Rotor shape vs. rotor field pole shorted turns

Impact on rotor induced vibrations on hydrogenerators

André Tétreault
Tests & Diagnostics Division
VibroSystM Inc.
Longueuil, Qc, Canada
andre.tetreault@vibrosystm.com

Abstract— **In the past few years, quite a few cases have arisen where shorted turns were detected or suspected on a pole of a hydrogenerator. In many instances, the shorted turns are suspected because of sudden excessive vibrations near the rotor, which are observed when the magnetic field suddenly appears in the air gap. In other instances, scheduled tests during outages, such as voltage drop tests, are performed and results indicate shorted turns on one or many poles.**

Many engineers believe that the presence of shorted turns on hydrogenerators cause excessive vibrations because the shorted turns create a weaker magnetic field at a specific pole when compared to the other poles. Therefore; it is believed that a corresponding vibration at the shaft is induced; which shows up at the upper guide bearing and/or at the combined guide bearing below the rotor. This paper will show that this is not the case, unless the conditions are quite severe, as in a case with an extremely high number of shorted turns, located on many specifically located poles.

We will discuss the causes of vibration emanating from the rotor, from the perspective of rotor magnetic flux as well as rotor mechanical anomalies. We will compare the principle of vibrations induced on non-salient 2-pole machines vs machines with large numbers of salient poles, explaining the confusion between the two concepts and why many believe the same issue exists on hydrogenerators.

Finally, we will explain why rotor shape is a greater contributing factor to rotor induced vibrations than actual rotor shorted turns.

Keywords-component; shorted turns; rotor shape; induced vibrations; hydro-generators

I. Introduction

In the past 25 years, VibroSystM has been involved in countless cases of increased vibration on hydro-electric generators following excitation of the rotor poles. In recent years, many such cases have occurred where the issue of rotor pole shorted turns was brought up. In fact, many power plant engineers presume that increased vibration levels reported at or near the rotor, once the excitation is on, is caused by shorted turns on rotor poles. In reality, our experience has shown that this particular issue is usually brought on by other causes; such as rotor shape distortions, rotor rim movements and/or stator shape distortions.

II. Observations

Case in point, example 1 is typical of an irregularly shaped rotor causing elevated vibration levels when the magnetic forces are introduced in the air gap. Fig. 1 below represents the raw vibration (X & Y, 90° apart) recorded at the upper guide bearing of this vertical hydro-generator before and after the excitation event. We can clearly see the dramatic increase in vibration recorded by both probes. Usually, when the magnetic forces appear in the air gap, the vibration levels decrease as the forces act as a stabilizing force.

Fig. 2 shows the Orbit graph of the same event and the apparent heavy spot is clearly identified as being at or near pole 16. It is quite common to see personnel begin balancing procedures when facing such a situation.

However, close scrutiny of the air gap data indicated that the increased vibration was caused by a bump on the rotor, located in the general area of pole 16 (as shown in Fig. 3), causing a cyclic oscillation whereas the protruding portion of the rotor was being dragged around the stator at each rotation. Therefore; balancing the rotor would not resolve the issue and in fact, would surely deteriorate the situation. The correct intervention in this case would be to re-shrink the rotor rim to significantly improve the rotor shape and stiffness.

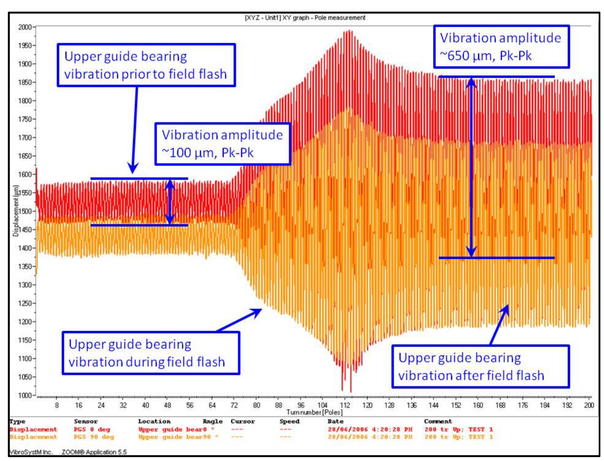


Fig. 1. Upper guide bearing vibration during field flash event.

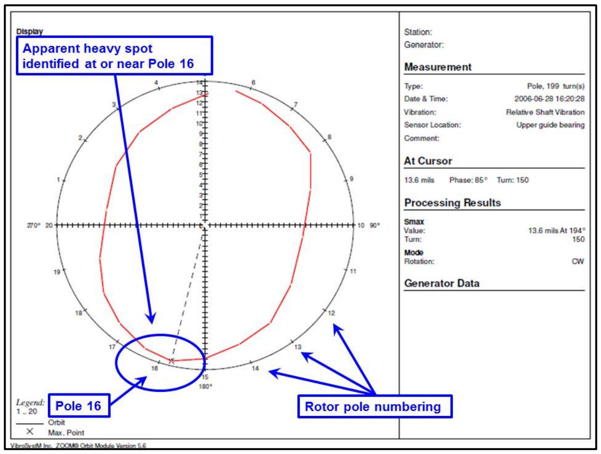


Fig. 2. Orbit pattern at upper guide bearing after field flash event.

