AIR GAP MONITORING

KEY ELEMENT TO CORRECTLY

IDENTIFY SOURCE OF SHAFT VIBRATION

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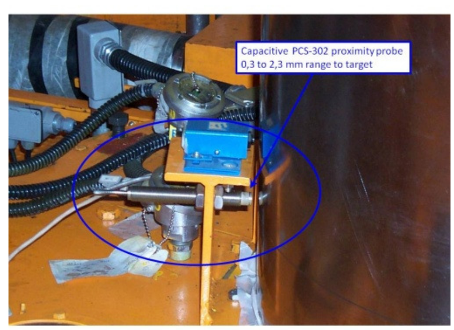
Abstract - This utility decided to install an on-line monitoring system on their 18 MWatts hydro-electric generator, in order to closely monitor the air gap and the relative shaft displacement. The monitoring system was installed to closely evaluate the performance of this newly commissioned hydro-electric generator. Dynamic behaviour tests were performed in order to produce a comprehensive analysis report. Tests were performed while the Unit was under most operating conditions. With the use of the ZOOM© diagnostic software, it was possible to determine the rotor and stator shapes, as well as their relative position. In addition, the relative shaft displacement probes were used to analyse the Unit's vibratory behaviour. This paper will show that this type of correlation between air gap and relative vibration is very valuable to correctly identify the source of specific vibration behaviour. No other tool is capable of providing the necessary information to ensure the safe operation of a generator in regards to generator/vibration interaction. It is also very important to have access to trained personnel when analyzing the data because, more often than not, the observed discrepancies are incorrectly identified and therefore; corrective actions are futile and in some cases counter productive. In many instances, the source of the problem is not always easily detectable and quite often is the result of multiple problems. In this particular case, the monitoring system, more specifically the air gap data, properly identified a vibratory problem as being caused by an unevenly shaped rotor, not an electromagnetic issue, as emphasized by many involved. The solution in this case would have been to improve the rotor circularity, in order to improve the magnetic field created upon excitation. Without the air gap data, the proposed solution would have been to balance the Unit. It is critical to be able to make these assessments during the warranty period so that the OEM can execute corrective actions and therefore; ensure the proper working condition of the Unit for its expected life duration.

I. INTRODUCTION

The air gap monitoring system consisted of four capacitive air gap sensors (VM3.12 type with a range of 2 @ 20 mm) located on the upper plane of the stator at 90º intervals. The vibration monitoring system consisted of capacitive proximity sensors (PCS-302 type with a range of 0,3 @ 2,3 mm) located on the X (90º) and Y (0º) axis at the upper guide, lower guide and turbine guide bearing levels. A key phaser for phase reference was also part of the system. Finally, a wicket gate position parameter was also integrated to the system. The whole system is controlled by comprehensive monitoring software interacting on various computers.

VM3.12 Air gap sensor on stator wall



PCS-302 capacitive proximity probe

II. OBSERVATIONS (VIBRATION)

The monitoring system was commissioned in the summer of 2006, during the commissioning stage of the Unit itself. It is during this commissioning that peculiar vibratory behaviour was observed, creating some concern on the part of the user engineers as this was a newly commissioned Unit. After a few months, a comprehensive analysis was requested by the user and performed by VibroSystM, using the existing monitoring system. Many specific tests were recorded, namely a Start up test, a field flash test and a load rejection test. The behaviour of the Unit was quite satisfactory when the Unit was operating at speed no load condition, without excitation.

