COLLECTION OF THE CTL DECISIONS
DECISION SHEET

Standard(s)- (year and edition): **IEC 60335-1:1991, 3rd Ed. and 2001, 4th Ed**.	**Sub clause(s):** **4.8.1(3rd)/5.8.1(4th)**	**Sheet No.** **DSH-543AA**
Subject: **Representative test voltage for induction motors including motor-compressors**	**Key words:** - Voltage - Induction motor - Locked rotor test	**Decision taken at 41st CTL meeting 2004 and modified at the 42nd CTL meeting 2005**

Question:

For locked rotor testing of induction motors, is testing at 50 Hz considered more severe than 60 Hz. testing, so that locked rotor testing at 50 Hz can be considered representative of testing at 60 Hz?

Decision:

For induction motors including motor-compressors rated 50 and 60 Hz, with the same rated voltage(s) at each frequency, locked rotor testing at 50 Hz is considered more unfavourable with respect to steady-state current. For induction motors including motor-compressors rated 50 and 60 Hz, locked rotor testing at 50 Hz, at the highest rated voltage(s) is considered more unfavourable condition with respect to steady-state current. For induction motors including motor-compressors rated 60 Hz, locked rotor testing at 50 Hz and rated voltage(s) is considered more unfavourable with respect to steady-state current. This does not necessarily apply to motor temperature or start-up currents.

Background/Rationale

Cyril G. Veinott, in his book *Theory and Design of Small Induction Motors,* and in the many papers he has authored on motor design and performance calculations, was a proponent of the revolving field theory of induction motors.

By distributing magnet wire in the slots of a magnetic material, a magnetic field is induced in the structure when a voltage is applied to the winding, creating a magnetic pole. If the magnet wires are distributed in four groups and each adjacent group interconnected so as to cause current to instantaneously flow in opposite directions, creation of four distinct magnetic poles occurs, adjacent poles being of opposite magnetic polarity. If the applied voltage is alternating, when the voltage reverses direction, causing the current to reverse, the polarity of each pole reverses. Thus, it appears the magnetic field is revolving in the structure. This revolving field occurs at synchronous speed.

Thus, for a four-pole stator, with 60 hertz applied, the field rotates at 1800 rpm; at 50 Hz, 1500 rpm.

The strength of the magnetic field is dependent on the applied voltage, the number of turns of magnet wire, the distribution of turns, the impedance of the winding, the type of magnetic material in the structure, and the design of the stator structure.

The strength of the magnetic field is normally given as so many magnetic lines or force, or flux.

The flux per pole is determined by the formula:

$$\Phi = \frac{E \times K_\phi \times 45 \times 10^6}{CK_w \times f}$$

E = line voltage for single-phase = phase voltage for polyphase
K_ϕ = primary resistance factor which varies from .90 to .98, depending on hp, but which is constant regardless of frequency
C = total series conductors in the winding (two conductors per turn)
K_w = winding distribution constant. Varies with the number of turns and span of teeth, but is constant regardless of frequency.
45×10^6 = a constant
f = frequency

In an induction motor under starting conditions (locked-rotor), in order for the rotor to create torque, a second magnetic field is necessary. This second or auxiliary magnetic field is introduced in the stator by the addition of a second winding displaced from the main winding. The action of these two magnetic fields causes the rotor to rotate or result in locked-rotor torque. A three-phase motor has three distinctive windings displaced from each other, thus resulting in three magnetic fields displaced from each other. Therefore, a three-phase motor is inherently self-starting.

However, a single-phase motor requires the introduction of a second or auxiliary winding, displaced from the main winding, to give a second magnetic field. The strength of this second magnetic field is determined by the formula given above. It is the relative strength of these two magnetic fields that determines the starting torque.

In order for a motor to start, the two magnetic fields must cross through the air gap between the stator and rotor, enter the rotor structure, and react on the rotor squirrel cage conductors. Once the rotor is up to operating speed, the auxiliary winding in a single-phase motor is switched out of the circuit and the rotor is rotating slower than the synchronous speed of the rotating magnetic field. Currents are induced in the rotor conductors, thus creating a second magnetic field.

Motor design engineers have found that the flux density in the air gap determines motor performance. An air gap flux density of about 35,000 lines per square inch usually results in an acceptable design.

The flux density in the air gap is determined by the formula:

$$\beta ag = \frac{\Phi \times Kr}{\text{Area}}$$

Where: Φ = flux per pole
Kr = a constant which varies from .90 to .99, depending on the number of poles and the hp, but is constant regardless of frequency.
Area = length of stator stacking x pole pitch at the stator bore

Referring to the formula for flux per pole, it is obvious that Φ will vary inversely as the frequency, or 6/5 from 60 Hz to 50 Hz. In order to attain the same air gap flux density and thus approximately the same locked rotor current performance, it is necessary to reduce the test voltage by 5/6 to test a 50 Hz motor on 50 Hz where only 50 Hz power is available. Conversely, a 50 Hz motor would be tested at 6/5 of the 50 Hz rating where only a 60 Hz supply is available.

Locked Rotor Test Comparison at 50 and 60 Hz – Some comparison data shown was generated at a lower test voltage at 50 Hz (i.e., at 200 V, 50 Hz rather than 208 V, 50 Hz), however, the data still confirms higher test currents at 50 Hz.

Compressor Samples	Test, V, ph	Hz	LRA after 3 h
1	240.3	60	124.3
1	240.3	50	132.2
2	208.1	60	100.3
2	208.1	50	112.5
3	240.3	60	118.6
3	240.3	50	137.5
4	208.1	60	142
4	208.1	50	153.5
5	240.3	60	124.6
5	240.3	50	138.1
6	208.3	60	134.7
6	208.3	50	149
7	208.1	60	126
7	208.1	50	146.5
8	240.3	60	92
8	240.3	50	105.4
9	208.1	60	107.3
9	208.1	50	115
10	240.3	60	109.6
10	240.3	50	116.5
11	240.3	60	86.9
11	240.3	50	95.7
12	240.3	60	74.6
12	240.3	50	82.6
13	240.3	60	67.1
13	240.3	50	73.3
14	240.3	60	63.6
14	240.3	50	68.1
15	208.3	60	45.7
15	208.3	50	49.8
16	240.3	60	44.6
16	240.3	50	49.6
17	208.3	60	39.5
17	208.3	50	44
18	240.3	60	43.6
18	240.3	50	46.2
19	100.1	60	9.8
19	100.1	50	10.8
20	100.1	50	10.5
20	100.1	60	11.1
21	208.1	60	34.3
21	200.1	50	35.7
22	208.1	60	28
22	200.1	50	33.6
23	208.3	60	173
23	200.3	50	182
24	208.1	60	70.5
24	200.1	50	79.5
25	208.1	60	34.5
25	200.1	50	36.6
26	208.1	60	102
26	200.1	50	107
27	208.3	60	105.5
27	200.3	50	114
28	208.1	60	61.8
28	200.1	50	64
29	208.3	60	36.7
29	200.3	50	38.5
30	208.1	60	120
30	200.1	50	127.5