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# CATASTROPHIC FAILURE DIAGNOSIS WITH MODAL ANALYSIS OF GENERATOR ENDWINDINGS

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Danilo received his MSc in Design of Rotating Machines from Cranfield University - England, being awarded the Engineering Mechanics Prize of that institution in 2014.

# ABSTRACT

In this paper, the catastrophic failure of a 2-pole 360MW unit will be presented.

This failure lead a root cause analysis and a series of investigations that was taken place in a similar design unit deployed at a different site. This paper will describe the bump test and modal analysis procedures and results that were carried out on the end of all coils of the stator winding in the sister unit of the failed 360MW generator which lead to conclusions that were crucial for the determination it´s failure root cause.

# Failure in generator stator phase connection coils

2-pole 360MW generator unit underwent a catastrophic failure nearly 2 years later after it was put into commercial operation.

As part of a root cause of failure analysis, a bump test was requested to be undertaken on a sister unit installed at another site

# Problem statement - Justification

The dynamic response that can result in excessive vibration of the overhung structures that compose the end coils of a generator stator winding bars can be basically attributed into two primary forces:

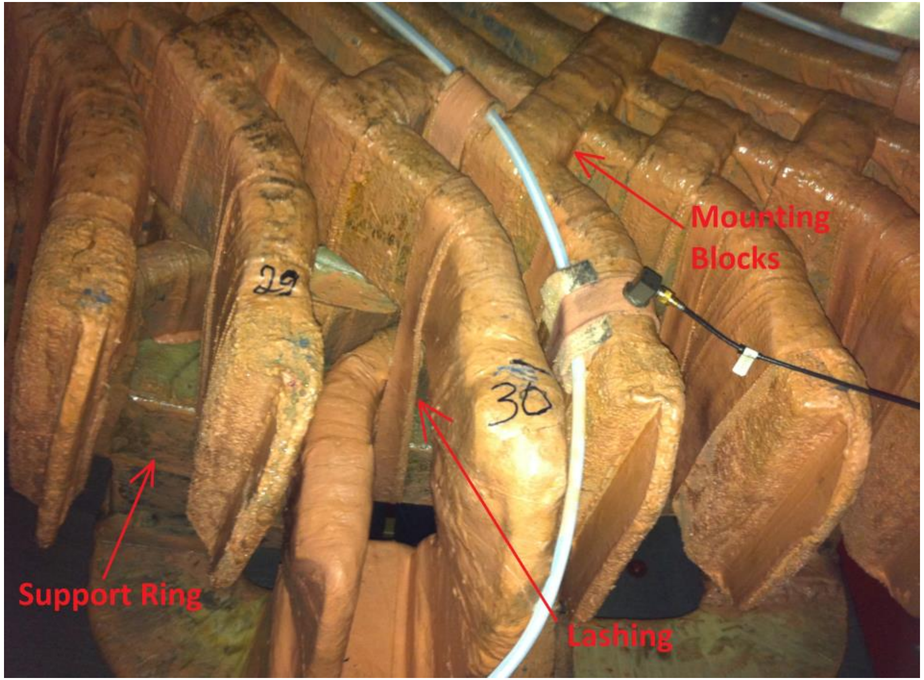
I. Electromagnetic force at twice the line frequency (120Hz in Brazil/USA or 100Hz in Europe)

II. Running speed frequency of the rotor
(60Hz in Brazil/USA or 50 Hz in Europe) 2-pole machines
(30Hz in Brazil/USA or 25 Hz in Europe) 4-pole machines...

# Problem statement - Justification

To contain these forces, the stator coil end-windings are often stiffened together by mounting blocks placed between the adjacent end-windings and are braced together by fiberglass or polyester cord lashings

In addition, the individual coil end windings are lashed to a support ring made of insulated metal that increases the hoop strength of the end-windings structure and hence its radial stiffness.