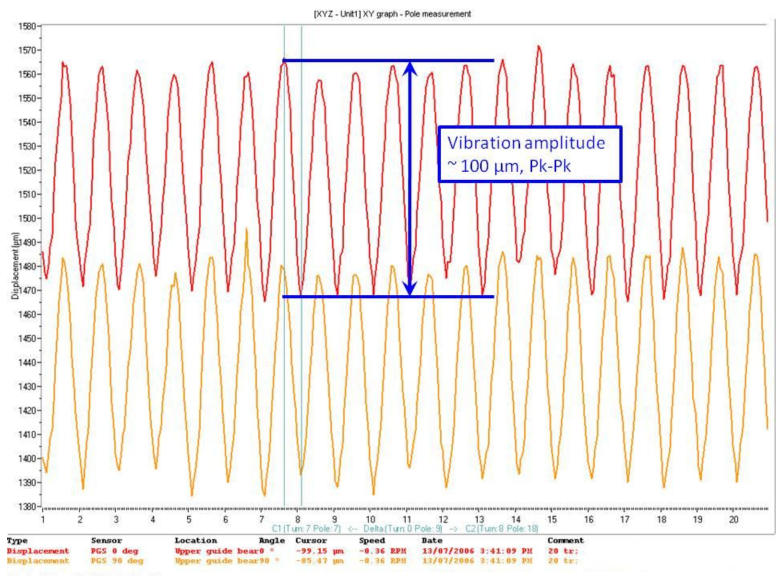


Figure 1. Upper guide bearing vibration at Speed No Load – No excitation.

Amplitude values of ~100 µm, Pk-Pk were quite acceptable, especially for a Unit that is operating at speed no load, without excitation. Typically, this is where hydrogenerators are most erratic basically because of the hydraulic forces exerted on the Unit, without the benefit of electromagnetic forces which usually settle the Unit down somewhat. *Figure 2* of the following page shows the amplitude values at the lower guide bearing under the same operating condition. We can see that the values were quite lower; in the range of ~30 µm, Pk-Pk.

II. OBSERVATIONS (VIBRATION) (Cont'd)

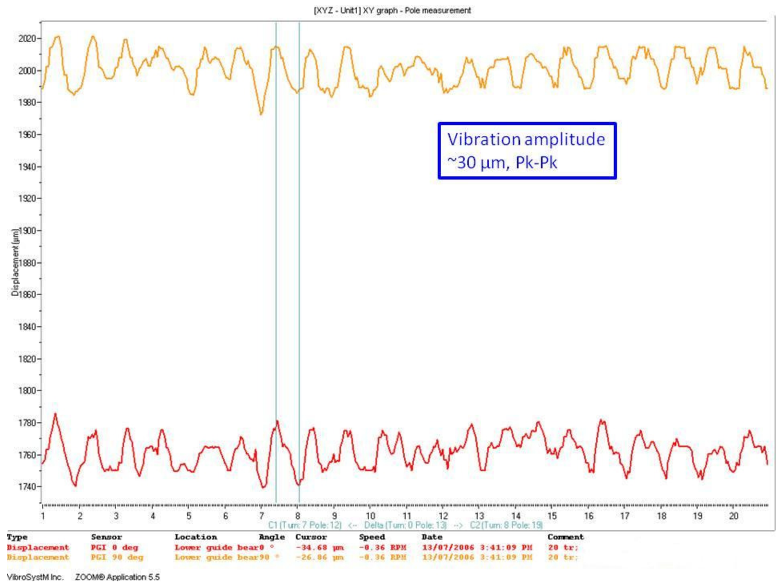


Figure 2. Lower guide bearing vibration at Speed No Load – No excitation.

The following Orbit graph (*Figure 3*) shows quite clearly that under this operating condition, the Unit was quite stable.

