ON-LINE MONITORING SYSTEMS
AS USED BY ELETRONORTE AT THE
TUCURUI II & COARACY NUNES POWER PLANTS

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SUMMARY

Abstract-- In the year of 2002, Eletronorte began their on-line monitoring program by proceeding with the installation of their first Zero Outage On-Line Monitoring (ZOOM®) system on Unit #13 of their new Tucurui II power station. This monitoring system supplied by CETUC, produced and installed by VibroSystM, comprised an impressive array of sensor, acquisition units and sophisticated diagnostic software. In the year 2003, Eletronorte decided to equip its Coaracy Nunes power plant with an air gap monitoring system in an attempt to analyze the behaviour of Unit 3 with a minimal set up because of urgent interventions. As we will see in this paper, these monitoring systems were instrumental in understanding the behaviour of two very different size hydroelectric generators, presenting unique and distinctive behaviour.

KEYWORD

Monitoring, National Event, Generation of Electrical Energy

1,0 INTRODUCTION

TUCURUI II

The ZOOM system at this power station was comprised of 16 air gap sensors (VM5.0) on the stator: 8 located at the top of the stator and 8 located at the bottom of the stator. These capacitive air gap sensors which have a range of 5 to 50 mm were chosen because of the specified air gap of 20 mm. A magnetic flux probe was installed at the top of the stator. This probe can measure the magnetic flux generated by each pole up to 1,5 Tesla at 60 Hz. This probe was chosen to correlate the air gap with its effect on the magnetic flux. The stator was also equipped with 24 capacitive stator bar vibration sensors (DCS-400), installed at the upper part of the stator, to monitor the behaviour of individual high voltage stator bars. The stator core was equipped with three accelerometers located at 120º intervals around the core. The shaft relative vibration was monitored by patented capacitive displacement sensors (PCS-202) at three different levels; the upper guide, the thrust guide and the turbine guide bearings. The system was completed by relative pressure sensors, absolute vibration sensors at all three guide bearings and four stator displacement sensors. All these measuring chains were monitored by five ZOOM Processing Units (ZPU) as well as by PCU-100 Vibrawatch protection racks. Finally, the monitoring software was installed in a LAN configuration, remotely connected to the head office in Brasilia. The software is also monitoring various parameters via a MODBUS+ network.

2.0 OBSERVATIONS (AIR GAP)

The ZOOM system was instrumental in verifying the air gap parameters necessary to determine the circularity/concentricity of the rotors/stators in relation to existing standards. Figure 1 shows the air gap as recorded by the capacitive sensors during a start up with field excitation. We can clearly see the effects on the air gap when the Unit speed increases and at the moment the excitation of the rotor occurs (magnetic flux is represented in purple). A sudden decrease of the air gap at all locations is quite noticeable. We can also observe that the Unit overshoots its nominal speed of 81.8 RPM during the start up.

