IRIS POWER
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Diagnostic News

May 2014

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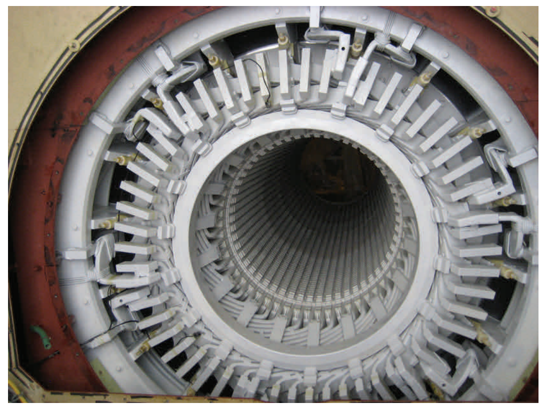
UPCOMING EVENTS 2014

GE 7F Users Conference	May 20-21 Phoenix, AZ **BOOTH 22**
IEEE Electrical Insulation Conference	June 8-11 Philadelphia, PA **BOOTH 6**
IEEE Pulp & Paper Industry Conference	June 22-26 Atlanta, GA **BOOTH 7**
EASA 2014	June 29-July 1 Boston, MA **BOOTH 201**
CIGRE	Aug 25-29 Paris, France

Endwinding Vibration—How much is too much?

By: John Letal



Stator winding problems related to excessive endwinding vibration have become more and more prevalent in the past decade as machine manufacturers try to reduce manufacturing costs. Operational forces primarily related to the electromagnetic effect of two parallel, current carrying conductors are enough to result in tiny (less than 1mm) movements of otherwise stationary windings. These movements are often most prevalent where the support is the weakest, that is, where the winding extends from the core resulting in a cantilever effect in the endwinding region. Over time or with the assistance of an operational fault current, the endwinding support system can loosen resulting in vibration higher than normal. Additionally, these tiny movements are amplified, sometimes catastrophically, if a structural natural frequency is influencing the operational forces resulting in a resonance condition. It is not clear though, how much endwinding movement is too much and can result in machine failure.

IEEE recently (March 2014) approved Standard 1129 [1], "Guide for Online Monitoring of Large Synchronous Generators" in which, based on experience with 60Hz generators in North America, unfiltered radial displacement magnitudes between 50 to 125 microns (2 to 5 mils) peak-to-peak are considered acceptable and between 200 to 250 microns (8 to 10 mils) peak-to-peak are typical alert levels.

Peak-to-peak is the amplitude from the time waveform positive peak to the negative peak such that the entire range of motion of the endwinding bar is being monitored (note: 0.001" = 1mil = 25.4 microns).

Unfiltered is the overall vibration at all frequencies present including the response associated with operational electromagnetic and turning speed forces, harmonics (multiples) of operational forces, and any subsynchronous (below turning speed) activity. Considering that the levels presented are in displacement it would suggest that focus is on lower frequencies (less than a few hundred Hz) because at higher frequencies displacements are generally negligible. Higher frequency harmonics that might be attributed to mechanical looseness are sometimes present in endwinding vibration measurements. Perhaps velocity, which offers an amplitude smoothing effect across a vibration spectrum, should be considered as well, to balance the effect of the operational forces and any harmonics that may develop.

If the stator endwinding is represented as a circle, *radial displacement* would be the distance moved in the direction between the center to the arc of the circle (i.e. the movement due to the electromagnetic force between a top and bottom bar). There are considerable forces present, and vibratory responses have been measured tangentially as well between two adjacent bars around the circumference of the endwinding. Vibration in the tangential direction should

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Endwinding Vibration—How much is too much?

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not be ignored when assessing stator endwinding vibration.

In 2011, EPRI published a Generator Stator Endwinding Vibration Guide [2] which considered the coil ends of any generator: less than 127 microns (5 mils) peak-to-peak is normal, 203 microns (8 mils) peak-to-peak is the recommended alarm level and, no more than 254 microns (10 mils) peak-to-peak, unless allowed by the OEM.

In the book, "Electrical Insulation for Rotating Machines" [3], published in 2004, displacement greater than 250 microns (9.84 mils) peak-to-peak is considered significant ,and in excess of 400 micron (15.75 mils) peak-to-peak as requiring attention in the very near future.

It is clear from the data presented in the last decade, from multiple sources that there is consistency in stator endwinding vibration limits. *In general, less than 100 microns (4 mils) peak-to-peak is considered acceptable and greater than 250 microns (10 mils) peak-to-peak is cause for some concern*. These should be used with caution! The historic data used to develop these limits may be from poor probe location and/or vibrating fiber optic leads. As well, the data from older sensors capable of only monitoring one frequency would have less vibration than the same vibration collected with an unfiltered or broadband frequency approach.

