Electric Motor Systems
EMSA

GUIDE FOR THE USE OF ELECTRIC MOTOR TESTING METHODS BASED ON IEC 60034-2-1

P_{LL} determined from residual loss (8.2.2.5.1 in Table 2)

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under the IEA Implementing Agreement for a Co-operating Programme on Efficient Electrical End-Use Equipment (4E)

** Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*

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1. Introduction

The MEPSA 2009 conference (Motor Energy Performance Standards Australia 2009 – regulating motors and motor systems components) brought together motor experts from around the world to review global progress on motor and motor system efficiency, and to consider the wider implications of the then-new IEC motor standards as they impact on manufacturers, users and policy makers. MEPSA 2009 was held at the University of Sydney, Australia from 4-5 February 2009. www.energyrating.gov.au/forums-2009-motors.html

During MEPSA discussions on the IEC 60034-2-1 test method standard, it emerged that there are some important points of detail which appear to be ambiguous or potentially confusing. For example, it is not clearly stated whether oil seals should be left in place during testing, nor the sequence of some of the tests. It was recognised that it is important to have a common approach on points such as these. Test method standards that are clear and unambiguous ensure a 'level-playing field' for manufacturers and suppliers.

An ad hoc working group was formed from a small group of interested MEPSA attendees, the aim of which was to produce a guidance document for IEC 60034-2-1 *Rotating Electrical Machines – Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles)*. The intention is that this document is used until such time that the IEC 60034-2-1 standard is formally revised. The current revision process of IEC 60034-2-1 is a welcome development and it is hoped that this guidance document can help inform the redrafting process.

This work has now been taken over by the IEA Efficient Electrical End-use Equipment (4E) Electric Motor Systems Annex (EMSA) Task C – Testing Centres. www.motorsystems.org Input from test laboratories and other experts around the world has helped inform the development of this document. We thank everyone for their time and effort involved in this work.

2. Flow charts for P_{LL} determined from residual loss

Background information and issues

The order of sub-tests within a test appears to be ambiguous in some cases in the current version of IEC 60034-2-1:2007 standard. As well as this, some of the clauses appear to contradict each other, such as these:

Clause 6.1 ('State of the machine under test and test categories') says:

> *The sub-tests that make up a test procedure shall be performed in the sequence listed.*
>
> *Clause 6.4.2 ('Constant losses') describes the testing which involves the no-load measurements, and this comes before Clause 6.4.4 ('Load losses'). This is therefore the standard's preferred order in which the tests and measurements are to be carried out.*

The following text is included in Clause 6.4.2.2, however:

> *The no-load losses are considered stabilized when the no-load power input varies by 3% or less, when measured at two successive 30 min intervals.*
>
> *Note 2 The no-load losses are also considered stabilized if the no-load test is carried out immediately after the load-test.*

The aim of this section is to eliminate these ambiguities by closely specifying the order of clauses for testing to P_{LL} determined from residual loss.

Recommended interpretation of IEC 60034-2-1

The test must be performed in the following order:

- First stator winding resistance measurement at ambient temperature
- Remove accessible drive-end sealing elements (without dismantling the motor)

- Clause 6.4.4.1 – Rated load temperature test
- Second stator winding resistance measurement (immediately after 6.4.4.1)
- Clause 6.4.4.2 and 6.4.5.3 – Load curve test with torque measurement (immediately after 6.4.4.1)
- Third stator winding resistance measurement (immediately after 6.4.4.2 and 6.4.5.3)
- Clause 6.4.2 – No-load test (immediately after third stator winding resistance measurement)
- Fourth stator winding resistance measurement (immediately after 6.4.2)

Determination of loss components must be performed in the following order:

- Clause 8.2.2.3 – Constant losses (8.2.2.3.1, 8.2.2.3.2 and 8.2.2.3.3)
- Clause 8.2.2.4 – Load losses (8.2.2.4.1.2 and 8.2.2.4.1.3)
- Clause 8.2.2.5 – Additional load losses (8.2.2.5.1 – From a load test with torque measurement)
- Clause 8.2.2.2 – Calculate total losses
- Clause 8.2.2.1 – Calculate efficiency

This is summarised by the flow chart on the next page.

