. The temperature rise from the reduced type test (see 7.3) where applicable, shall not vary by more than ± 8 % or ± 10 K, whichever is the highest, from the original type test.

At rated speed, the declared maximum current, the voltage at the rated current and the induced voltage (Points Ch1, Ch2, Ch3 in Figure 1) shall not vary from the corresponding values on the specified curve by more than ± 10 %.

8.3 Overspeed test

An overspeed type test shall be carried out on all types of machines. Machines shall be run for 2 min when hot at 1,2 times the maximum working speed as defined in 3.8. Alternatively, rotors may be tested before assembly in the stator subject to means being provided to heat them to approximately the same temperature as that obtained at the end of the guaranteed rating test. In both cases, measurements shall be taken before and after the test to determine the extent of any distortion of the rotor.

8.4 Vibration tests

A quantitative vibration measurement is to be taken as a type test. Where a motor incorporates an integral gearbox, the gear assembly shall be removed or gearbox replaced by a supporting end shield. Where a generator incorporates an engine, the engine assembly shall be removed or engine replaced by a supporting end shield.

For vibration measurement during type test the machine could be placed only on the test board without any mounting equipment. The velocity of vibration at machine speeds up to 3 600 rev/min shall be within the limit of 3,5 mm/s. For speed above 3 600 rev/min the velocity shall be less than 5,25 mm/s.

If the machine design has no fixed bearing the longitudinal velocity of vibration could be excluded.

For additional information see IEC 60034-14.

Measurements on variable speed machines shall be taken at a number of speeds covering the whole working range.

Vibration velocities in excess of the limiting values may arise from the resonances in the test mountings, in which case they shall be disregarded provided that they do not coincide with a discrete working speed and that the general level of velocity over the speed range is within limits.

Should such a resonance occur at a discrete working speed, the test shall be repeated with an alternative mounting arrangement.

8.5 Noise measurements (optional)

For details, see Annex C.

9 Routine tests

9.1 General

Routine tests shall be carried out in one direction of rotation using a frequency used in service.

The frequencies used for different tests need not be the same but, once established, they shall not be changed. The declared values for the test points shall be the average of the tests on four machines, one of which shall be the machine which has been type-tested. In order to reduce the effect of temperature variations, the tests shall be carried out in the same sequence on all machines.

To confirm consistency within a series, the temperature rise from the type test on sinusoidal supply (see 7.3.3), or type test on a general converter supply (see 7.3.1 or 7.3.2), or type test on generating mode with passive load (see 7.3.4), may be undertaken at intervals throughout the series, either randomly or at set intervals with agreement between user and manufacturer. The tolerances are as defined in 8.2.2.1 (traction motor) or 8.2.2.2 (main generator).

9.2 Characteristic tests and tolerances

9.2.1 General

Permanent synchronous machines shall be tested under no-load and current load conditions.

9.2.2 No-load tests

The test shall be performed with a cold machine. In order to know the magnet temperature, the temperature of machine shall be documented. The chosen test method shall be one of cases a), b), c) or d).

a) The machine has to be mechanically coupled with a load-machine (Figure 2). The load-machine shall be powered to drive the tested machine between 10 % and 100 % of the speed shown in the declared characteristics. The fundamental root-mean-square voltage shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %. The speed shall be established on the first motor to be tested and shall be used for all subsequent tests.

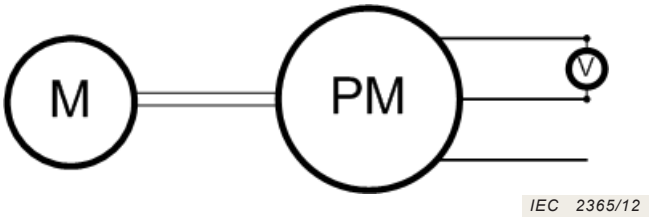


Figure 2 – Open terminal

b) The machine shall be powered by a sinusoidal voltage between 10 % and 100 % of the speed shown in the declared characteristics (Figure 3). The voltage has to be changed until the fundamental root-mean-square current has a minimum. The speed shall be established on the first motor to be tested and shall be used for all subsequent tests. The fundamental root-mean-square voltage shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

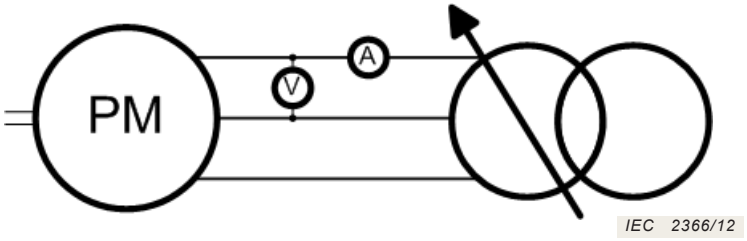


Figure 3 – Sinusoidal supply

c) The machine shall be powered by a voltage different from sinusoidal waveform between 10 % and 100 % of the speed shown in the declared characteristics (Figure 4). The voltage has to be changed until the fundamental root-mean-square current has a minimum. The speed shall be established on the first motor to be tested and shall be used for all subsequent tests. The fundamental root-mean-square voltage shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

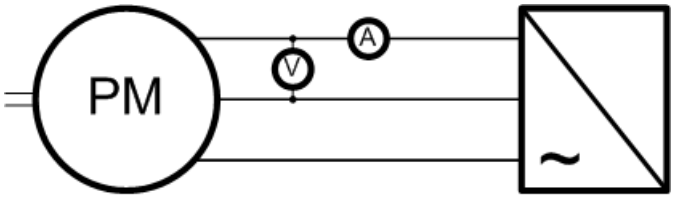


Figure 4 – Converter supply

d) The machine shall be powered between 10 % and 100 % of the speed shown in the declared characteristics (Figure 5). The speed shall be established on the first motor to be tested and shall be used for all subsequent tests. Immediately after reaching the speed, cut off the power and measure the voltage and the speed over the time. The fundamental root-mean-square voltage of the first oscillation after cut off shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