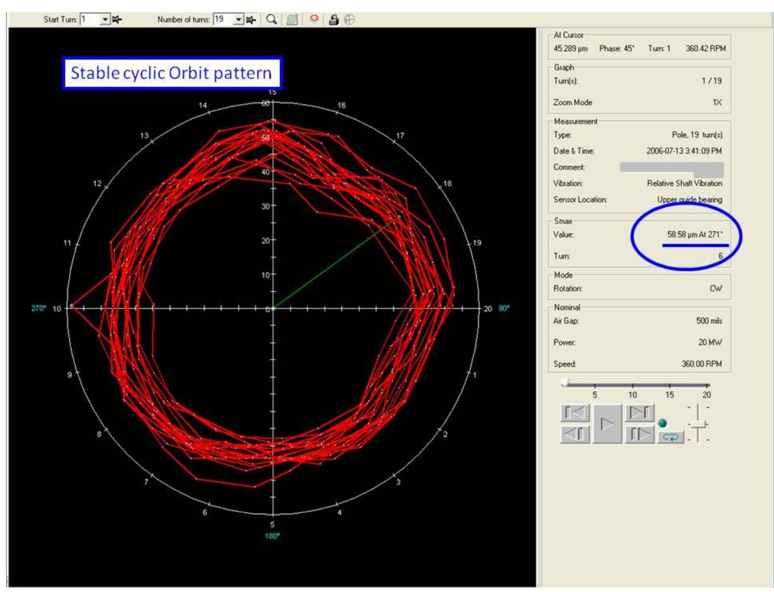


Figure 3. Orbit pattern at Upper guide bearing at Speed No Load – No excitation.

However, when the Unit was subjected to electromagnetic forces, the behaviour changed drastically. We can see in *Figure 4* of the following page that the amplitudes of vibration increase suddenly from ~100 µm, Pk-Pk up to values near 650 µm, Pk-Pk. Evidently, these values are well beyond accepted tolerance levels. Normally, the peak-peak vibration levels

II. OBSERVATIONS (VIBRATION) (Cont'd)

should never exceed 300 µm, Pk-Pk. The vibration levels remained constant under all operating conditions including full load – hot conditions.

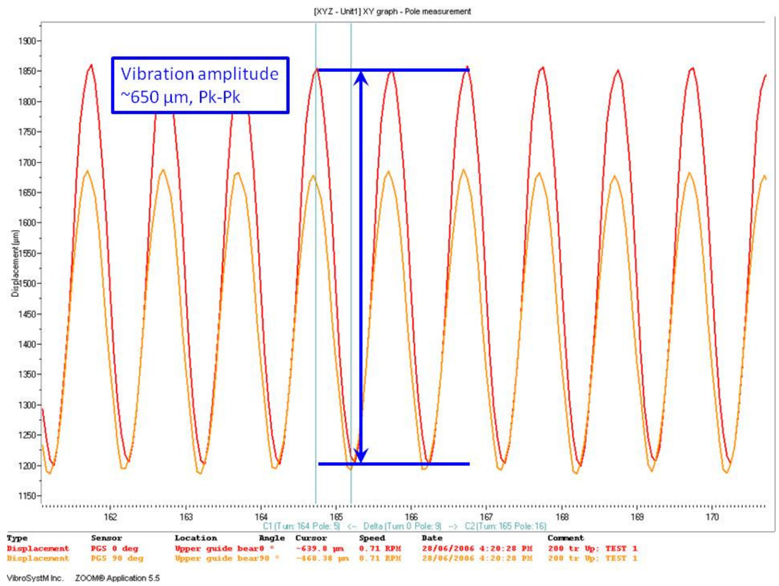


Figure 4. Upper guide bearing vibration at Speed No Load – with excitation.

Figure 5 below clearly shows what happens to the upper guide bearing shaft displacement when the Unit is subjected to the presence of electromagnetic forces.