# Problem statement - Justification

1. Difficulty to analytically model these structures with precision
2. Design analytical results can carry imprecisions

*Experimental impact testing can better detect radial and tangential natural frequencies of the stator coil end windings and validate analytics results*

AND

3. With load transients, copper expands when hot and shrinks cold
4. Lashes can go loose, resin based insulations can shrink or crack

*Experimental impact testing can be useful in keeping track of the mechanical integrity of such components in the long term, if performed as standard on every major overhaul*

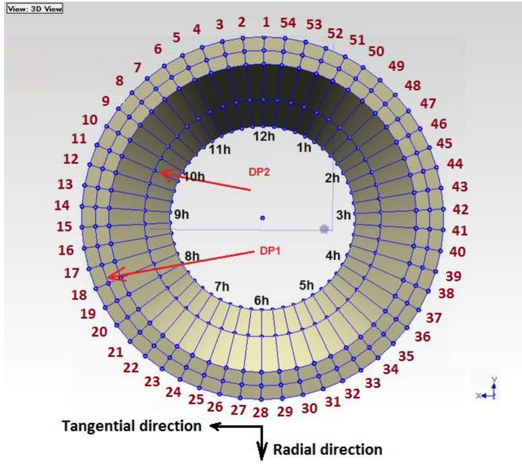
# Methods

## Local tests

- ✓ Impact test of each end-winding individualy for radial and tangencial directions;
- ✓ Mount acelerometer into the same end-winding being impacted;

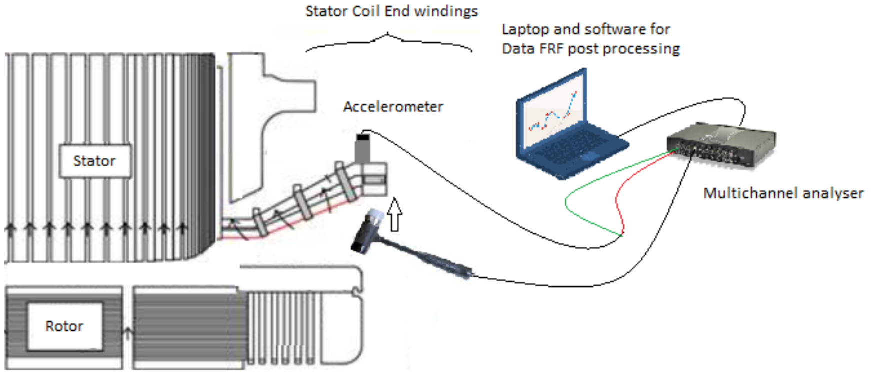
## Global tests

- ✓ Divide the cage into a minimum of 12 equally distanced points;
- ✓ One bar head-joint shall be taken as a reference point for the impacts
- ✓ Mount accelerometer on each end winding respective to the 12 selected positions



# Methods

- ✓ Use a instrumented force hammer;
- ✓ Attach accelerometers with wax;
- ✓ FRF post-processing in accelerance response;
- ✓ If coherence is below 0.9, repeat impacts;
- ✓ Spectrum of excitation: 20 - 500 Hz
- ✓ Average least 3 impacts at each test.



**Criteria**

Separation Margin:

- Exclusion band frequencies of 60 Hz and 120Hz (or 50Hz and 100Hz)

  - ✓ **-6% and +17%**

- *In service, the natural frequencies may drift due to rise in temperature, aging, copper expansion, resin shrinkage/deformation and other variable factors*

Response amplitude:

- current general criteria:

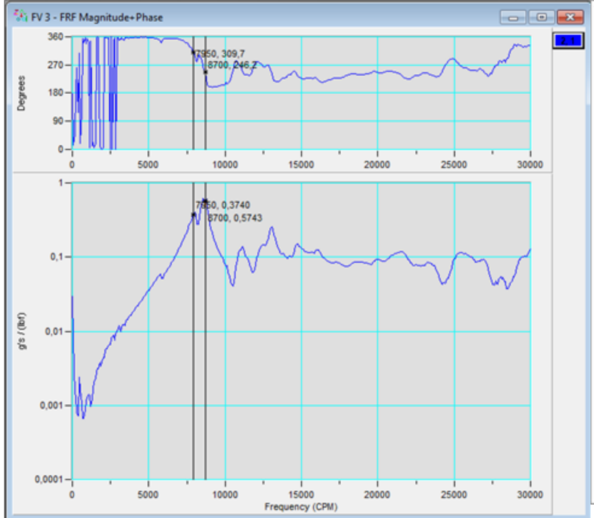
  - ✓ Accelerance or inertance limit level of 0,05 g/lbf for the exclusion band of frequencies

