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TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

Electric traction – Rotating electrical machines for rail and road vehicles –
Part 3: Determination of the total losses of converter-fed alternating current motors by summation of the component losses

Traction électrique – Machines électriques tournantes des véhicules ferroviaires et routiers –
Partie 3: Détermination des pertes totales des moteurs à courant alternatif alimentés par convertisseur par sommation des pertes élémentaires

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60349-3, which is a technical specification, has been prepared by IEC technical committee 9: Electrical equipment and systems for railways.

This second edition cancels and replaces the first edition, issued in 1995, and constitutes a technical revision.

The main technical changes with regard to the previous edition are as follows:

– Omissions in some formulas in 3.2.1.2 and Table A.2 were fixed.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
9/1267/DTS	9/1342/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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

Part 3: Determination of the total losses of converter-fed alternating current motors by summation of the component losses

1 Scope and object

This technical specification applies to machines complying with IEC 60349-2.

The total losses of a converter-fed motor may be determined by summation of the component losses derived from no-load and load tests. The total input power is the sum of the power at the fundamental frequency and at all other frequencies. In all practical cases the latter input includes the losses resulting from the voltage and current harmonics in the converter supply by using suitable instrumentation it can be derived from measurement of the total and fundamental frequency power inputs when the machine is on load.

The losses supplied at the fundamental frequency cannot be measured directly and so are derived from measurement of the fundamental frequency load current and the fundamental frequency no-load power input.

2 Instrumentation

The extra loss due to operation on a converter supply is obtained from the difference of the total and fundamental frequency power input on load.

The power inputs shall be measured simultaneously on each phase by a digital sampling instrument. Measurement on all three phases is preferred but the two wattmeter method is permissible as an alternative.

The total power is obtained from the product of voltage and current over a period of time and the fundamental power from a Fourier transform using the same sampling.

It is necessary to consider the accuracy of the whole instrument chain taking into account both amplification and phase shift errors over the desired frequency range. As the power factor of the harmonics is generally very low (less than 0,1 for voltage imposed asynchronous systems) particular attention is drawn to the need for minimum phase angle errors.

At the time of publication of this technical specification, wattmeters accurate within the following limits, at 0,08 power factor, were available:

below 2 kHz	±0,5 %;
between 2 kHz and 20 kHz	±1,0 %;
between 20 kHz and 50 kHz	±2,0 %.

Instruments often contain attenuators compensated and adapted to them, but if an external attenuator is used, it is desirable that it be accurate within the following limits given in Table 1.

Table 1 – Accuracy of external attenuators

Frequency kHz	**Ratio error** **%**	**Phase shift error** degrees
< 2	±0,5	±0,1
2 to 20	±1,0	±0,2
20 to 50	±2,0	±0,5

Taking all factors into account, Table 2 lists the highest overall accuracy of power measurement which it is considered could be achieved at the time of publication of this specification.

Table 2 – Overall accuracy of power measurement

Frequency kHz	**Power factor >0,8** %	**Power factor 0,4** %	**Power factor <0,1** %
< 2	±1	±2	±10
2 to 20	±2	±5	±14
20 to 50	±4	±8	±20

NOTE The frequency range over which measurements are necessary depends on the harmonic content of the output from the particular converter used and should therefore be decided for each individual case. With the instrumentation presently available, the overall accuracy of the total harmonic loss measurement is likely to be of the order of ±10 %, but as the loss is unlikely to exceed 3 % of the total power input, this will result in only 0,3 % error in the calculated torque, which is well within the permitted tolerance of –5 % specified in IEC 60349-2.

At the time of publication of this technical specification, current transformers are significantly less accurate at the low power factors and high harmonic frequencies involved than non-inductive shunts, which can have a ratio accuracy within ±1 % and a phase shift within ±0,2°.

3 Summation of losses

3.1 The total losses are the sum of the following component losses.

3.1.1 Losses supplied at the fundamental frequency on no-load (no-load losses):

– losses in the active iron and other metal parts;

– losses due to friction and windage including the power absorbed by integral fans.