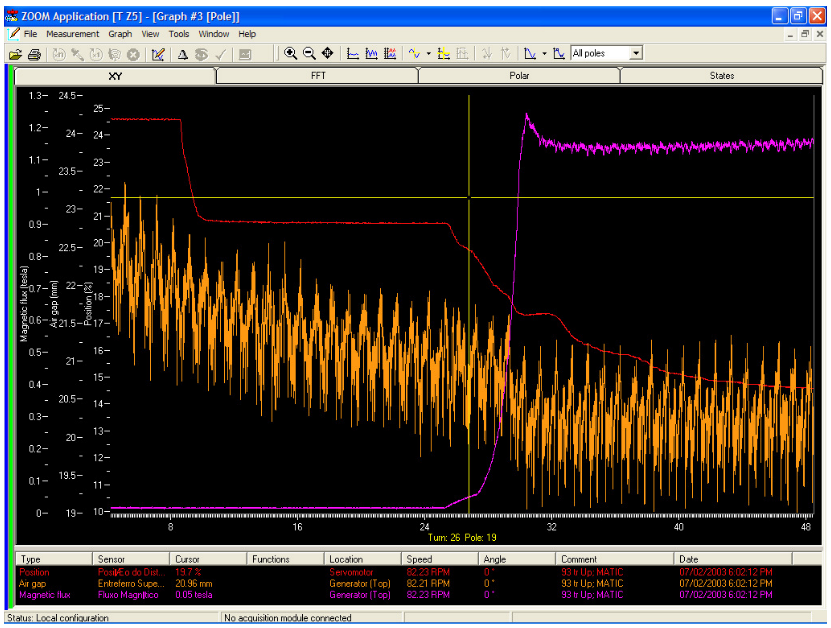

Figure 1. Unit 13 Start up

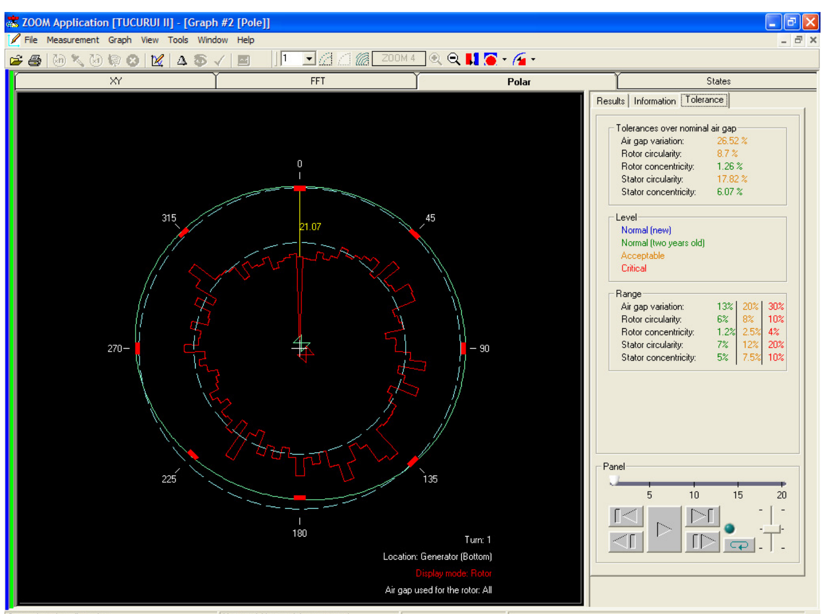

Figure 2. Unit 13 at 380 MWatts – Full Load

Measurements were recorded for the first 4 Units (Units 13 to 16) and only Unit 15 was found to have results which do not exceed existing CEA (Canadian Electrical Association) guidelines for a new Unit. Figure 2 shows Unit 13 at Full Load with a comparison to existing CEA guidelines displayed by the ZOOM software. We can see that the circularity values for both the rotor and stator exceed acceptable guidelines for a new Unit. Although the values are not alarming, these values should be monitored closely to identify any deterioration and perform an intervention if required.

3.0 OBSERVATIONS (SHAFT VIBRATION)

During the commissioning stage of Unit 13, the ZOOM system was critical in its capacity to record with precision the behaviour of the Unit, especially with regards to the shaft vibration aspect. The ZOOM system provided the necessary information and analysis capability to confirm the shaft vibratory behaviour in respect to the expected behaviour as per the manufacturer's laboratory testing. In this case, the Unit performed as expected, which is to say that the Unit experienced high vibration levels at Speed No Load but saw the vibration levels decrease significantly as the load increased.