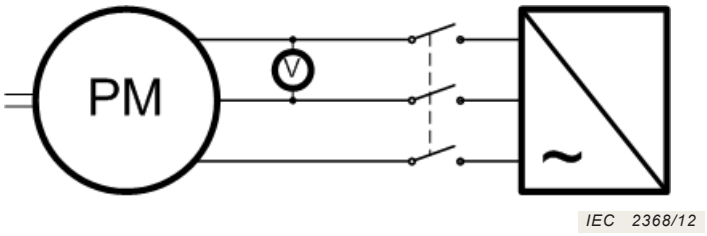


Figure 5 – Converter supply with cut off

9.2.3 Current-load tests

The chosen test method shall be one of cases a), b) or c).

a) The machine has to be mechanically coupled with a load-machine and the terminal of the machines has to be shorted as close as possible (Figure 6). The load-machine shall be powered to drive the tested machine with the same speed as in the case of no-load conditions. The fundamental root-mean-square current shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

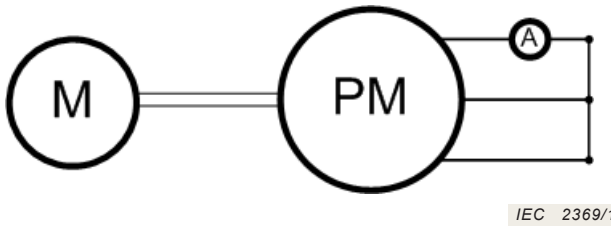


Figure 6 – Short-circuit

b) The machine shall be powered by a sinusoidal voltage with the same speed as in the case of no-load conditions (Figure 7). The voltage has to be decreased compared to the voltage in case of minimum current until the fundamental root-mean-square current is higher than 20 % of the rated current. The load current and the speed shall be established on the first motor to be tested and shall be used for all subsequent tests. The fundamental root-mean-square voltage shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

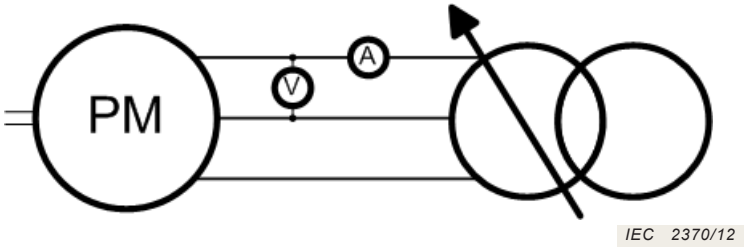


Figure 7 – Sinusoidal supply

c) The machine shall be powered by a voltage different from sinusoidal waveform with the same speed as in the case of no-load conditions (Figure 8). The voltage has to be decreased compared to the voltage in case of minimum current until the fundamental root-mean-square current is higher than 20 % of the rated current. The load current and the speed shall be established on the first motor to be tested and shall be used for all subsequent tests. The fundamental root-mean-square voltage shall not vary from the declared value established in accordance with 9.1 by more than ± 10 %.

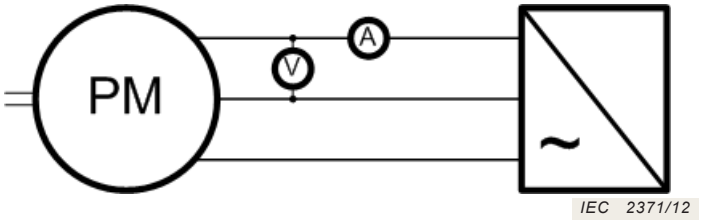


Figure 8 – Converter supply

9.3 Overspeed tests

Overspeed tests may be agreed between user and manufacturer.

Machines subjected to an overspeed test shall be run for 2 min at 1,2 times the maximum working speed as defined in 3.8. Any deviation from these conditions needs to be agreed between user and manufacturer.

In carrying out the routine overspeed test, precautions may be necessary to avoid damage to roller bearings as a result of operating at high speed on no-load (e.g. reduction of the test speed to not less than the maximum working speed).

In carrying out the routine overspeed test with open terminals, precautions (e.g. reduction of the test speed to not less than the maximum working speed) may be necessary against the effect of high induced voltage.

9.4 Dielectric tests

The tests shall normally be carried out at standstill using a.c. of near sinusoidal waveform and a frequency between 25 Hz and 100 Hz, but d.c. testing may be employed if agreed between user and manufacturer before placing an order.

The test voltage shall be applied in turn between the windings of each circuit and the frame, with the windings of all other circuits connected to the frame. The full value of the voltage shall be applied only to new machines with all their parts in place as under normal working conditions. The test shall be carried out with the machine immediately after completion of the routine tests specified in the preceding clauses.

The test voltage shall be the highest of the values listed in Table 3 for the chosen test method and shall be applied gradually, commencing at not more than one third of the final value. When reached, this final value shall be maintained for 60 s.

Table 3 – Dielectric test voltages

Winding	**Test voltage** V	
Stator windings of motor or generator	AC tests	$2 \times U_{dc}$ + 1 000 or $2 \times U_{rp} / \sqrt{2}$ + 1 000 or $U_{rpb} / \sqrt{2}$ + 1 000 or $U_{imax} / \sqrt{2}$ + 1 000
	DC tests	$3{,}4 \times U_{dc}$ + 1 700 or $2{,}4 \times U_{rp}$ + 1 700 or $1{,}2 \times U_{rpb}$ + 1 700 or $1{,}2 \times U_{imax}$ + 1 700

NOTE

U_{dc}	is the highest mean voltage to earth which can be applied to the d.c. link when the contact system is at its maximum voltage and the machine is motoring (see Annex D).
U_{rp}	is the maximum repetitive peak voltage to earth which can be applied to the machine winding when the contact system is at its maximum voltage and the machine is motoring. (Repetitive peak voltage is defined in 3.4.)
U_{rpb}	is the maximum repetitive peak voltage to earth which can appear on the winding when the machine is braking.
U_{imax}	is the peak voltage to earth which can appear on the winding when the machine is operated at maximum working speed with open terminals (zero current).