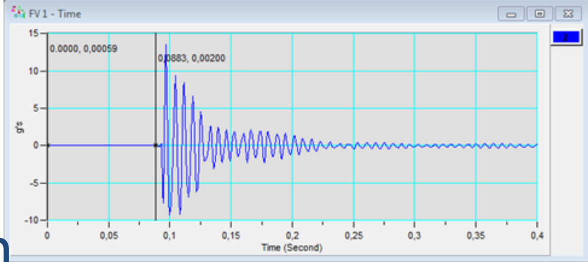
# Local test results

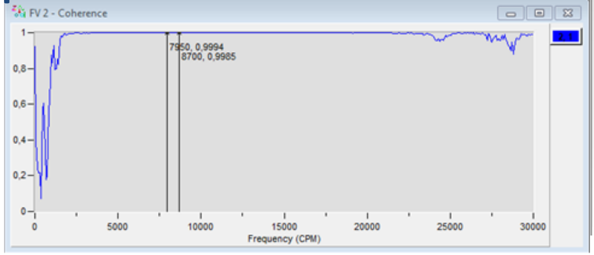
## NDEwindings:

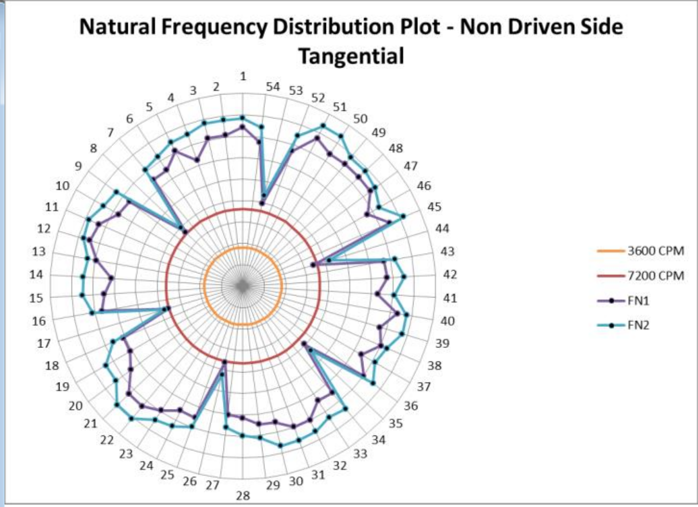
Unacceptable dynamic conditions according to the results obtained for the tangential direction.

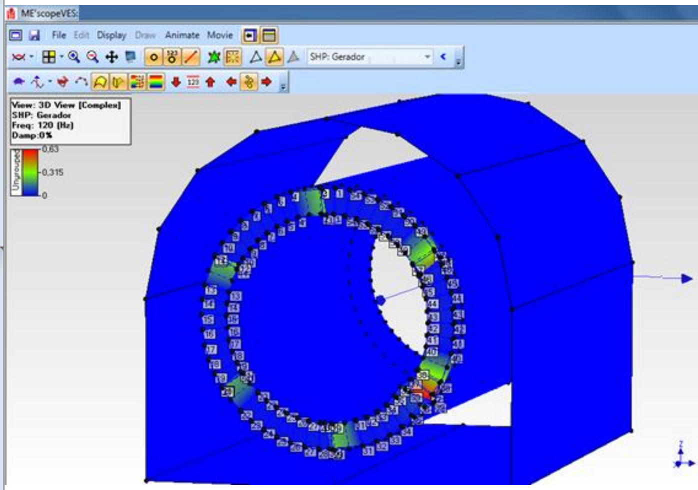
06 coils presented an abrupt drop of their Nfs close to 120 Hz and high excitation response