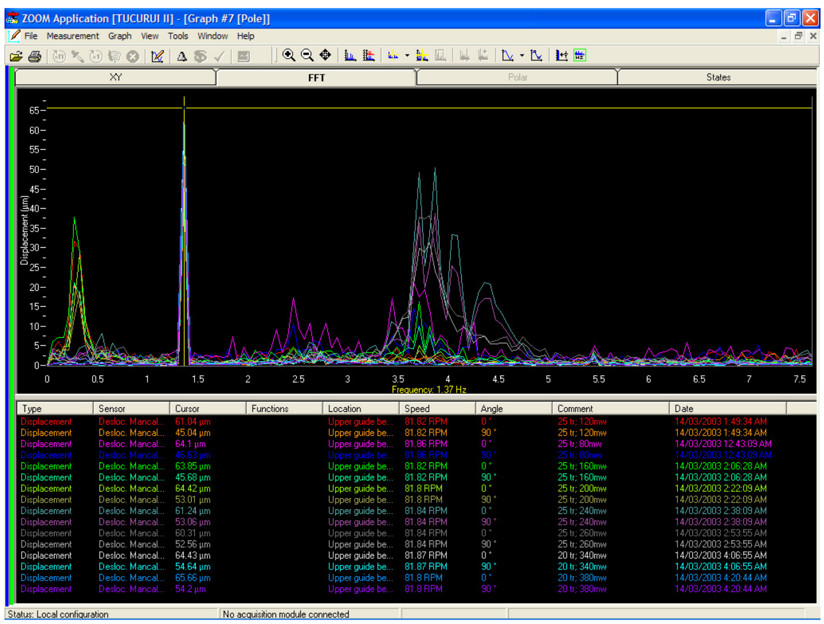

Figure 3. Spectral analysis at different loads – Upper guide bearing – Unit 13

Figure 3 shows the different frequency signatures according to the load as recorded by the two upper guide bearing capacitive sensors (PCS-202) installed at 90º X & Y angle. We can see that low loads, 120 – 160 MWatts for example, present frequency signatures at 0.3 Hz (1/5 the fundamental frequency for this Unit) while loads at around 260 MWatts have a distinct signature at ± 3.8 Hz (close to 3 times the fundamental frequency) and finally, all loads present a signature at the fundamental frequency for these Units which is 1.36 Hz ((120 poles/s)/88 poles). After analysis of all 4 Units (Units 13 to 16), it is apparent that all Units present the same frequency signatures at the upper guide bearing. Figures 4 and 5 show the orbit graphs for Unit 16 at three different load conditions (76 MW & 380 MW). We can clearly see the Unit settle down as the load increases. The orbit path stabilizes to a distinct circular pattern while the *SMax* (the maximum distance from the theoretical center) decreases significantly. At 76 MW, the SMax is 204 µm peak at 0º while at 380 MW; the SMax is 128 µm peak at 185 º. The orbit graph provided by the ZOOM software can easily identify the heavy spot, which on Unit 16 was in the area of pole 85 at full load (380 MW). The orbit graph displays the actual position of the rotor poles while the Unit is turning which provides valuable information in regards to the exact location of the heavy spot thus rendering balancing the rotor a much simpler process. In fact, during the commissioning of Unit 13, the VibroSystM service representative identified the heavy spot as being in the area of pole 43. The manufacturer informed the service representative that support brackets for weights had been left near that position. The Unit was stopped and the supports were removed.