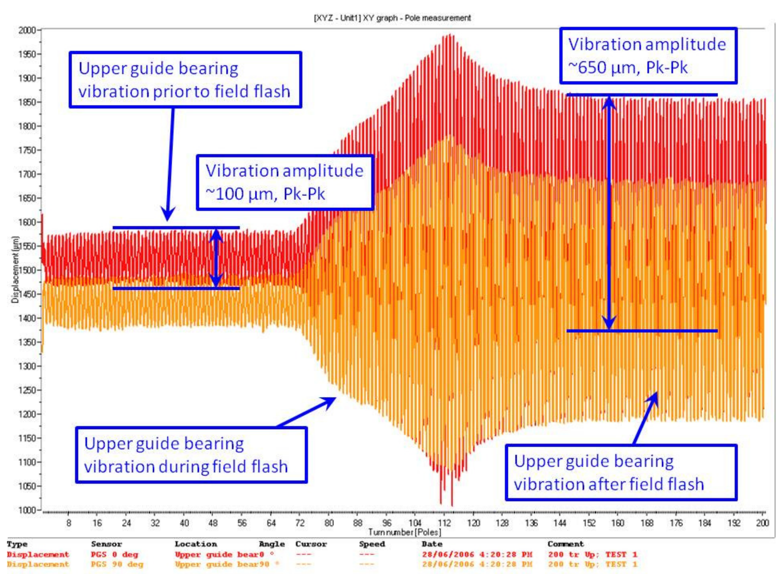


Figure 5. Upper guide bearing vibration before, during and after field flash.

II. OBSERVATIONS (VIBRATION) (Cont'd)

Figure 6 shows a classic representation of the effects on the Unit. The Orbit graph clearly displays the increase in the Orbit pattern at the upper guide bearing as the field is applied. The orbit pattern at the lower guide bearing showed a similar pattern. Although the increase in relative shaft displacement is spectacular, it is still quite stable in that the apparent heavy spot remains at or near pole 16 at all times (275° phase offset). The ZOOM© system software has a unique Orbit feature which allows for a quick and easy identification of the apparent heavy spot

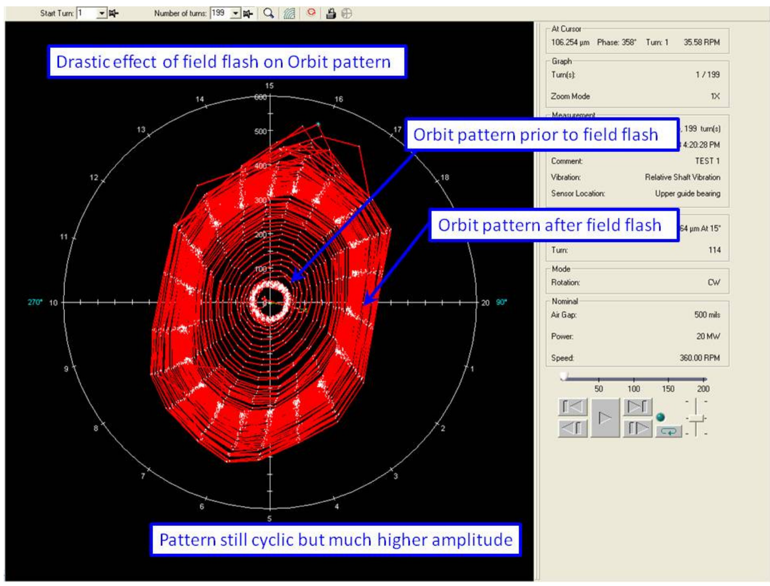


Figure 6. Orbit pattern at Upper guide bearing before and after field flash.

with any measurement with enough data to establish an Orbit graph. VibroSystM's unique measurement strategy, where measurements are pole referenced instead of time referenced,