Modern fiber optic technology with low noise, measuring a wide frequency range (up to 1000Hz) in 2 directions (radial and tangential) should be used to gain the most insight in how endwindings are vibrating. The measurement locations should be based on where the operational forces are greatest as well as from results of a bump test to identify components which are most likely to vibrate at the highest amplitudes.

An unfiltered displacement acceptance limit is a great start to answering how much endwinding vibration is too much, but acceptable vibration in the radial direction could be different than in the tangential direction. Perhaps a 2 directional overall approach should be taken. Additionally, acceptable vibration at specific frequencies could be different at turning speed, electromagnetic frequency, and other frequency bands of interest (subsynchronous, turning speed harmonics, electromagnetic frequency harmonics). When considering higher frequency harmonics other measures of vibration (acceleration and/or velocity) should be used where displacements are negligible.

A better understanding of the nature of winding failures due to endwinding vibration will hopefully lead to a more complete standard: where and how to collect vibration, acceptable displacement amplitudes at specific frequencies, acceptable velocity amplitudes, etc. A significant takeaway from all of these sources [1-3] is the need for continuous online monitoring especially for two-pole machines. Most machines with endwinding vibration are avoiding costly problems with monitoring. It is important to compare a machine's own vibration against a good baseline at consistent operating conditions so any subtle changes to these tiny movements can be identified and maintenance efforts can be scheduled accordingly.

References:

[1] *IEEE Guide for Online Monitoring of Large Synchronous Generators (10 MVA and Above)*, IEEE Standard 1129, 2014.

[2] H.O. Ponce, B. Gott, G. Stone, *Generator Stator Endwinding Vibration Guide: Tutorial*, EPRI, Project ID 1021774, 2011.

[3] G.C. Stone, E.A. Boulter, I. Culbert, et al. *Electrical Insulation for Rotating Machines*. Hoboken NJ: Wiley, 2004.§

NETA InterNational Electrical Testing Association
Setting the Standard.

Qualitrol-Iris Power's Vicki Warren received the Alliance Recognition Award for Outstanding Alliance Member of the Year. The Award was presented by James Cialdea, Chairman of the NETA Alliance Program Committee.

MDSP3 with 2 CTs

Iris Power MDSP3™—Detects Abnormal Air Gap Eccentricity in a Fuel Gas Compressor

Background

The Iris Power MDSP3 test was recently performed on a 2700 hp, 4.16 kV induction motor for a Fuel Gas Compressor with a synchronous speed of 1200 rpm. The plant supervisor and the tester were unaware of any faults that could be present in the motor. The test was carried out by simply obtaining the nameplate information of the motor.

Test Results

Motor nameplate data such as rated power, rated voltage and rated speed along with the number of rotor bars and main CT Ratio were fed into the MDSPPro software application. In this case the 6 pole motor had 84 rotor slots. The tests were conducted at the secondary side of the 400/5 ratio CT with the 5A/1V probe supplied with the MDSP3, clamped around the same phase current.

The motor was running at a speed of 1194 rpm and the load current was measured at 194A (49% full load current).

The MDSP3 instrument performed one High-Resolution measurement within 80 seconds, including data collection and analysis of both air gap eccentricity and cage winding failure mechanisms. The high sampling rate (>6500 samples/sec) ensured an enhanced reconstruction of the current signal in the frequency domain. The air gap spectrum is shown in Figure 1.

Figure 1 shows the highest magnitude rotor slot passing frequency component of 1732 Hz (HRSPFC) frequency and two rotational speed frequency components (f_r),

$$fr = f_1 * \left[\frac{1 - Slip}{p} \right]$$

where f_1 = Supply Frequency and p= number of Pole Pairs. The two rotational speed frequency components, equally placed at, HRSPFC $\pm fr$ have the magnitudes and frequencies as -72.5 dB at 1712 Hz and -71.0 dB at 1752 Hz. The diagnosis of air gap eccentricity severity is 15.3 db which is calculated using:

$$dbav = db\ HRSPFC - \frac{dbfrl + dbfru}{2}$$

The severity of 15.3db indicates air gap eccentricity problem exists in the motor. One subsequent test was performed and the MDSP3 again returned an air gap eccentricity severity of 15.3db.