If neither the d.c. link nor the machine windings are normally earth referenced, then U_{dc} and U_{rp} shall be taken as the highest voltages to earth that can appear on their respective circuits, should any point on them become connected to earth.

A lower value for repeated tests shall be agreed between user and manufacturer of the machine.

Remark: The value used to test the converter (see IEC 61287-1) shall be lower or equal to the value used to test the machine.

9.5 Vibration tests (imbalance)

Each machine shall be checked for vibrations associated with machine imbalance. It shall normally be adequate to demonstrate that a machine runs smoothly when mounted on the test bed. Where a machine incorporates an integral gearbox or an engine, which is fitted for the rest of routine test, the vibration check above can also be undertaken with it fitted.

In applications where machine vibration is considered critical, if agreed between user and manufacturer, the tests detailed in 8.4 can be carried out on each machine.

10 Investigation tests

10.1 Measurement of cogging torque

The torque of the machine is measured with open terminals. Details have to be agreed between user and manufacturer.

10.2 Temperature rise test of the machine in high speed with open terminals

The machine is driven by a motor to the defined speed with open terminals.

The test time and speed and cooling conditions should be agreed between user and manufacturer.

The temperature shall be measured in accordance with annex.A.

The temperature rises of windings at the “commencement of cooling” as defined in Clause A.4 shall not exceed the values given in Table 2.

10.3 Temperature coefficient measurement of the induced voltage

To confirm the temperature coefficient of the induced voltage, a no-load measurement in hot condition (e.g. just after finishing the temperature rise test) may be performed.

Annex A
(normative)

Measurement of temperature

A.1 Temperature of the machine parts

The temperature of insulated windings shall be measured by the resistance method. The permanent magnets shall be measured by thermometer or another suitable method.

No correction shall be made to the measured temperature rises if the temperature of the cooling air is between 10 °C and 40 °C during the test.

If the cooling air temperature is outside these limits during a type test, a correction to the measured temperature rises may be agreed between user and manufacturer.

Before starting a short-time test, it shall be confirmed, by either thermometer or resistance measurements, that the temperatures of the windings are within 4 K of the temperature of the cooling air. When calculating the winding temperature rises, any such difference in initial temperature up to 4 K shall be subtracted from the result if the winding is the hotter or added to it if it is the cooler.

a) Resistance method

In this method, the temperature rise of a winding is determined by its increase in resistance during the test.

For copper windings, the temperature rise at the end of a test is determined by the following formula:

$$\text{temperature rise} = t_2 - t_a = \frac{R_2}{R_1}\,(235 + t_1) - (235 + t_a)$$

where:

t_1 is the initial temperature, of the winding in degrees Celsius;

R_1 is the resistance of the winding at temperature t_1;

t_2 is the temperature, of the winding at the end of the test in degrees Celsius;

R_2 is the resistance of the winding at the end of the test;

t_a is the temperature of the cooling air at the end of the test in degrees Celsius.

NOTE For materials other than copper, the value 235 in the above formula should be replaced with the reciprocal of the temperature coefficient of resistance at 0 °C for the material.

b) Electrical thermometer method

In this method, the temperature is determined by means of electrical thermometers applied to the hottest accessible spots of the relevant parts immediately after the machine is stopped.

A.2 Temperature of the coolant

A.2.1 Air cooling

For totally enclosed machines, the cooling air temperature shall be measured by not less than four thermometers distributed around the machine and spaced between 1 m and 2 m.

In all other cases, the temperature of the cooling air shall be as measured at its entry to the machine and, in the case of more than one entry point, this temperature shall be the average of the measurements at each of the points.

In all cases, the thermometers shall be protected from radiated heat and draughts so that they record the true temperature of the air entering the machine and around it. In order to avoid errors due to variations in the temperature of the cooling air, all reasonable precautions shall be taken to keep such variations to a minimum.

The temperature of the cooling air at the end of a test shall be the average of measurements taken at approximately 15 min intervals during the last hour of a continuous rating test or throughout the duration of short-time test.

A.2.2 Liquid cooling

In case of liquid cooling the temperature of the coolant shall be measured at the inlet.

The temperature of the cooling medium at the end of a test shall be the average of measurements taken at approximately 15 min intervals during the last hour of a continuous rating test or throughout the duration of short-time test.

A.3 Measurement of resistance

A.3.1 Initial cold resistance

The initial cold resistance measurement shall be carried out using the same instruments as for subsequent hot measurements but the measurement need not be repeated at the beginning of each test. The temperatures of the windings shall be taken as their surface temperature as recorded by thermometer at the time of the resistance measurement and shall not differ from the temperature of the ambient air at that time by more than 4 K.

A.3.2 Hot resistance

The hot resistance shall be measured as soon as practicable after stopping the machine at the end of the test. Measurement may be by the voltmeter and ammeter method (volt-ampere method), or by means of a bridge or other suitable means, but the same method shall be employed for all readings on a given winding, including the initial cold one.

If the voltmeter and ammeter method is used, the current shall be high enough to give the necessary accuracy without itself influencing the temperature rise. (In general, a value not exceeding 10 % of the rated current will meet the latter requirement.)

A.4 Stopping of machines and time of “commencement of cooling”

At the end of a test, the machine shall be stopped in as short a time as possible.

A method of braking in which the machine under test does not carry current is preferred. In this case, the “commencement of cooling” shall be the instant when the main circuits are opened immediately before braking, any separate cooling being cut off at this instant.

If such a method is impracticable, methods in which the test machine carries current may be used provided they stop the machine quickly and the load current remains reasonably constant during the braking period. The “commencement of cooling” shall be when the load current has fallen to 80 % of the test value, at which instant the cooling shall be cut off.

A.5 Time of the hot resistance measurement and extrapolation of the cooling and heating curves

Resistance measurements of each winding shall commence not later than 45 s after the “commencement of cooling” and shall be continued for at least 5 min.