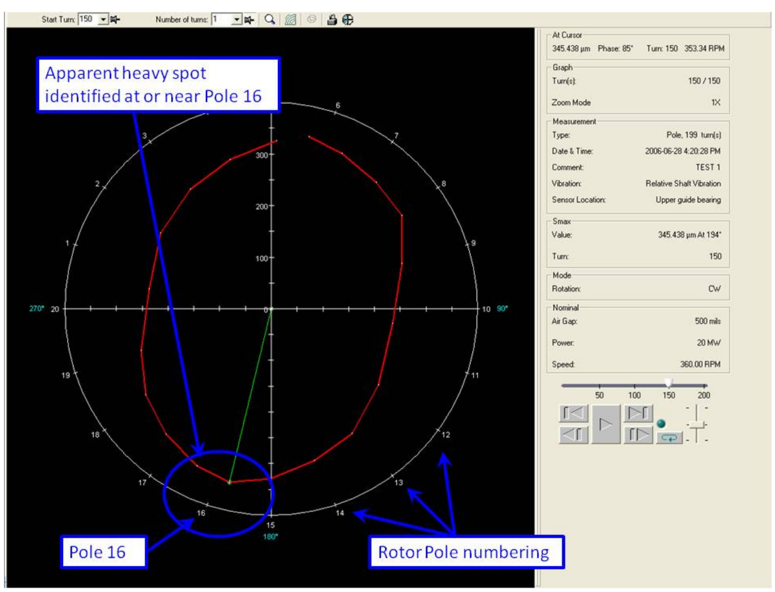


Figure 7. Orbit pattern at Upper guide bearing after field flash.

III. OBSERVATIONS (VIBRATION) (Cont'd)

allows for a quick identification of the apparent heavy spot and thus renders balancing much easier. The following graph (*Figure 7*) shows how the orbit feature clearly identifies the apparent heavy spot location, which in this case is at or near pole 16. The numbers displayed all around the circumference of the Orbit represent the position of the rotor poles when the Orbit center point was recorded.

Many engineers faced with this kind of vibration situation would begin balancing procedures in order to reduce the vibration amplitude levels down to accepted tolerance levels. Based on the information provided by the Orbit feature, engineers would calculate the true heavy spot, based on OEM published data. The correction is usually anywhere from 5° to 25°, depending on many factors such as rotor mass, inertia properties ...etc. With this correction, a compensating weight is added to the rotor in an attempt to reduce the vibration levels. The amount of weight and its location radially depends on the properties of the rotor itself and is particular to each Unit. Usually, a test weight is used, and the results once the Unit is brought back to speed no load – excited condition are compared with the original results to evaluate the success or failure of the attempt. If the unbalance is stable, in that the apparent heavy spot does not change from one rotation to another, usually the balancing is performed in two (2) or three (3) attempts, depending on the final objectives set forth prior to the balancing procedure.

III. OBSERVATIONS (AIR GAP)

However, as mentioned in the Introduction segment of this paper, along with the vibration monitoring system, this customer also installed an air gap monitoring system. Data from these sensors were then analysed in support to the vibration. *Figure 8* on the following page shows the effects of the electromagnet forces on the rotor. A clear increase in rotor shape can be easily observed. All four (4) air gap sensors report the same pattern. However, the rotor shape did not