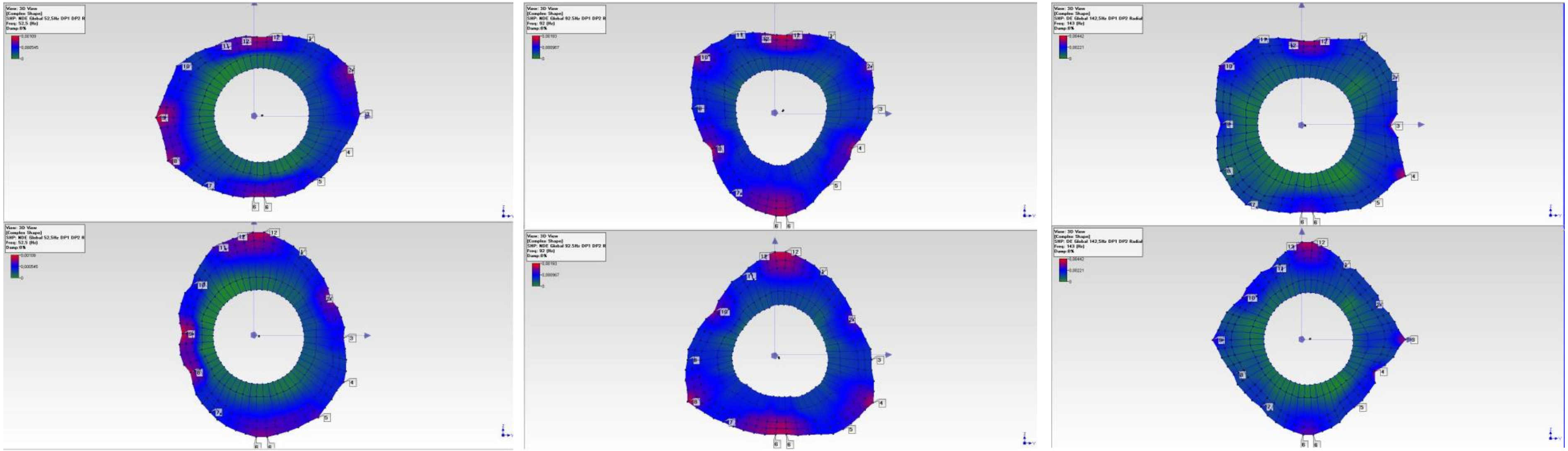



## Local test results

The global bump tests did not result in a condition that could indicate problems.

*No significant modes found within 112 Hz to 140 Hz.*

This indicated that the cage structure itself was in good condition of design.



2-lobe mode at 52.5 Hz.

3-lobe mode at 92.5 Hz.

4-lobe mode at 142.5 Hz.

# Conclusions and Recommendations

Resonant condition of phase conections at 120 Hz caused these endwindings to operate under high vibrations.

This most likely caused premature fatigue of insulating material and short circuit among adjacent endwindings.

It was recommended to the generator's OEM a design modification to alter the tangential natural frequency of these phase connection end windings by increasing the tangential stiffness and to improve the tangential damping among them as an effort to decrease its accelerance response.

# Lessons Learned

- ✓ ***Experimental bump testing of generator end-windings is an extremely important tool!!***

Design/Pre-comissioning:

- ➢ Analytical modeling (FEM) can carry a few uncertanties mainly due to borderline assumptions of stiffness and damping coefficients of components such as handmade epoxy-based insulations, mounting blocks, lashing and braces.

Major maintenance overhauls:

- ➢ System disturbances, high working temperatures and transients overtime will age and wear components, usually causing looseness and changes into stator end-windings natural frequencies

# Acknowledgments

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شكراً جزيلاً
рахмат
danke
謝謝
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Баярлалаа
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