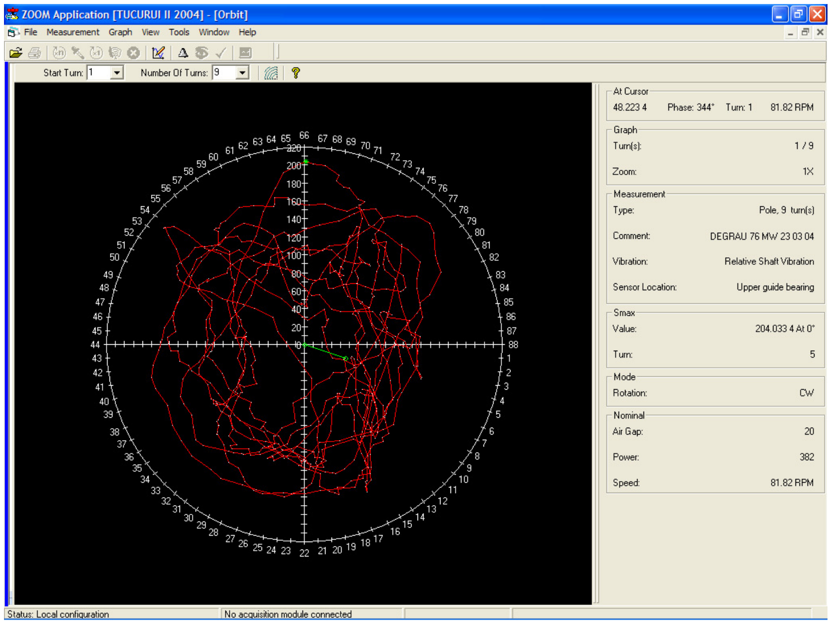

Figure 4. Orbit of Unit 16 – Upper guide bearing - 76 MWatts

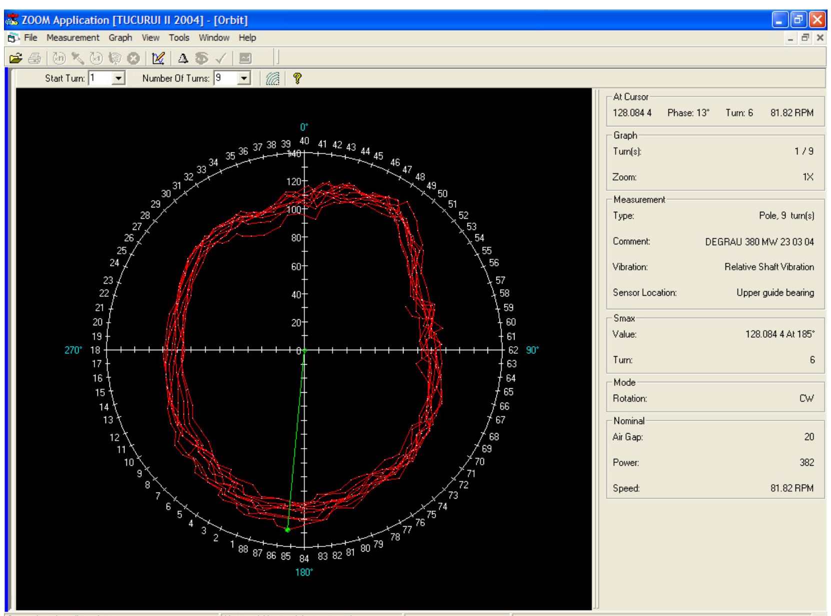

Figure 5. Orbit of Unit 16 – Upper guide bearing - 380 MWatts

During the commissioning of all Units, radial vibration was recorded by two thrust guide bearing capacitive sensors (PCS-202) installed at 90º X & Y angle and there again, at small loads, vibration appears and slowly disappears in relation to the load increase. However, in the case of the thrust guide bearing, the phenomenon is located at a frequency of ± 22.5 Hz for all Units except Unit 14, which does not experience any activity whatsoever in that frequency range. Figure 6 shows the frequency signatures of Unit 13 at various loads (Units 15 and 16 are quite similar) and figure 7 shows Unit 14's lack of activity.