Flow chart for PLL determined from residual loss
(IEC 60034-2-1, Table 2)

Stator winding resistance measurement at ambient temp.

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Remove accessible drive-end seal(s) (but without dismantling)

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Rated load temperature test (Clause 6.4.4.1)

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Stator winding resistance measurement: - *Follows immediately*

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Load curve test with torque measurement (Clauses 6.4.4.2 and 6.4.5.3) - *Follows immediately*

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Stator winding resistance measurement: - *Follows immediately*

↓

No-load test (Clause 6.4.2.3) – *Follows immediately*

↓

Stator winding resistance measurement: - *Follows immediately*

↓

Determination of loss components:

Constant losses to Clause 8.2.2.3.1
(Friction and windage losses: 8.2.2.3.2)
(Iron losses: 8.2.2.3.3)
Load losses to Clause 8.2.2.4.1:
(Stator and rotor winding losses, including temp. correction)
(8.2.2.4.1.2 and 8.2.2.4.1.3)
Additional load losses to Clause 8.2.2.5.1
(Residual losses)

↓

Calculate total losses (Clause 8.2.2.2)

↓

Calculate efficiency (Clause 8.2.2.1)

3. Removal of sealing elements

Background information and issues

Sealing elements can have a significant effect on measured efficiency values, especially in the case of small, high speed (ie, 2 pole) motors.

Compliance check testing for the regulation of minimum energy performance standards (MEPS) is almost always performed on brand new ‘off the shelf’ motors. These new motors are usually in the first few hours of their working lifetimes, and under such circumstances, seals generally have not been ‘run-in’. At that stage, a seal which is slightly tight can cause a motor to have a lower measured efficiency value. Manufacturers often perform efficiency tests on motors in which at least the drive-end seal has been removed.

In the current version of IEC 60034-2-1:2007 standard, Clause 6.1 (‘State of the machine under test and test categories’) says:

> *Tests shall be conducted on an assembled machine with the essential components in place, to obtain test conditions equal or very similar to normal operating conditions.*

However, the second Note immediately below this statement says

> *NOTE Sealing elements may be removed during the tests, if an additional test on machines of similar design has shown that friction is insignificant after adequately long operation.*

The issue of sealing elements is also partially dealt with in *IEC 60034-30:2008 Rotating electrical machines - Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code)* under 5.1.3 Auxiliary devices which states:

> *Geared motors and pump motors are often standard motors equipped with shaft seals to prevent ingress of oil or water into the motor. The seals are therefore considered a feature of the gearbox or pump and consequently the efficiency of these motors shall be determined without the seals installed.*

The aim of this section is to provide clarity on the removal of seals for testing to ensure uniformity of practice around the world.

Recommended interpretation of IEC 60034-2-1

External contact seals at the drive (shaft extension) end(s) shall be removed prior to testing. Sealing elements that can only be removed by dismantling the motor shall be left in place. That is, the motor shall not be dismantled to remove sealing elements.

4. Selection of measurement points for load and no-load tests

Measurement points - Clause 6.4.4.2 – Load curve test

Clause 6.4.4.2 – Load curve test describes testing the motor under different loads. In the current version of IEC 60034-2-1:2007 standard, Clause 6.4.4.2 states that 6 measurement points should be used. However, this causes some problems:

1. The rated load temperature test (Clause 6.4.4.1) very carefully brings the motor to a stable temperature at under its most important load condition, namely full load.

   Subjecting the motor then to a series of overload conditions causes significant additional internal heating, and this procedure has the capacity to change significantly the temperatures of both stator and rotor circuits. This should be avoided.