The time between successive measurements on each winding shall not exceed 20 s during the first 3 min and 30 s thereafter.

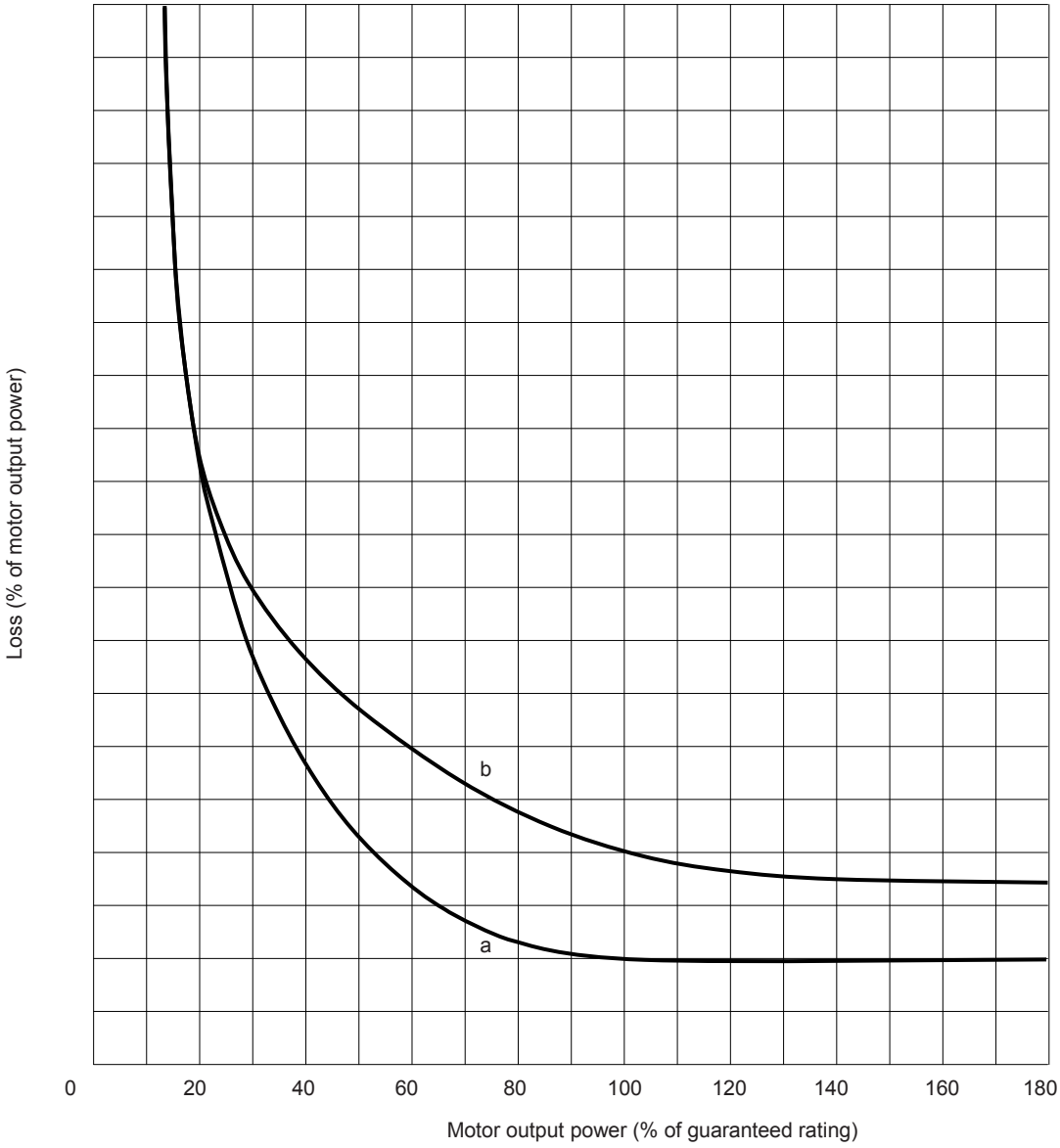
For large machines for which it is not possible to stop in time for measurements to commence within 45 s, special braking arrangements and an extension of time to not more than 2 min shall be agreed between user and manufacturer.

The temperature rises calculated from these readings shall be plotted as a function of time using a logarithmic scale for temperature and a linear scale for time. The resulting curve shall be extrapolated to the time of “commencement of cooling” to give the temperature rise at the end of the test.

Annex B
(normative)

Conventional values of traction motor transmission losses

If conventional values of traction motor transmission losses are included in the efficiency calculation they shall be in accordance with Figure B.1.



Curve a: Loss per stage of reduction for gears with parallel shafts
Curve b: Loss per stage of reduction for gears with shafts at right angles
Both curves include suspension or gearbox bearing loss.

NOTE These conventional losses are for use in vehicle performance calculations in the absence of more specific information. They are not a basis for acceptance or rejection of machines or gearing.

IEC 2372/12

Figure B.1 – Conventional values of traction motor transmission losses

Annex C
(informative)

Noise measurement and limits

C.1 Noise measurement

C.1.1

If noise measurement is required, this should be specified by the user and carried out on one machine only from the order. If however, a test record showing that the noise requirements have been met on an identical machine, constructed on a previous occasion, using the test method detailed in this annex, or a previous edition of IEC 60349, is deemed acceptable to the user, this may be regarded as meeting the requirement for noise measurement.

C.1.2 Sound pressure level measurement and calculation of sound power level produced by the machine shall be made in accordance with Clauses C.5 to C.6, unless one of the alternative methods specified in C.1.3. below applies.

C.1.3 The maximum sound power levels and the correction for pure tones are specified in Clauses C.7 and C.8.

C1.4 When appropriate, one of the methods of precision or engineering grade accuracy, such as the methods of ISO 3741, ISO 3743-1, ISO 3743-2, ISO 3744, ISO 3745, ISO 9614-1 or ISO 9614-2 may be used to determine sound power levels.