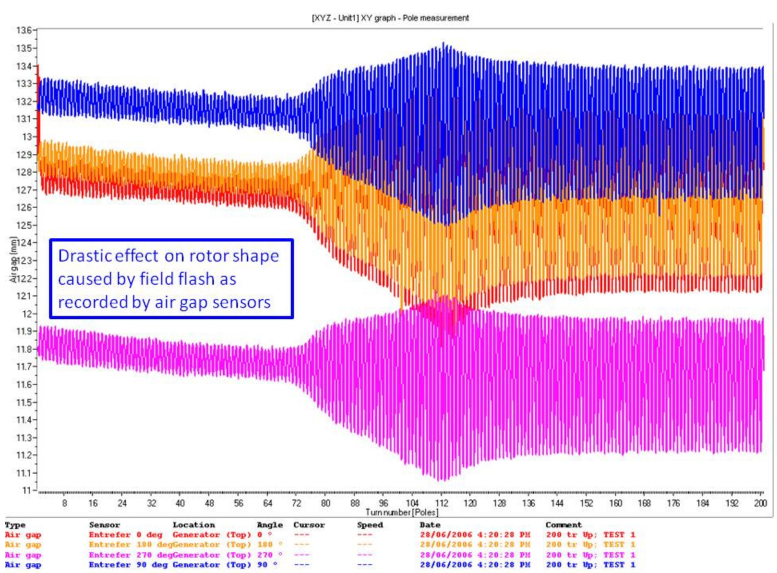


Figure 8. Air gap behavior before and after field flash

III. OBSERVATIONS (AIR GAP) (Cont'd)

increase significantly, as we can see in *Figure 10*. In fact, the increased runout near the rotor, at the upper and lower guide bearings, confirmed by results from these shaft displacement probes are causing significant distortions in the air gap readings. The air gap sensors are mostly recording rotor movement variations instead of pure rotor shape changes. The ZOOM© software has a feature which allows for this excessive runout, as recorded by two (2) displacement probes, to be removed from the air gap results, in fact leaving the user with a clear picture of the actual rotor shape changes. *Figure 9* below compares the air gap variations (rotor shape and position changes) with the upper guide bearing shaft displacement without the runout filter activated. We can see that the patterns are identical.

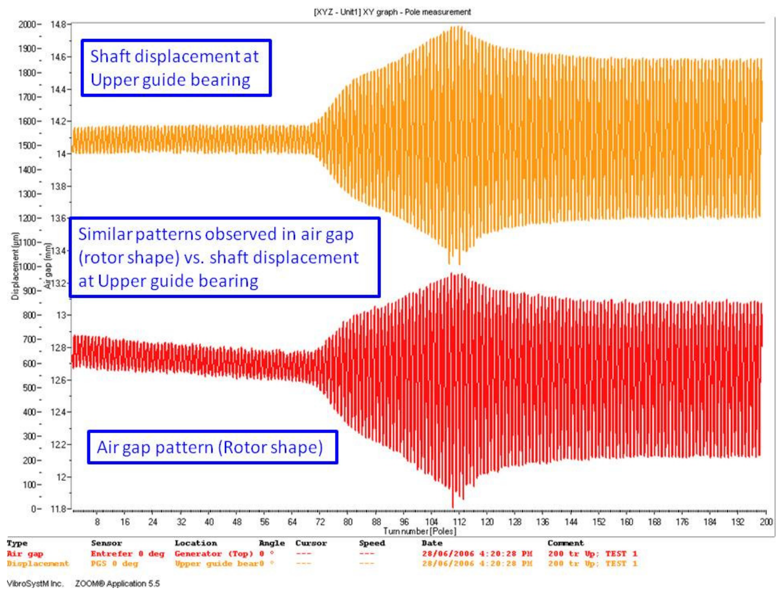


Figure 9. Rotor shape without runout filter applied.

Figure 10 below compares the actual air gap variations (rotor shape and position changes) with the upper guide bearing shaft displacement but with the runout filter activated, leaving the actual results instead of those displayed in *Figure 8*. The increase in rotor shape is common as the rotor rim, dove tails, rim to spider attachments are subjected to the electromagnetic forces therefore; some shape irregularity is usually observed. This situation is normal, so long as the overall rotor circularity (its overall shape performance) and concentricity (its overall position) remains within accepted tolerance levels. Figure 11 of the following page is a representation of the rotor spinning around inside the stator, where we can see that the rotor bump creates an uneven