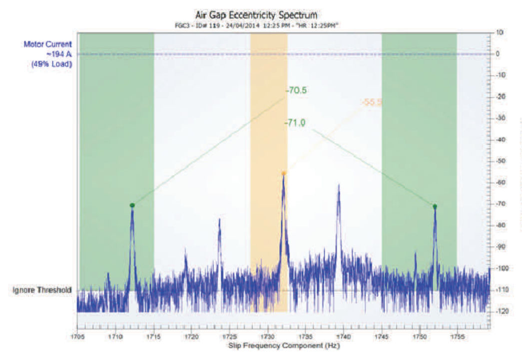

Figure 1: Air Gap Eccentricity Current Spectrum

Corroboration

The customer was shown the result from the MDSP3 instrument. To confirm that the tests were correct, the plant technician was asked to take bearing housing vibration measurements for the motor. The vibration data (shown in figure 2) confirmed that there was a high vibration component at 2**power supply frequency (120 Hz) in the vertical direction,* which is an effect of abnormal air gap eccentricity. This correlation proved that MDSP3 analysis was indeed effective in detecting this problem.§

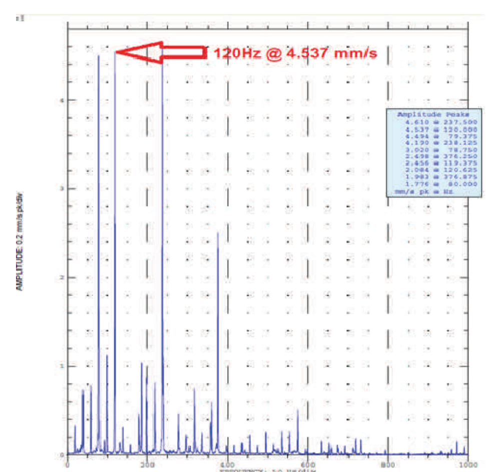

Figure 2: Vibration Spectrum

2014 Training Courses

EL CID Training Seminar
September 23-25
Toronto, Canada

Hydrogenerator Maintenance Course
October 21-23
Sacramento, CA, USA

For more information, contact:
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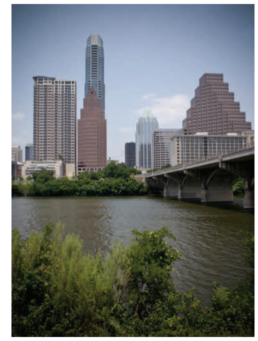
IRMC—COMET: DECEMBER 2-4, 2014

The Iris Rotating Machine Conference is taking on a new look! The 2014 conference, to be known as the **Conference on Online Monitoring of Electric Assets** (COMET), will be held in Austin, Texas in affiliation with the University of Texas Center for Electromechanics! After 16 years, the IRMC program will change to provide attendees with parallel sessions on Rotating Machines, and Transmission System Equipment. This conference will be devoted not just to presentations on condition monitoring tools, but also to educating attendees on the practical aspects of implementing condition-based maintenance in transformers, switchgear, large motors and generators.



The first Conference will be held in Austin, Texas, December 2-4, 2014.

Mark your calendars for what will prove to be an exciting event covering all aspects of electrical equipment condition monitoring. Monitor http://www.utexas.edu/research/cem/comet/comet.html for more information!

IEEE 43 (2013)
Recommended Practice for Testing Insulation Resistance of Electric Machinery

A revised version of IEEE 43 was published on March 6, 2014, which replaces the previous IEEE 43: 2000 edition. The working group that developed this new version of IEEE 43 was chaired by Mr. Ian Culbert of Qualitrol - Iris Power. This standard is one of the most widely used IEEE standards in the power equipment field. The working group to revise IEEE 43 had more than 40 experts from around the world, and it took over 5 years to complete its work. IEEE 43:2013 is likely to be the basis of a new IEC standard on insulation resistance and polarization index testing. Greg Stone, also of Qualitrol - Iris Power, is the convenor of this new IEC working group.

The major changes included in the new version of IEEE 43 are as follows;

- Revision of Figure 1 – Equivalent Circuit to better reflect the characteristics of the absorption current that flows during an insulation resistance test.
- Information on the effects of stress control coatings on both insulation resistance (IR) and polarization index (PI) measurements.
- Provision of different IR temperature correction factors for thermoplastic, e.g. asphaltic mica and thermosetting, e.g., epoxy mica insulation systems.
- More detailed guidelines on the interpretation of PI measurements for AC machine rotor and DC machine armature windings.
- The addition of a new Annex C providing information on the identification of some types of winding insulation degradation from the analysis of charge and discharge current profiles, as can be obtained from the PDTech DRA3 instrument.
- Recognition that stator windings which have their complete overhang treated with voltage stress control material will have a PI close to 1.0 and that surface tracking may develop in such windings.
- A new Annex D which gives a brief introduction to insulation resistance profiling. This technique involves interpreting the condition of a stator winding insulation system from the shape of a 10 minute PI test profile. The IEEE 43 working group did not feel that this technology was sufficiently advanced to include details of it in the standard itself.

There were no significant changes made on how to interpret IR and PI results.§