C.1.5 The simpler but less accurate method specified in ISO 3746 or ISO 3747 may be used, especially when the environmental conditions required by ISO 3744 cannot be satisfied.

However, to provide compliance with this standard, unless a correction due to inaccuracy of the measurement has already been applied to the values determined by this method in accordance with ISO 3746 or ISO 3747, the levels of Table C.1 shall be decreased by 2 dB.

C.1.6 If testing under rated load conditions, the methods of ISO 9614-1 or ISO 9614-2 are preferred. However, other methods are allowed when the load machine and auxiliary equipment are acoustically isolated or located outside the test environment.

C.2 Terms and definitions

For the purposes of this annex the following terms and definitions apply.

C.2.1
sound pressure level
sound pressure level L_p, expressed as

$$L_p = 20 \log_{10} \frac{p}{p_0} \quad \text{in dB}$$

where

p is the measured sound pressure;

p_0 is the reference sound pressure expressed in the same units as p.

$$p_0 = 2{,}10^{-5} \text{ Pa or } 20 \ \mu\text{Pa}$$

C.2.2
sound level
reading given by a sound level meter complying with IEC 61672

C.2.3
noise spectrum
spectrum showing the sound pressure level distribution throughout the frequency range. The appearance of the spectrum depends on the bandwidth characteristics of the analyser used.

C.2.4
band pressure level
for a specified frequency band, the effective sound pressure level corresponding to the sound energy contained within the band

C.2.5
sound power level
sound power level L_w is expressed as

$$L_w = 10 \log_{10} \frac{W}{W_0} \quad \text{in dB}$$

where

W is the measured sound power;

W_0 is the reference sound power expressed in the same unit as W

$$W_0 = 10^{-12}\ W \text{ (or 1 pW)}$$

Note 1 to entry: L_{WA} is a weighted sound power level determined in such a manner that the acoustic power level in each of the frequency bands is weighted according to the A scale.

C.2.6
prescribed path
imaginary line around the machine as detailed in this annex and along which the measurement points are located

C.2.7
equivalent hemisphere
hypothetical hemisphere surrounding the machine on which the measurements are assumed to be made, its radius being denoted by r_s

C.3 Test conditions

C.3.1 Preparation of the machine

Structure-borne vibrations from a machine to its mounting, or other parts of the test room, can influence the sound pressure level in the test room. Such effects should be minimised, for example by mounting the machine on suitably designed resilient mountings.

The machine is fully assembled with all covers in position and is not coupled to any other equipment. Traction machines are tested without their associated gears.

Separately ventilated machines are tested with their normal airflow but the ventilation fan is arranged so that its own noise does not significantly affect the results.

C.3.2 Operating conditions

The machine should be run on no-load at its normal operating speed or, if there is a speed range, at the maximum working speed of the application. A machine designed to operate at two or more discrete speeds should be tested at each of those speeds. A reversible machine should be tested in both directions of rotation.

C.3.3 Background noise

The results of the measurement at each measuring point should be corrected for the effects of any background noise i.e. any noise at the points of measurement other than that of the machine being tested. It also includes the noise of any test equipment.

The background noise reading when the machine is not on test should be determined, for each octave band, at the same points as for the test. The readings at each point with the machine on test ought to exceed those due to the background noise alone by at least 10 dB. When the differences are less than 10 dB, corrections as given Table C.1 should be applied.

Table C.1 – Corrections

Increase in level produced by the machine dB	Decibels to be subtracted from the measured values
3	3
4 to 5	2
6 to 9	1

When corrections of 3 dB are applied, the corrected levels should be reported in brackets.

When the increase is less than 3 dB, measurements in general cease to have any significance.

C.4 Measuring instruments

C.4.1 Grade

The sound level meter should be type 1 as specified in IEC 61672.

Any filters used for noise analyses should be class 1 as specified in IEC 61260.

C.4.2 Calibration of measuring equipment

The overall acoustical performance of the complete measuring equipment should be checked, and any specified adjustments made, immediately before each series of machine noise measurements and re-checking should be carried out immediately after.

These site checks should be augmented by detailed laboratory calibrations of the whole measuring equipment carried out at least once every two years.

C.4.3 Location of instruments and observer

Any measuring amplifiers or filters should be at least 0,3 m and the observer should be at least 1 m from the microphone to reduce errors due to reflections.

When the noise radiated from a machine has marked directivity, measurement of the machine noise under semi-reverberant conditions should be regarded as an approximate method of machine noise measurement.

C.5 Method of measurement

C.5.1 Method

For all machines, measurements should be made on the prescribed paths, shown in Figure C.2 or Figure C.3.

For machines having a maximum linear dimension l (excluding shaft) equal to or exceeding 0,25 m, these rectilinear paths are, at their nearest point, 1 m from the surface of the machine.

For cases where l is less than 0,25 m, these rectilinear paths are, at their nearest points, at a distance d from the surface of the machine between 4l and 1 m but not less than 0,25 m.

For all horizontal machines, the prescribed path parallel to the reflecting ground plane should be at shaft height or 0,25 m above the ground, whichever is the greater (see Figure C.2).

For vertical machines, the prescribed path parallel to the reflecting ground plane should be at half the height of the machine but not less than a height of 0,25 m (see Figure C.3).

In all cases, the prescribed path in the vertical plane should be in the plane of the shaft.

C.5.2 Location of measuring points

The position of the measuring points around the prescribed paths given should be as indicated in Figures C.2 and C.3, the measuring points being marked off at successive intervals of 1 m commencing at the five key measuring points in Figures C.2 and C.3.

C.5.3 Quantities to be determined

From the measurements required in C.5.1, the following quantities should be determined at each measurement point:

a) sound level in dB (A);

b) pressure levels in octave bands centred on 125 Hz to 4 000 Hz with the sound level meter set to linear response or (C) weighting, where linear response is not available.