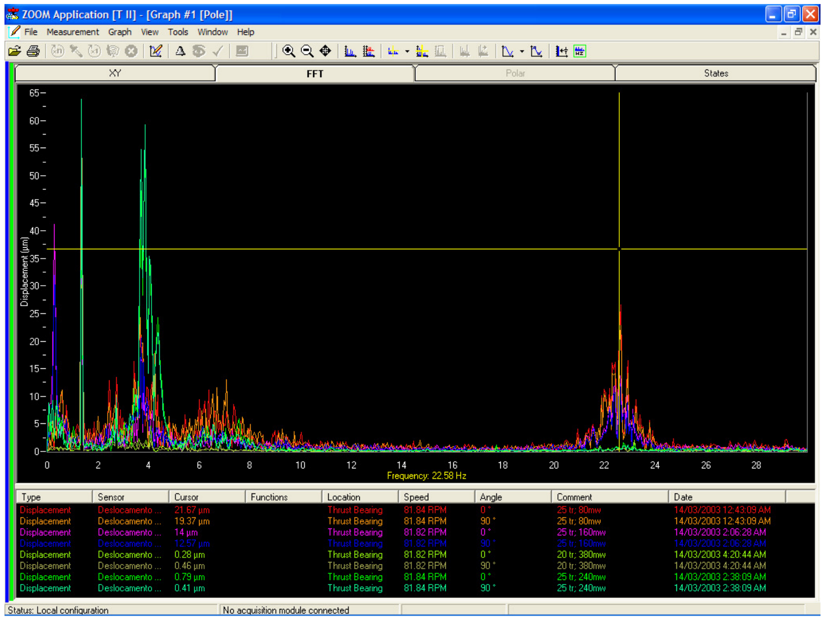

Figure 6. Spectral analysis at different loads – Thrust guide bearing – Unit 13

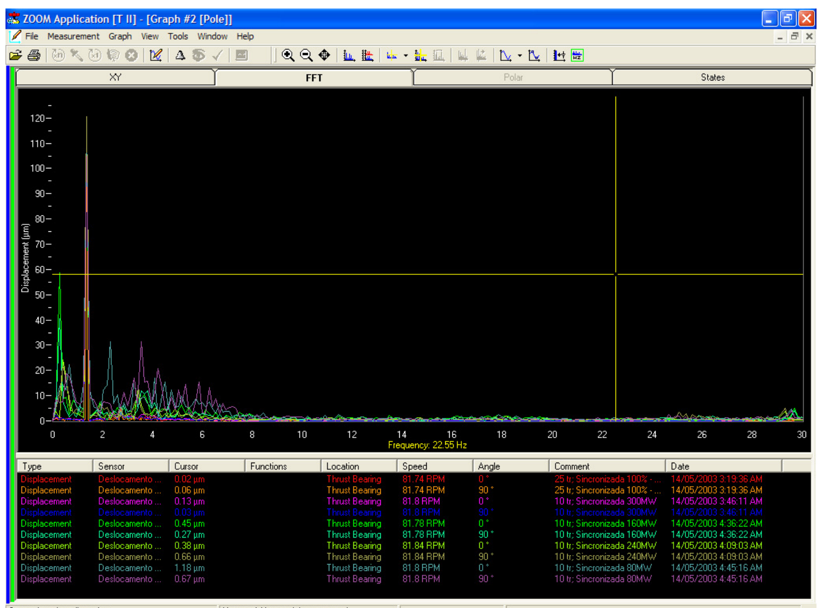

Figure 7. Spectral analysis at different loads – Thrust guide bearing – Unit 14

This phenomenon is caused by the fact that Unit 14 was designed by a different manufacturer than Units 13, 15 and 16 thus the displacement sensors at the thrust guide bearing were installed differently because of the thrust guide bearing housing. This installation was not possible for Units 13, 15 and 16 so the supports for these sensors were installed on the lower bracket which was designed differently. This is what we observe in the spectral graphs at ± 22.5 Hz. We can see in figure 8 that the absolute vibration at the thrust guide bearing confirms vibration activity which decreases significantly (± 14 mm/s down to ± 2 mm/s) as the load is increased. Verification of the absolute vibration at the upper guide bearing revealed a similar decrease in vibration (± 5 mm/s down to ± 1 mm/s) although smaller in scale.

The turbine guide bearing sensors recorded a variation of ± 12 mm/s down to ± 3 mm/s. This behaviour was found to be similar on all four Units.

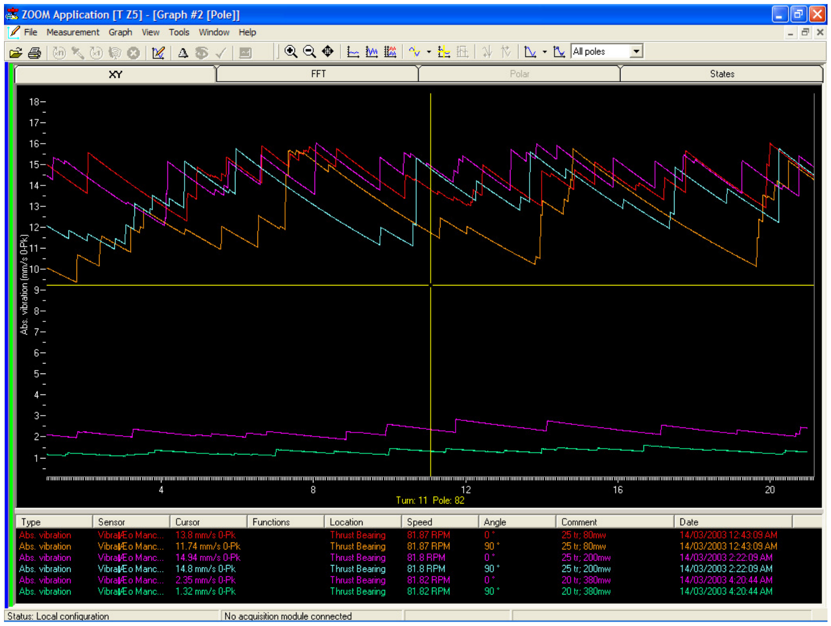

Figure 8. Absolute vibration – Thrust guide bearing – Unit 13

4.0 OBSERVATIONS (STATOR BAR VIBRATION)

Twenty four capacitive stator bar vibration sensors (DCS-400) were installed at the upper part of the stator to monitor the vibration of the high voltage bars. These sensors were connected to an instrumentation rack (PCU-100) in order to process the signal into a peak-peak reading. During the commissioning stage, these vibration readings were recorded by the ZOOM system and found to be quite acceptable. In fact, the readings rarely exceeded 20 µm pk-pk, which confirms the stator wedge tightness. Figure 9 shows a one month period of readings from the stator bar vibration sensors.