3.1.2 Losses which occur when the motor is supplied at the fundamental frequency and which vary with load (load dependent losses):

– I^2R losses in the stator windings;

– I^2R losses in the rotor winding of asynchronous motors;

– additional load losses (load loss) consisting of:

- losses in the active iron and metal parts other than the conductors;
- eddy current losses in the stator and rotor windings arising from current dependent flux pulsation.

3.1.3 Losses supplied at other than the fundamental frequency.

3.1.4 I^2R and brush contact losses in the excitation circuit of synchronous motors.

3.2 Determination of the component losses

3.2.1 Asynchronous motors

3.2.1.1 No-load losses supplied at the fundamental frequency

The losses shall be determined by running the motor on no-load at the voltage and fundamental frequency of the point on the specified characteristic for which they are being determined. The losses shall be taken as the fundamental frequency power input minus the I^2R loss in the stator. The no-load I^2R loss in the rotor shall be neglected.

3.2.1.2 Load dependent losses supplied at the fundamental frequency

The fundamental frequency I^2R losses in the stator shall be calculated from the fundamental frequency current in each winding at the point for which the losses are being determined and from the measured resistance of the winding corrected to the temperature of reference.

The I^2R loss in the rotor winding shall be taken as:

$$s \times [\, P_f - (I^2R_{pf} + P_{of} - P_{fw})\,]$$

where

s is the slip;

P_f is the fundamental frequency input power;

I^2R_{pf} is the stator fundamental frequency I^2R loss;

P_{of} are the fundamental frequency no-load losses;

P_{fw} is the friction and windage loss.

NOTE 1 The friction and windage loss should be determined either by driving the motor on open circuit by a calibrated machine or by the graphical method described in Annex A. The drive may be through a transmission system of known efficiency.

Unless otherwise specified, the additional load losses at current I and fundamental frequency f (in Hz) shall be taken as:

$$P_s = P_{50} \times (I / I_r)^2 \times (f / 50)^{1,5} \times 0{,}01$$

where

P_s is the additional load losses;

P_{50} is the equivalent 50 Hz rated input power;

I_r is the total current at the guaranteed rating.

The equivalent 50 Hz rated input power is based on the assumption that the rated current is independent of frequency and that the motor voltage and input power are both proportional to frequency over the range of operation with full flux (see Figure 1), that is:

$$P_{50} = P_m \times 50 / f_m$$

where

P_m is the assumed input power at maximum voltage, rated current and full flux;

f_m is the fundamental frequency (in Hz) at input power P_m.

NOTE 2 At the time of publication of this specification, the validity of the formula in all cases had not been fully established by experience. Additional information may be obtained by carrying out a low power test described in Annex B.

NOTE 3 This calculation may be applied not only at 50 Hz but also similarly at 60 Hz.

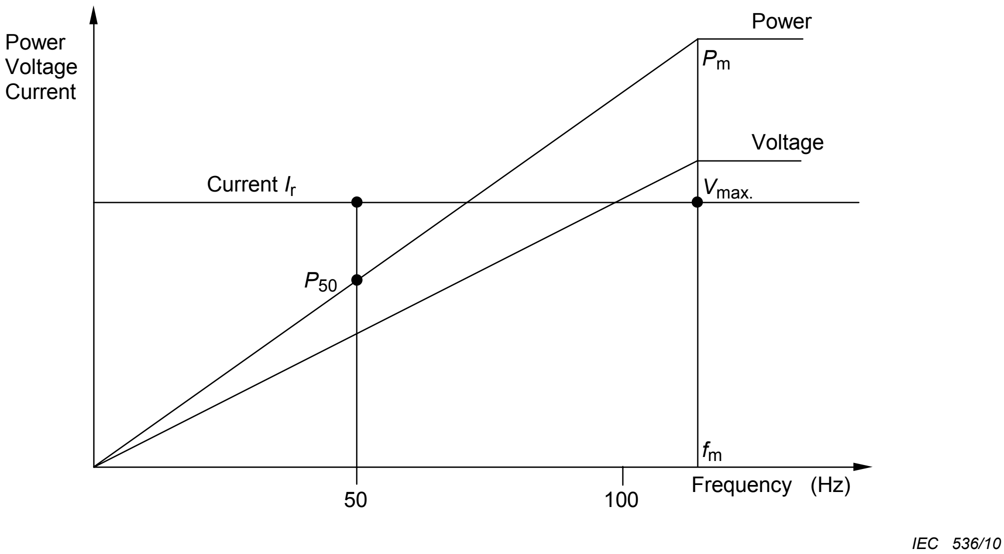


Figure 1 – Derivation of equivalent 50 Hz rated power input

3.2.1.3 Losses supplied at other than the fundamental frequency

The losses arising from the supply harmonics are the difference between the total and fundamental frequency power inputs to the motor when on load with the stator windings at approximately the temperature of reference.