C.6 Calculation

C.6.1 Measurement corrections

The results of the measurement at each measuring point should be corrected for the effects of any background noise i.e. any noise at the points of measurement other than that of the machine being tested. It also includes the noise of any test equipment (see C.3.3).

C.6.2 Calculation of the mean levels

The mean sound level and band mean sound pressure levels should be calculated from the results of the measurement at all the test positions (after correction according to C.6.1), by averaging according to the equation:

$$L_{p(M)} = 10 \log_{10}\left[\frac{1}{n}\left(\text{antilog}_{10}\frac{L_{p(1)}}{10} + \text{antilog}_{10}\frac{L_{p(2)}}{10} + ... + \text{antilog}_{10}\frac{L_{p(n)}}{10}\right)\right] \quad \text{dB}$$

where

$L_{P(M)}$ is the mean sound level (A) (or band mean pressure level) in decibels;

$L_{P(1)}$ is the sound level (A) (or band pressure level) in decibels at the first position;

$L_{P(n)}$ is the sound level (A) (or band pressure level) in decibels at the n^{th} position;

n is the number of measuring positions.

When the readings in dB at the various test positions do not differ by more than 5 dB, a simple arithmetic average of the dB readings will give a result differing by not more than 0,7 dB from that given by the equation above.

C.6.3 Calculation of the radius and area of the equivalent hemisphere

For the purpose of the calculation of the mean levels at the reference radius, the measurements made along the prescribed paths of Figures C.2 and C.3 should be assumed to have been made over a hemisphere of radius

$$r_s = \left[\frac{a(b+c)}{2}\right]^{0,5}$$

where a, b and c are as shown in Figures C.2 and C.3.

The area of this equivalent hemisphere is given by

$$S = \pi\, a\, (b + c)$$

NOTE The area of the equivalent hemisphere with radius r_s as specified is somewhat smaller than the surface area denoted by the paths of measurement.

C.6.4 Calculation of the approximate octave band power levels

The octave band power levels can be deduced from the octave band mean pressure levels by taking into account the influence of the test room on the measured mean sound pressure levels.

This effect can be determined by using a small broad band reference sound source (some types of aerodynamic noise source may not be suitable), of known acoustic power W_r.

NOTE If the machine under test is sufficiently small and of broad band noise character, it may be taken as a reference source.

The determination of the sound power W_r of the reference source (in octave bands) should first be carried out by the method of C.5.1.

The reference sound source should then be substituted for the machine under test in the semi-reverberant room and the octave band mean sound pressure levels deduced from the measurements at the same measuring points as for the machine under test.

The octave band sound power levels of the machine under test can then be determined from the equation:

$$10 \log_{10} \frac{W}{W_0} = 10 \log_{10} \frac{W_r}{W_0} + 20 \log_{10} \frac{p_M}{p_0} - 20 \log_{10} \frac{p_{Mr}}{p_0}$$

or $L_w = L_{W(r)} + L_{p(M)} - L_{p(Mr)}$

where

L_W is the octave band power level of the machine under test;

$L_{W(r)}$ is the specified octave band power level of the reference source;

$L_{p(M)}$ is the measured octave band mean pressure level of the machine under test;

$L_{p(Mr)}$ is the measured octave band mean pressure level of the reference source.

C.6.5 Calculation of (*A*) weighted sound power level

From the band power levels obtained in accordance with C.6.4, calculate the approximate (A) weighted sound power level in accordance with the method of C.6.7, reading power level in place of pressure level.

C.6.6 Calculation of the octave band approximate mean sound pressure level

The octave band free field mean pressure levels at the reference radius of 3 m may be deduced by subtracting 18 dB from the octave band power level calculated according to C.6.4.

C.6.7 Calculation of the mean sound level (A)

The mean sound level (A) at the reference radius of 3 m can be computed from the octave band pressure levels of C.6.6.

a) Apply to the octave band sound pressure level values of C.6.6 the following weighting corrections of Table C.2.

Table C.2 – Corrections

Octave band centred on Hz	Correction dB
125	–16
250	–9
500	–3
1 000	0
2 000	+1
4 000	+1

b) Sum these octave band weighted sound pressure levels according to the equation below:

$$L_{A(M)} = 10 \log_{10}\left[\text{antilog}_{10} \frac{L_{p(01)}}{10} + \text{antilog}_{10} \frac{L_{p(02)}}{10} + ... + \text{antilog}_{10} \frac{L_{p(06)}}{10} \right]$$

where

$L_{A(M)}$ is the mean sound level (A) in decibels;

$L_{p(01)}$ is the first octave band weighted sound pressure level;

$L_{p(06)}$ is the sixth octave band weighted sound pressure level.

C.7 Correction for pure tones

To determine the presence of pure tones, a frequency scan using a FFT analysis should be carried out at the measuring position having the highest sound pressure level.

If this indicates the presence of one or more pure tones in any octave centred between 250 Hz and 4 000 Hz, it should be regarded as significant only if the sound pressure level L_p of the one-third octave band containing the tone frequency is more than 5 dB above the average of the levels L_{p-1}, L_{p+1} of the two adjacent one-third octaves. In such cases, the sound power level derived from the measurements should be increased by the appropriate dB correction from Table C.3. If more than one octave contains significant pure tones, the amount to be added should be the greatest of the individual dB corrections.

$$\Delta L = L_p - \frac{L_{p-1}+L_{p+1}}{2}$$

Table C.3 – Correction for pure tones

Decibel above average	Correction dB
$5 < \Delta L \leq 6$	3
$6 < \Delta L \leq 8$	4
$8 < \Delta L \leq 10$	5
$\Delta L > 10$	6

C.8 Noise limits

The maximum recommended sound power level for a traction machine, including any correction for pure tones, is given in Figure C.1 for traction machines and by IEC 60034-9 for other types of auxiliary machines.

The recommended limits are those which can be expected for machines which follow normal traction design and construction standards. If lower values are required, the weight of the machine and the complexity of its enclosure may be expected to increase.

