Inspection (testing) stators of AC induction machines - Part 3

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Part 1 presented tests for insulation resistance (Megger and PI), tan delta test, resistance and impedance tests. Part 2 presented insulation tests such as the DC high-potential test and surge comparison test (SCT). Part 3 addresses the stator core tests, thermal test and others, helping the repairer to detect a stator’s hidden defects.

Testing the stator core

Two active materials are essential for a motor to function: copper, the material that supports currents, and iron laminations, the material that supports magnetic flux.

The stator core test at rated flux density [1] assesses stator core losses, not only with reference to: motor performance, including temperature rise; motor vibrations and thermal misalignment; but also motor life expectancy. Magnetic flux test values are controlled by volts/turns (V/T).

Assessing the stator core magnetising curve

Calculated volts/turns (V/T) is an indication of rated flux density for a specific stator core. The magnetising curve for a specific stator core can be assessed by monitoring the absorbed current while varying volts/turns between 0,25 and 1,25 of calculated value for the rated flux density.

Assessing the stator core iron losses - $P_i$

When the stator core test at the rated flux density is performed according to [1], the following data must be recorded:

- voltage drop at the end of the testing loop $\Delta U$; absorbed current $I_c$; and absorbed power $P_i$.
- Power factor of the test circuit $PF = P / (\Delta U \times I_c)$

Based on previous experience the stator core status is acceptable if $PF < 0,7$; marginal if $PF$ is between 0,7 and 0,9; unacceptable if $PF > 0,9$.

Taking the stator core mass in kg, the core is acceptable if the ratio $W/kg$ is below 13,2; a result between 13,2 and 22 W/kg indicates marginal status; higher than 22 W/kg indicates an unacceptable core.

Example 1: A stator core with: $ID = 0,34$ m, $CL = 0,405$ m, back iron $BI = 0,05$ m, slot depth = $0,022$ m, tooth width = $0,010$ m, number of slots = 48, stacking factor = 0,94 and iron density of 8700 kg/m³ has a mass of $M = 228$ kg.

The required volts/turns for the stator core test at rated flux density of 1,35 Tesla was calculated empirically [1]:

$$V/T = \frac{(CL[dm] \times BI[dm] \times 1,35 \text{T})}{48,44}$$

$= 5,64 \text{ V}$

Under test the following data have been recorded:

$\Delta U = V = 5,62 \text{ V}, I_c = 295 \text{ A}, P_i = 679 \text{ W}$.  

{\text{Fig.1: Stator core test diagram [1]}}
These give a power factor PF = 0.41 (acceptable)
The W/kg losses = 679 W/228 kg = 2.98 W/kg (acceptable)

**Testing the core vibrations at rated flux density**

When the stator core is excited at the rated flux density, another test can be performed: stator core vibration. This will give an indication of: the stator core’s contribution to the motor’s overall vibration level; the stator core’s looseness in clamping; the stator core’s stacking condition; and if there are loose laminations.

For example, from experience it was found that a four-pole stator core is excited at its rated flux density and produces overall vibrations greater than 0.3 mm/s rms, that motor will have unacceptably high vibrations on load and reduced mean time between failures. The correlation between loose laminations and hot spots can be explained as follows.

Loose lamination energized by 50 Hz magnetic flux pulsations will knock both neighbouring laminations 100 times/sec (Fig. 2). As it vibrates, this lamination will start breaking off the varnish that initially acted as a damper until the varnish disintegrates completely. As a result, locally absorbed magnetic energy will increase, being converted into mechanical energy consumed for vibrations and scratching the slot insulation like a razor blade; and thermal energy (heat radiation on the spot) as a result of 100 knocks/sec and scratching the insulation slot.

After time, the lamination varnish will be damaged and eddy currents will appear in the spot. Thermal degradation is accelerated in a snowball effect – refer “hot spots on laminations” in part 2 of this series.

**Testing stator core hot spots**

The test is regulated by [1]. The following temperatures to be monitored, and the criteria for rejection are when:

\[
T_{hs} > T_{core} + 10 \, ^\circ C, \\
T_{core} > T_{amb} + 20 \, ^\circ C,
\]

where:

- \( T_{hs} \) = “hot spot” temperature
- \( T_{core} \) = stator core average temperature (excluding \( T_a \))
- \( T_{amb} \) = ambient temperature

Other tests on the core, using a Rogowski coil (ELCID) are specialised and will not be discussed here.

**Thermal tests**

These tests are partially simulating the stator comportment at rated current and rated temperature. By applying a controlled three-phase voltage, windings can be brought to the rated temperature. In this situation the following tests can be performed: assessing the RTD’s function; and assessing the stator insulation system comportment.