NOTE If the converter is a voltage source type and its modulation pattern is independent of load, the difference may be measured on no-load.

3.2.2 Synchronous motors

3.2.2.1 No-load losses supplied at the fundamental frequency

The motor shall be driven on open circuit by a calibrated machine at the speed for which the losses are being determined and shall be excited by an independent source to generate the voltage shown on the specified characteristic at the same speed. The losses are equal to the mechanical power input to the motor shaft.

3.2.2.2 Load dependent losses supplied at the fundamental frequency

The fundamental frequency I^2R losses in the stator shall be calculated from the fundamental frequency current in each winding at the point for which the losses are being determined and from the measured resistance of the winding corrected to the temperature of reference.

Unless otherwise specified, the additional load losses shall be determined by driving the machine with the stator windings short-circuited at the speed of the point on the specified characteristic for which the losses are being determined. The excitation shall be adjusted to give the fundamental frequency stator winding currents for the same point. The losses shall be taken as the power supplied to the machine shaft minus the sum of the total stator I^2R losses and the power supplied when the machine is driven unexcited at the same speed.

3.2.2.3 Losses supplied at other than the fundamental frequency

The losses arising from the supply harmonics are the difference between the total and fundamental frequency power inputs to the motor when on load with the windings at approximately the temperature of reference.

3.2.2.4 Loss in the excitation circuit

The loss in the excitation circuit shall be the product of the current in the winding and the total excitation voltage at the point for which the losses are being determined. The voltage shall be the value required to supply the excitation current with the winding at the temperature of reference. Account shall be taken of any ripple in the excitation current.

NOTE The specified characteristic may state that the excitation power is not included in the calculated motor losses as it is accounted for elsewhere, for example as part of the vehicle auxiliary load.

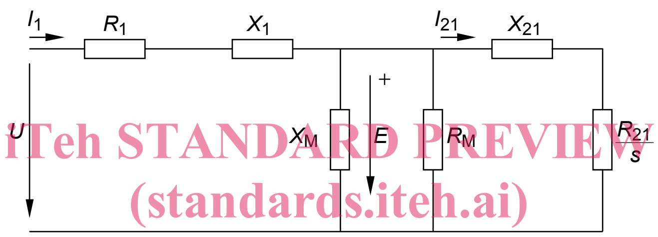
Annex A
(informative)

The equivalent circuit of an asynchronous motor

A.1 Circuit description

An asynchronous motor on no-load can be represented by the equivalent circuit illustrated in Figure A.1. The circuit parameters are obtained from no-load and impedance (locked rotor) tests on a sinusoidal supply voltage, the quantities measured being voltage, current and power.

If the circuit parameters and no-load losses are determined for a number of voltages and frequencies covering the range of operation of the motor, curves can be plotted which enable the motor torque and input current to be calculated for chosen values of voltage, frequency and slip.



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Key

f frequency (Hz);

U phase voltage (V);

I_1 stator current (A);

I_{21} rotor current transformed to the stator side (A);

X_1 stator reactance (Ω);

X_{21} rotor reactance transformed to the stator side (Ω);

R_1 stator resistance (Ω);

R_{21} rotor resistance transformed to the stator side (Ω);

X_M magnetizing reactance (Ω);

R_M magnetizing resistance (Ω);

E induced electromotive force (e.m.f.) (V);

s slip (-);

P_{10} input power on no-load (W);

P_{Cu1} stator resistance losses (W);

P_{Fe} core loss (W);

P_{fw} friction and windage loss (W);

Q_{10} total reactive power on no-load (VAr);

Q_{1L} total reactive power with locked rotor (VAr).

Figure A.1 – Equivalent circuit of an asynchronous motor on no-load