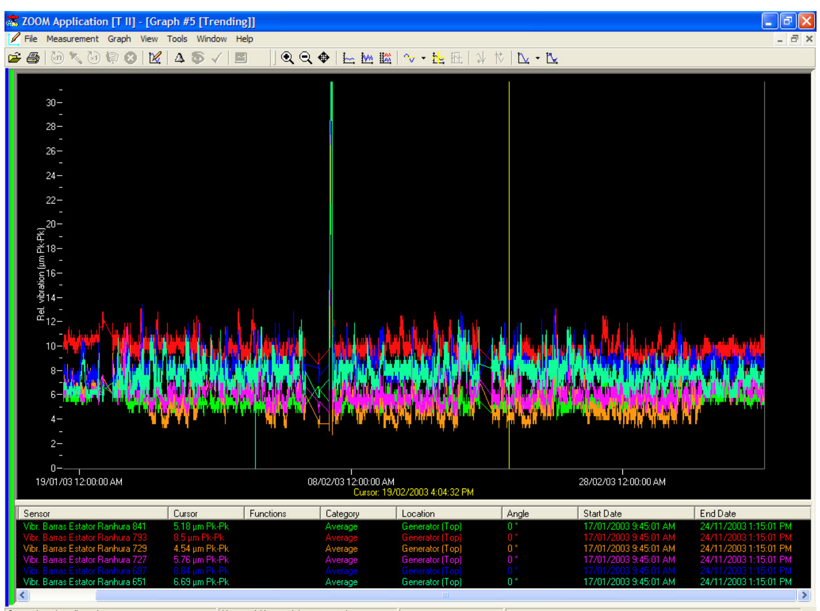

Figure 9. Trending graph of Stator bar vibration – Unit 13

5.0 OBSERVATIONS (PRESSURE PULSE)

Pressure pulse sensors were installed in four strategic locations; two in the draft tube at 90º intervals, one in the spiral case and one at the turbine head cover. These sensors are used to record the pressure at these locations thus providing critical information in regards to hydraulic stability. There was some concern as to the Unit's ability to produce power when the water levels were low. In fact, the manufacturer set strict guidelines as to the safe operation of the Units with low head. Eletronorte is able to run the Units beyond these limits with the help of these pressure sensors which provide the necessary information to ensure the Unit's stability under these conditions.

COARACY NUNES

6.0 INTRODUCTION

The ZOOM system at this power station was comprised of four capacitive air gap sensors, installed at the upper part of the stator, as well as two capacitive relative vibration sensors installed above the rotor in order to provide some vibration data. There again, diagnostic software was installed in order to monitor the measuring chains.

7.0 OBSERVATIONS (AIR GAP)

Measurements with the ZOOM system were taken in July of 2003 and the data was analyzed. The air gap sensors, installed at 90º intervals (0º, 90º, 180º and 270º) were able to record the position and shape of the rotor with the Unit at different operating conditions from Speed No Load up to Full Load with the temperature stabilized. This data showed quite clearly that the rotor suffered a displacement in the 180º downstream direction when the rotor is excited as shown by comparing figures 11 and 12. As the load increases, the rotor remains quite stable while the stator expands due to the increase in stator temperature. Figure 10 shows the air gap variation as seen by sensor 0º at 5 different operating conditions (S.N.L., Excited 0% MW, 50% MW, 100% MW and 100% MW fully hot).

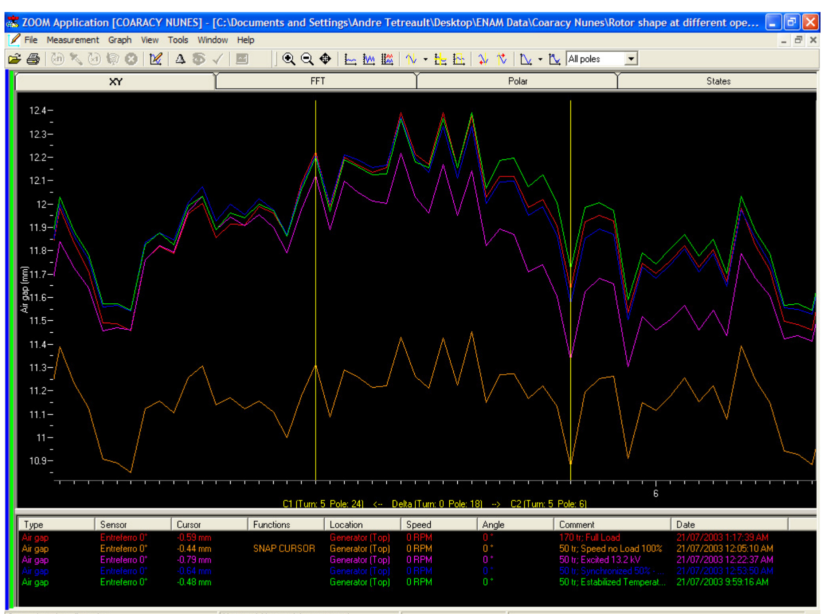

Figure 10. Rotor shape and position evaluation

With the help of Figures 11 and 12, we can see that the rotor circularity is acceptable at speed no load while it slightly exceeds the CEA guidelines at full load. It is also possible to observe that some poles are protruding abnormally (especially poles 2 and 6). Usually, the difference between 2 successive poles should not exceed 250 µm. This data can be used to investigate the pole to rim assembly and make sure that there are no discrepancies. The circularity of the stator experiences the same behaviour as the rotor which is to say that at speed no load, the values are acceptable. But at full load, the values exceed the CEA guidelines. Stator displacement sensors would be quite valuable in this case to confirm the stator behaviour.