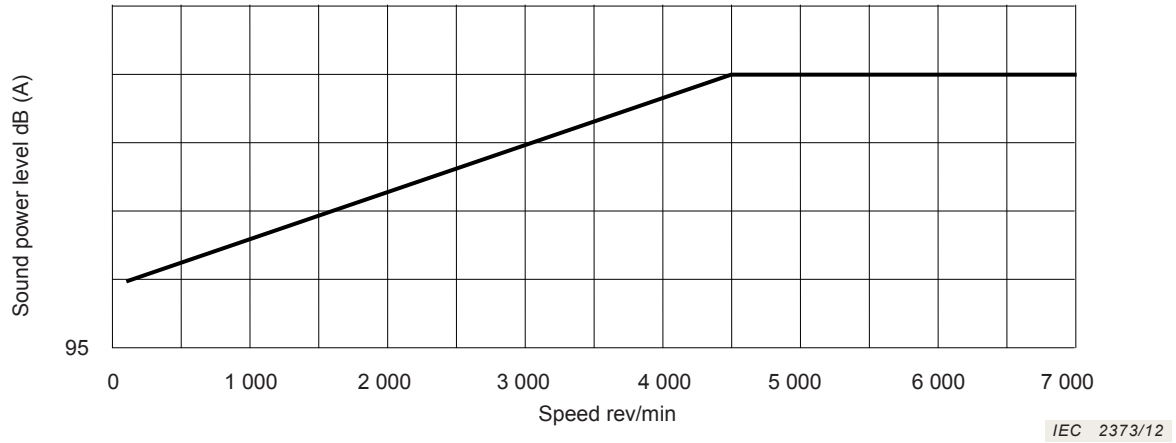


Figure C.1 – Limiting mean sound power level for airborne noise emitted by traction machines