III. OBSERVATIONS (AIR GAP) (Cont'd)

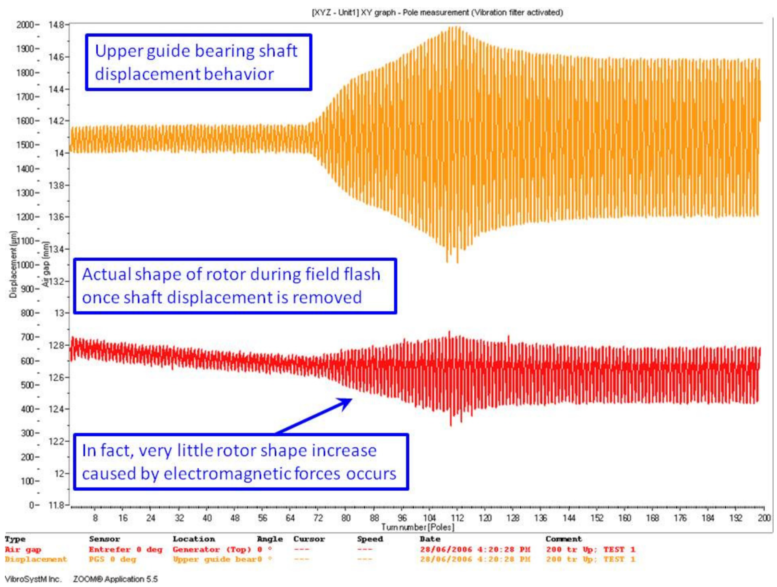


Figure 10. Actual rotor shape with runout filter applied.

magnetic field at various locations as the Unit rotates. This varying magnetic field creates the excessive vibration values and phase, observed by the relative shaft displacement probes.

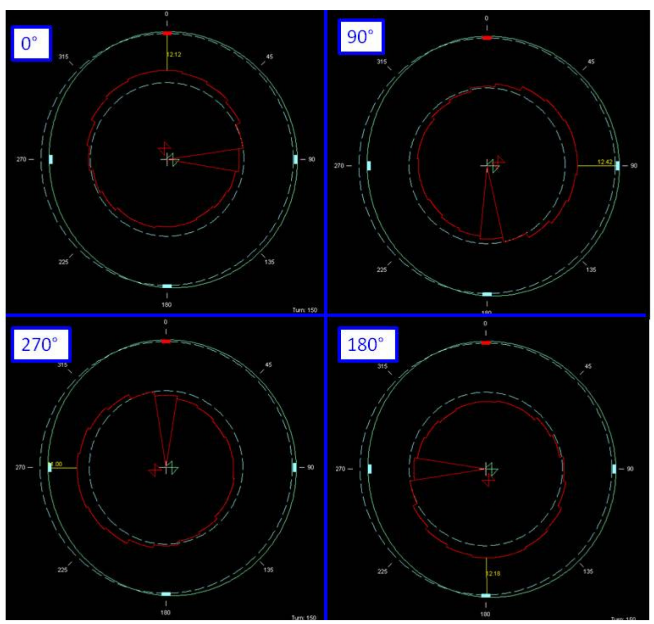


Figure 11. Bump on rotor as it rotates inside the stator.

IV. CONCLUSIONS

Arguments could be made that the solution would be to balance the rotor however; in this case, balancing was not the issue at all. Balancing the rotor would only hide the fact that the rotor shape did not meet acceptance criteria. Clearly the bump located in the general area of pole 16 generated an uneven magnetic field at field flash, creating a magnetic instability thus increasing the upper and lower guide bearing vibration to unacceptable levels. Balancing the Unit would not correct the bump therefore; the uneven magnetic field would still remain, causing short term damage to both the rotor and stator. Rotor wear and tear would occur based on the fact that the area where the bump is located would be subjected to higher than expected electromagnetic forces, creating excessive stress and hot spots on the components of the poles, rim and spider. As for the stator, varying magnetic fields, created by the oscillation of the rotor, would induce stator core vibration at once per revolution cycle, and would eventually cause stator structure fatigue, deterioration of the stator bar insulation, induce stator bar vibration and eventually, stator bar insulation failure.

The availability of information such as was demonstrated in this paper is pivotal if users are to understand machine behaviour and intervene when such behaviour is problematic. It is even more critical when Units are under the warranty period so as to be in a better position to file warranty claims if such issues arise. Not only will the data allow for early detection of problems but allow for better analysis in order to quickly resolve the issues.