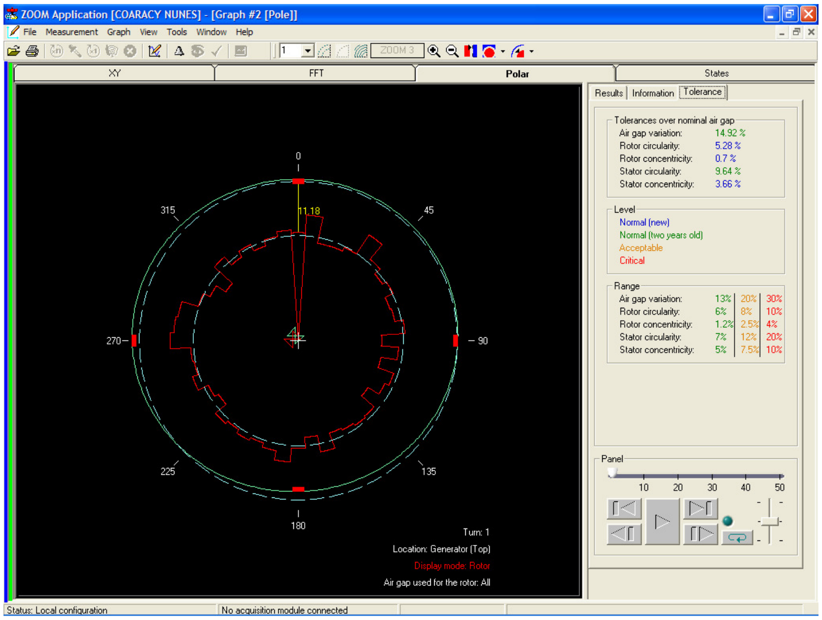

Figure 11. Polar graph at Speed No Load

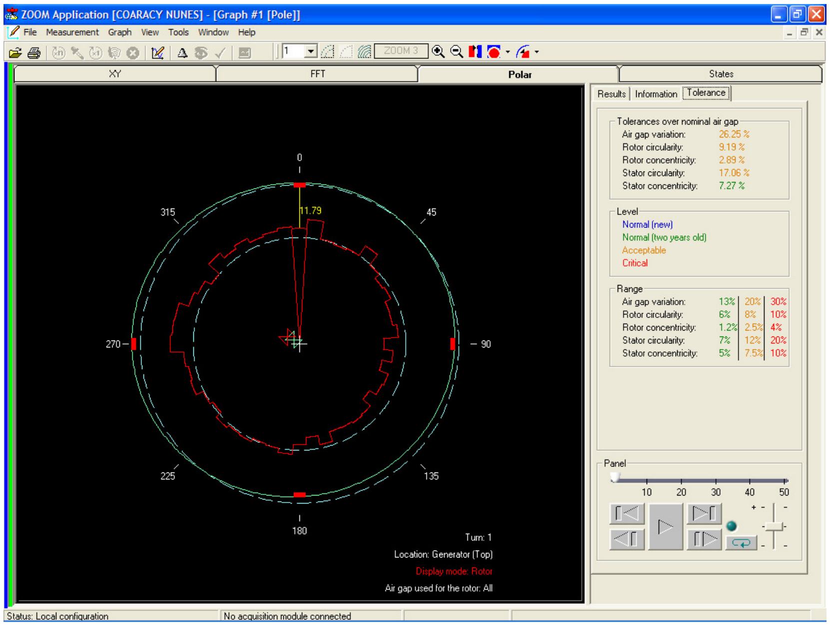

Figure 12. Polar graph at stabilized temperature

8.0 OBSERVATIONS (VIBRATION)

The data recorded during the testing showed that there was a sharp increase in the vibration once the field was applied. We can see this increase on Figure 13. However, the vibration decreases somewhat as the load is increased. It is interesting to note that the analysis software was able to show a particularly interesting phenomenon related to the vibration frequencies at Speed No Load compared to excited, all the way up to Full Load. Figure 14 shows a spectral analysis of the two vibration probes installed above the rotor (at the Kaplan oil head) recording data at the five operating conditions mentioned earlier in this paper. We can see that at Speed No Load, the predominant frequency is located at 1.2 Hz while as the load is increased, the predominant frequency shifts to 2.5 Hz, the actual mechanical fundamental frequency for this Unit.