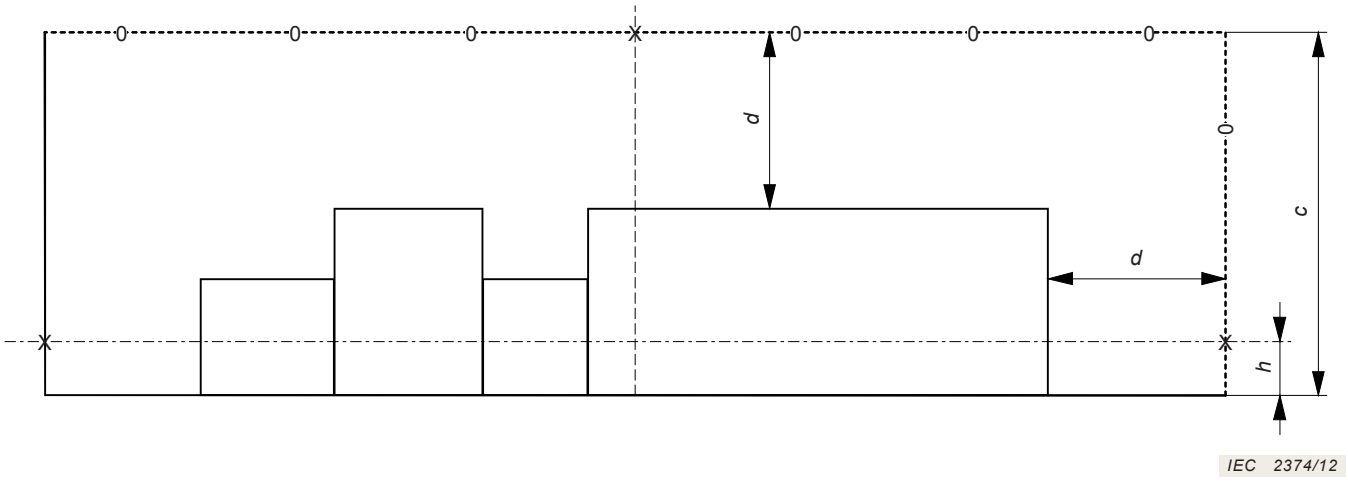


Figure C.2 a) – Prescribed path in vertical plane

l m	***d*** m
≥ 0,25	1
< 0,25	4 *l* ≤ *d* ≤ 1 *d* > 0,25

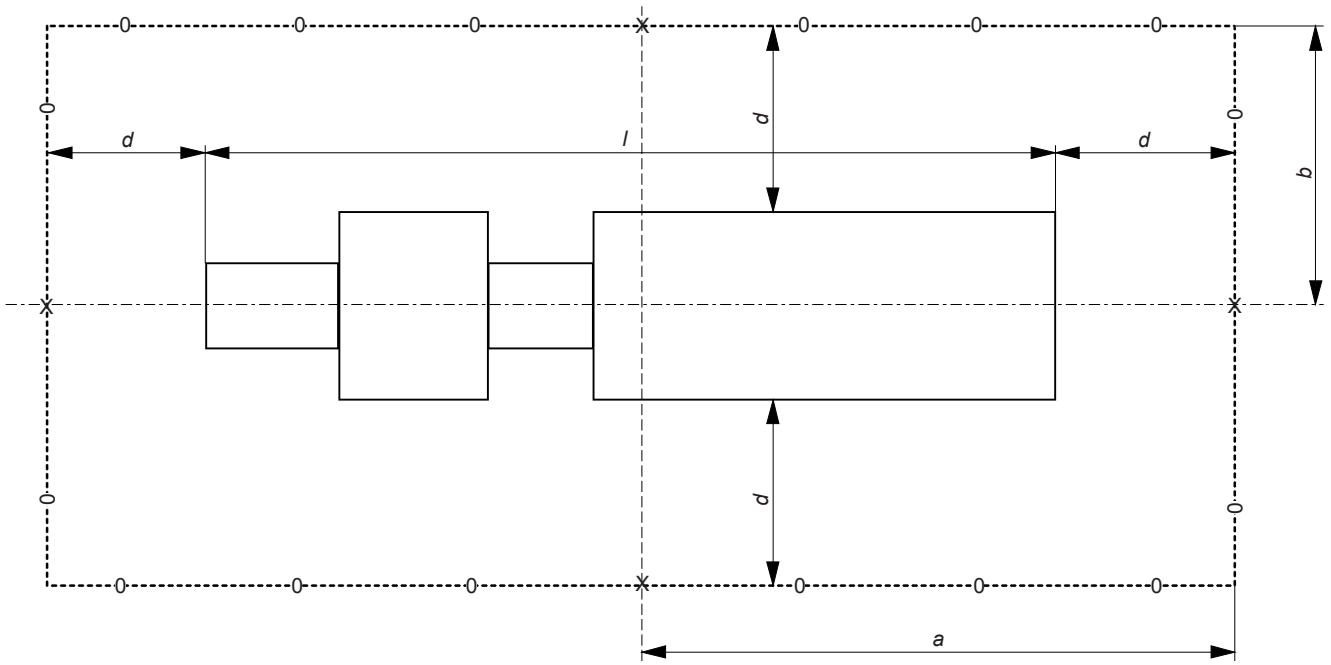


Figure C.2 b) – Prescribed path in the horizontal plane (at height *h* above reflecting plane)

Key

h shaft height or 0,25 m, whichever is greater

X key measuring points

0 other measuring points marked off at intervals of 1 m from key points

Figure C.2 – Location of measuring points and prescribed paths for horizontal machines

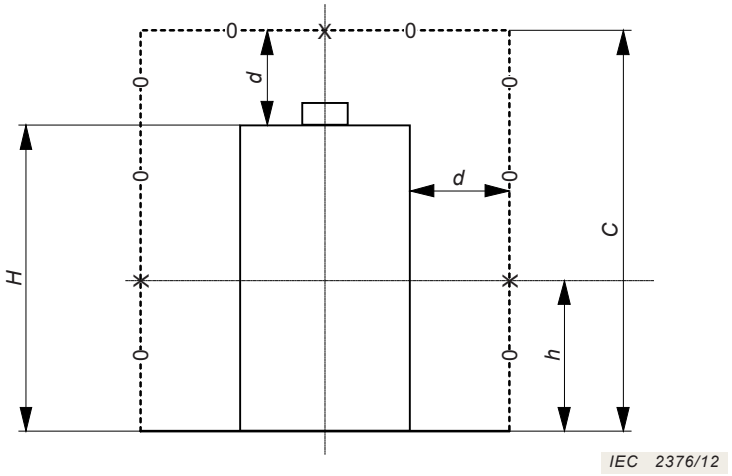


Figure C.3 a) – Prescribed path in the vertical plane

H m	***d*** m
≥ 0,25	1
< 0,25	$4H \leq d \leq 1$ $d > 0,25$

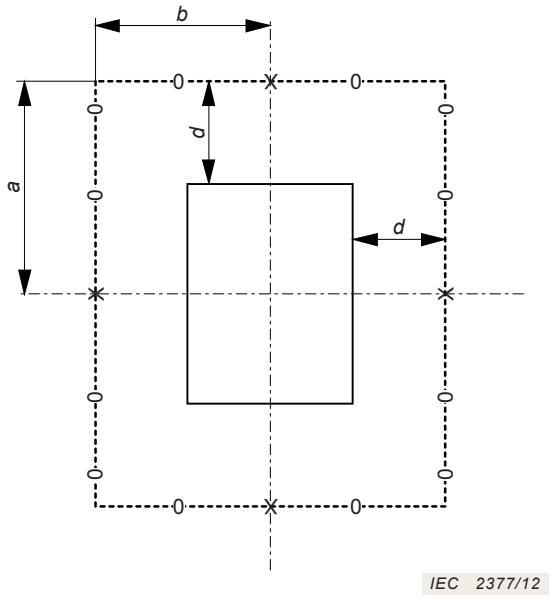


Figure C.3 b) – Prescribed path in the horizontal plane (at height *h* above reflecting plane)

Key

h H/2 but not less than 0,25 m

X key measuring points

0 other measuring points marked off at intervals of 1 m from key points

Figure C.3 – Location of measuring points and prescribed paths for vertical machines

Annex D
(normative)

Supply voltages of traction systems

The nominal, lowest and highest voltages of the traction supply system shall be specified by the user. They should preferably be the standard values which have been adopted in IEC 60850.

The nominal voltage is the basis of motor ratings and characteristics and for the calculation of vehicle performance.

Performance at other than nominal voltage may vary inherently or may be controlled to reduce such a variation, but the holding of constant performance over a wide range of system voltage is not generally desirable.

Auxiliary machines shall have adequate performance to permit operation of the vehicle with the auxiliary supply voltage at any value within the specified limits but it may be acceptable to limit the duration of operation at the minimum voltage.

Annex E
(normative)

Agreement between user and manufacturer

E.1 Special requirements of the user to be specified and agreed with the manufacturer

Clause	Subject
4	Exceptional environmental conditions.
5.4	Voltage of the specified characteristics.
6.2	Terminal and lead markings not in accordance with IEC 60034-8.
7.2.1	Similarity of test and service power supplies.
8.1.6	Specification of short-time overload tests.
10	Investigation tests.
Annex C	Noise tests.
Annex D	Supply voltage values.

E.2 Special requirements of the manufacturer to be specified and agreed with the user

Clause	Subject
1	Duplication of tests.
5.4	Declared characteristics different from an existing one.
7.3	Reduced type test.
9.3	Overspeed test, conditions.
8.1.2	Special external cooling arrangements.
8.1.6	Alternative short-time overload test method and additional temperature measurements. (If this test is specified by the user.)
A.5	Special braking arrangements and extension of time for the first resistance measurement.

E.3 Other additional requirements which may be the subject to an agreement between user and manufacturer

Clause	Subject
9.1	Additional temperature rise tests.
9.3	Routine overspeed tests.
9.5	Quantitative vibration tests.

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