2. A requirement for loads up to 150% requires that the measurement system be able to cope with the significantly higher values of current, power and particularly torque involved. The more critical values of current, power and torque are thus required to be much further 'down scale' than they would otherwise be, and the uncertainty associated with those measurements is therefore compromised.

3. The much wider range of measured values encountered if the machine were required to be heavily overloaded increases the likelihood of a requirement for the instrumentation range to change, which may occur either manually or automatically.

   Small differences encountered in measured values when changing ranges on the various measuring instruments involved can prejudice the smoothness of the residual loss data which is used to determine the additional load losses (see Clause 8.2.2.5.1), and can result in a non-compliant value of correlation factor (see Clause 8.2.2.5.1.2).

Recommended interpretation of IEC 60034-2-1

The load curve test should be carried out at the following loads:

100%, 75%, 50% and 25%.

This represents a reduction on the number of points specified in Clause 6.4.4.2 from 6 points to 4 points. Measurements recorded at all four load values, as above, shall be used for the determination of additional load losses.

Another reason for poor correlation in the data smoothing process used to determine additional load losses is the way in which IEC 60034-2-1 treats stator resistance. Therefore, the stator resistance for all load points should be taken as the average of the values read and recorded immediately prior to, and immediately after the load-curve test.

Measurement points - Clause 6.4.2.3 - Friction and windage losses, iron loss

Clause 6.4.2.3 Friction and windage losses, iron loss describes testing the motor under no-load conditions. The no-load test follows the load-test immediately, with the motor at essentially the same temperature as at the end of the load test. Facilities must be available for decoupling the motor from the loading system in seconds.

No no-load measurements above rated voltage are required in the determination of motor efficiency. Measurements at rated voltage are the most important. Correction of iron losses for voltage drop across the stator resistance as described in Clause 8.2.2.3.3 requires a knowledge of the variation of iron loss with voltage at levels just below rated voltage. Clause 8.2.2.3.3 requires a curve fit, the procedure for which is not explicitly stated in IEC 60034-2-1.

Recommended interpretation of IEC 60034-2-1

Correction of iron losses for stator resistance voltage drop under load shall be by the use of the formula in Clause 8.2.2.3.3 and by linear interpolation of no-load test results between 90% and 100% of rated voltage.

The no-load test measurements at 70%, 60%, 50% and 40% shall be used for the separation of no-load losses into iron load and friction and windage components, using the technique described in Clause 8.2.2.3.2

Measurements of no-load parameters shall be made at the following supply voltages:

100%, 90%, 70%, 60%, 50% and 40% of rated voltage.

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5. Measurement techniques and data averaging

Background information and issues

Although not mentioned in standards, data averaging, particularly during the load tests can very significantly improve the process of separating out the additional load losses.

Induction machines often exhibit small but significant (amplitude) modulation of line currents (and possibly also terminal voltage, depending on the impedance of the power supply system) and output power.

The instrumentation system which measures both electrical and mechanical quantities associated with the load-curve test should therefore be capable of providing values of voltage, current, electrical power, shaft speed and torque which represent averages over a significant number of slip frequency cycles.

The time over which these averages are determined is a compromise between a short period (which reduces the time needed for the testing process, and minimises motor cooling during the load-curve test) and a long period (which includes many slip frequency periods).

It should also be noted that the slip frequency is lower for larger machines, suggesting that longer averaging times may be necessary for larger motors.

In practice, averaging times between 10 and 30 seconds are recommended.

Another area which needs to be addressed is the question of the measurement of slip, as the calculated rotor losses are directly proportional to this quantity, and any error in slip measurement contributes a corresponding error in the determination of the rotor losses. (See Clause 8.2.2.4.1.3).

The per-unit value of slip is defined as the fractional departure of motor shaft speed from synchronous speed, as follows:

$$s = (n_s – n)/n_s = 1 – n/n_s$$

where s is per unit slip, and n and n_s are shaft and synchronous speeds respectively, in compatible units (usually rpm or min^{-1})

The question of the measurement of speed and frequency measurement is covered in Clause 5.5.5, which states that '*the speed measurement should be accurate within 0.1% or 1 revolution per minute whichever gives the least error*'.