**Assessing the RTD’s function**

The RTD’s values can be measured by comparing them with witness-calibrated instruments. For instance, the thermistors’ thermal protection must react by increasing resistance beyond 3 kΩ/unit. If this will not happen, that means one or more of the following situations are present: faulty thermistors; the fitted thermistors have incorrect values; the thermistors have been placed in the wrong position; too much extra insulation has been applied to a thermistor. These situations are known as “unprotected windings”.

The RTD’s insulation with respect to the winding is another relevant factor when a motor is operating in hot conditions (Fig. 3). The high voltage penetration can also lead to a winding-to-earth condition via the control circuits.

**Case study**

A 6.6 kV motor tripped numerous times under load. It was sent for a rewind. When it was tested at normal ambient temperature, the motor did not display any symptoms of failures of its insulation system. The stator was then brought to its rated temperature. Winding insulation (Megger test): 40 MΩ at 110 °C, but it was found that one RTD’s insulation to the winding gave 1 kΩ at 110 °C. The leakage current through the control circuits was enough to trigger the earth protection.

**Assessing the stator insulation system**

The tests can be performed on the stator according to Part 1 and Part 2 of this
series, but at the rated temperature. It is only a matter of agreement with customer.

Other tests

Many tests can be performed to help artisans, repairers or designers. Two are presented here.

Measuring stator components in stray-load loss

This test is intending to measure the stray-load loss occurring at fundamental frequency.

The stator must have the rotor removed but the endshields or bearing brackets and other structural parts in which current might be induced must be in place.

By applying a controlled three-phase voltage, the windings can be brought to the rated temperature.

The followings measurements are taken: the line current used in performing this test - \( I_t \) (can be in a range of \( 0,25 \) to \( 1,5 \times I_{\text{nom}} \)); electrical input \( P \); winding temperature rise (rated temperature).

The applied current \( I_t \) value can be calculated as:

\[
I_t = \sqrt{I^2 - I_o^2}
\]

where:

- \( I \) = operating value of stator line current for which stray-load loss is to be determined;
- \( I_o \) = Motor no-load current.

For example consider a motor with rated current \( I_{\text{nom}} = 56 \, \text{A} \) and no-load current \( I_o = 20 \, \text{A} \). The value of stator winding current during stray-load loss test is thus \( I_t = 52,3 \, \text{A} \).

The fundamental frequency stray-load loss is:

\[
P_{\text{stray}} = P - R I^2
\]

where \( R \) is the hot resistance or reference resistance (according to type or class of insulation).

From experience, we proposed to estimate the entire stray-load loss occurring at high frequencies \( P_{\text{strayf}} \) (avoiding the necessity to perform a reverse rotation procedure) by considering the motor efficiency (minus windage losses).

\[
P_{\text{strayf}} = P_{\text{stray}} (1 - \eta)
\]

Finding a “reverse” coil by a conventional method

The “rotor test” is considered unreliable because of the high number of coils in a set-group. If the winding shop does not have a surge comparison test machine, there is a very easy conventional method to find a reverse coil. This is presented in a practical example.

For example, a stator has 6 set-groups of coils. One of them is suspected to be “in reverse”.

The coils are connected in series, top to bottom, leaving the first T1 and the last B6 connection available (Fig. 4). For this example, coil no. 3 was put in a reverse connection (the top-to-bottom sequence was changed).

Then a voltage of 33,8 V 50 Hz was applied between terminals T1 and B6. The following voltage drop values are measured between the coil terminals:

- Coil no. 1 = 7,3 V
- Coil no. 2 = 1,6 V
- Coil no. 3 = 10,4 V
- Coil no. 4 = 1,6 V
- Coil no. 5 = 7,3 V
- Coil no. 6 = 5,6 V

Clearly, coil no. 3 is taking the maximum voltage drop - is in “reverse connection”.

The coils next to coil no. 3 (coils 2 and 4) show a lower voltage drop than the coil’s flux being dumped by coil no. 3, whose flux is in opposition. Coils no. 1 and 5 have a relatively higher voltage drop in order to compensate the lack of flux. Only coil no. 6 does not suffer any influence from the disturbance.

If the coil terminals are in the right sequence, and 33,8 V, 50 Hz is applied, then on every coil is found a perfectly balanced drop voltage of 33,8 V with 5,63 V is recorded on each of the six coils.

Conclusions

Experience gained by testing a large number of stators allows a tester to make a better evaluation of the stator’s condition and a better prediction of failure. Statistical results of stator tests are also important.

Often it is important to have a double check, confirming a result by means of another type of test.

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