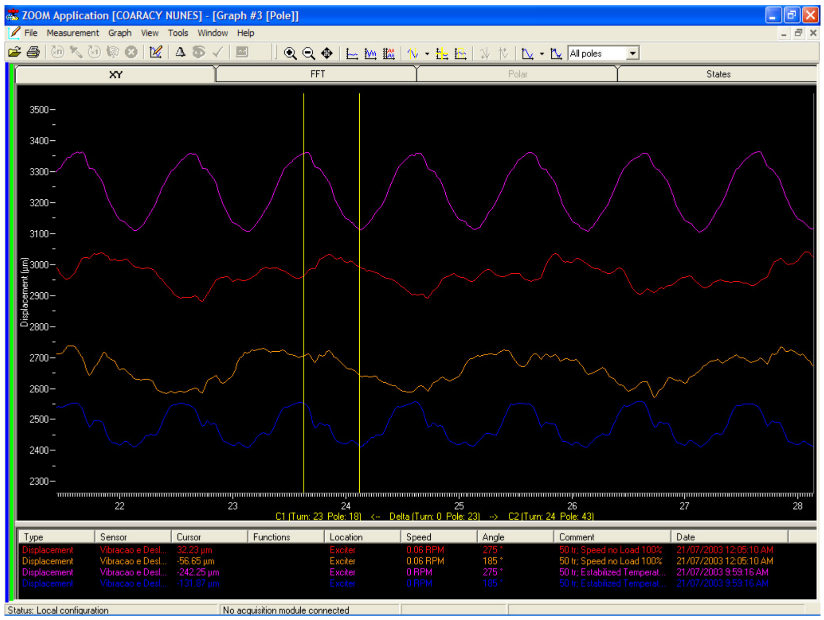

Figure 13. Displacement - SNL @ Full Load

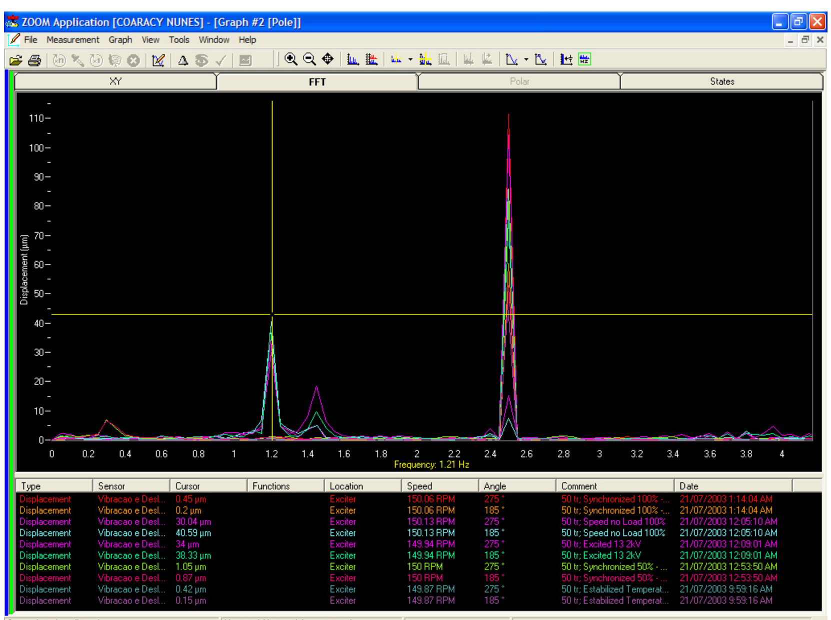

Figure 14. Frequency shift from 1.2 to 2.5 Hz

9.0 CONCLUSION

The ZOOM system was able to provide immediate, clear and precise information as to the behaviour of these generators at both power plants. In the case of the Tucurui II power plant, valuable information in regards to start up behaviour, shaft and stator bar vibration behaviour as well as pressure pulse behaviour was recorded. It was also interesting to show the importance of sensor positioning in order to record behaviour as we saw with the location of shaft vibration sensors at the thrust guide bearing. Finally, the ZOOM system was able to provide baseline information on all parameters, especially air gap data, for future reference in the all important warranty period. In regards to the Coaracy Nunes power plant, we were able to determine that the rotor moved in the downstream direction upon field excitation, while confirming that the rotor maintains a good shape. We were also able to show that the vibration increased upon field excitation but decreased according to load increases. The ZOOM user can then investigate and determine if there is a close relationship between both behaviours and thus implement corrective measures to resolve the problem and ensure the long term health of their investment.

10.0 ACKNOWLEDGEMENT

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11.0 REFERENCES

Standards:

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