However, the accuracy can be greatly improved. For example, a 45 kW 6 pole motor could be expected to have a full –load speed of 990 rpm. It is clear that an error (or uncertainty) of 1 rpm (as required by the standard) will give rise to an error or uncertainly in the slip of 10%. That error carries through to the calculation of the rotor losses as explained above.

The situation is actually worse than it would appear, because the above error does not take into account uncertainty in the measurement of supply frequency, and therefore in the value of the synchronous speed, n_s which is also involved, as shown above, in the calculation of slip.

One method to improve this accuracy is using a relatively simple scheme for slip measurement which is at least two orders of magnitude better than the result obtained with a ± 1 rpm speed measurement. It is based on the use of high resolution shaft encoders mounted both on the shaft of the test motor and the shaft of the motor-generator set which supplies power to the motor test bed.

A dual channel counter is used to measure the ratio between the number of pulses generated by such encoders over the same period as is used to average the other measurement data, as discussed above.

6. Temperature measurement

Background information and issues

For check testing purposes, it is essential that a motor not be dismantled in any way to avoid any perception that the motor has been ‘tampered with’ or otherwise maltreated by a testing laboratory. Therefore a motor should be tested in its ‘as received’ state, except that any accessible drive-end seals must be removed.

Temperature measurements are required both to obtain a reference stator resistance measurement (ie, a ‘cold’ resistance measurement which is made at or very close to ambient temperature) and for the purpose of determining temperature stability during the ‘Rated load temperature test’ (Clause 6.4.4.1).

In both cases, temperature is determined using a temperature measuring device which can only have access to the external parts of the motor.

A thermocouple is probably the best device to use, and this is to be located as closely as possible to the iron stator core as possible, while remaining outside the machine.

For a smooth-bodied motor, the thermocouple may simply be attached using self-adhesive metal (eg aluminium) tape to the approximate centre of the motor stator stack.

Holes may often be found in the stator which can be used as ‘thermometer wells’, and a few drops of oil placed in such a hole minimises the thermal resistance between the stator and the thermocouple.

Holes at the top of the motor for lifting lugs or ‘eyes’ may be useful, but these can lead straight through to the stator lamination stack itself, and are then not oil-tight. In this case, suitable short bolts designed to fit into the lifting lug sockets, and equipped with a central oil-filled hole make good and leak-proof thermometer wells.

Note that this external temperature measurement has no direct relation to actual internal temperatures in a ‘hot’ motor. In the rated load temperature test, they are used solely for the purpose of establishing the point (in time) at which temperature stability has been reached.

7. Calculation algorithm

Background information and issues

Complex algorithms such as outlined in IEC 60034-2-1 are normally implemented by individual laboratories using software developed using a variety of 'packages' such as Excel, MatLab, MathCad etc. However, even 'perfect' laboratory measurements are useless if the measurement data is not processed correctly.

A motor efficiency software round-robin is currently being conducted as part of EMSA Task C – Testing Centres. The aim of this exercise is to check calculation algorithms and software. Real test data from a test conducted on a 11kW 2 pole motor has been sent to 12 test laboratories who have been asked to calculate the energy efficiency with their own laboratory software.

Results have been received from 10 laboratories, and significant variations have been found between final efficiency figures and almost all loss components which have been used to calculate them.

The variations in calculated efficiency values are much greater than is acceptable, and work is currently under way to determine how these discrepancies have occurred.

One conclusion which has already been reached, however, is that the present standard offers too much latitude in the calculation process, and needs to be much more explicit, and to offer fewer choices.

This version of the Interpretative Guide is unable to provide guidance on the calculation of energy efficiency but we hope that future versions of this Guide may be able to provide information and advice on consistent calculation of efficiency values.