The second example shows how little effect small numbers of shorted turns have, not only on the overall intensity of the magnetic flux, but also on the vibration levels at or near the rotor. Fig. 4 is a representation of an air gap signal vs. a magnetic flux intensity signal at the same location. As expected, the air gap and magnetic flux signals are inversely proportional in that the smaller the air gap, the higher the intensity of the magnetic field, with a small variation caused by each poles capacity to produce the expected magnetic field intensity. Fig. 4 in this case indicates pole 16, which was reported to have two shorted turns out of a total of 23, following a voltage drop test. This represents 8.7% of the total number of turns however; we can see that the corresponding flux is not significantly affected by this problem. Data recorded three years before the shorted turns were detected, showed no significant variation in flux density and in fact, the actual vibration levels were less than 50 µm, pk-pk with the shorted turns.

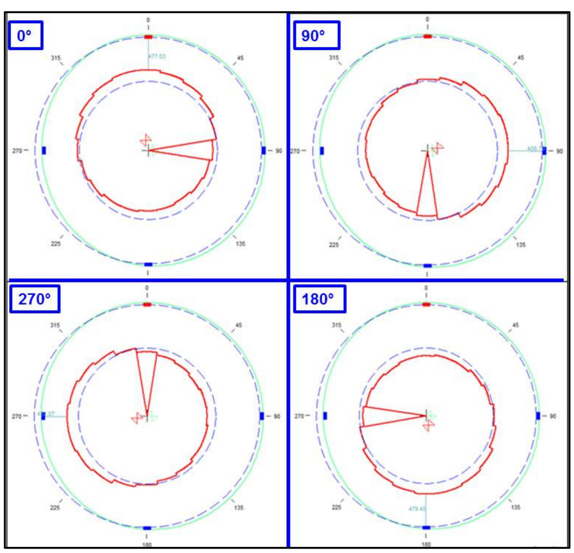


Fig. 3. Bump on rotor as it rotates inside the stator.

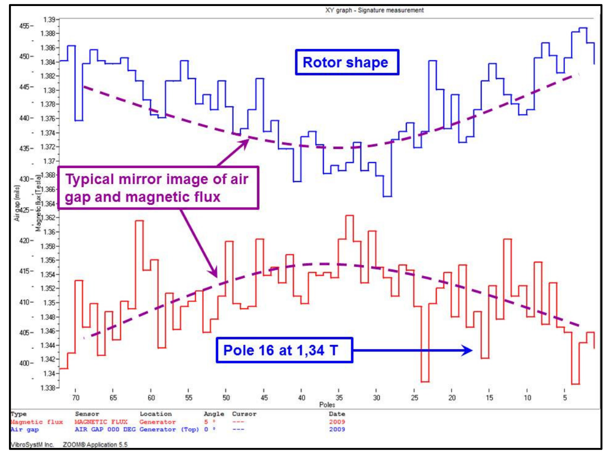


Fig. 4. Air gap vs. magnetic flux.

Therefore; it is reasonable to say that the presence of shorted turns did not have any impact on the vibration levels. Fig. 5 below contains the results for the same generator but 3 years prior to the detection of the shorted turns on pole 16. We can see that no magnetic flux intensity variation is noticeable.

Fig. 6 represents the clear relationship between the air gap found in one location of the generator and the magnetic flux intensity. We can clearly see how an out of round rotor (significant air gap variation) produces a corresponding varying magnetic flux signal. This variation easily produces increased vibration levels that can be recorded not only on the shaft, but also on the stator bars and core. Excessive electro-magnetic force variations on the stator bars will wear down the insulation prematurely and eventually will cause insulation failure. In addition, excessive variations in the forces exerted on the stator core can easily lead to stator core and frame structural problems such as wear of insulation between core laminations due to increase of the vibration levels overall.

Fig. 7 represents the distribution of electro-magnetic forces in the air gap of the aforementioned generator which had one pole (Pole 16) that had the two reported shorted turns.

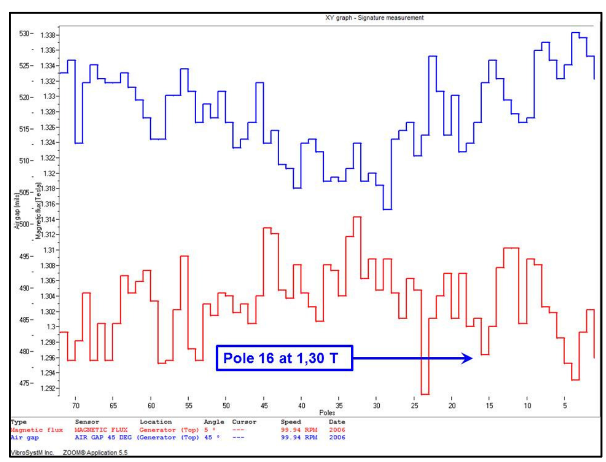


Fig. 5. Air gap vs. magnetic flux 3 years prior to detected shorted turns.

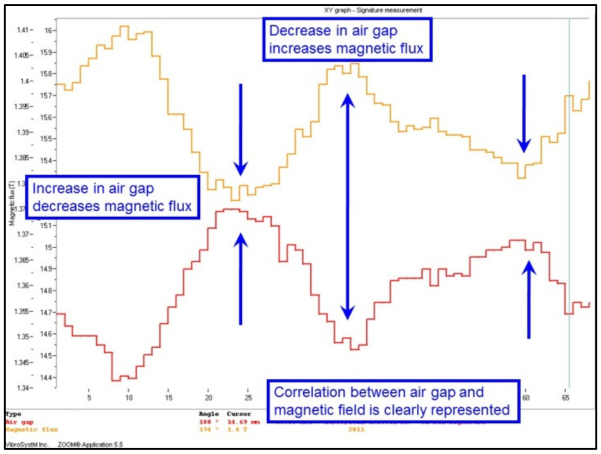


Fig. 6. Correlation between air gap and magnetic flux.

We can see that, even if this particular pole received less current (ampere-turns), it produced little less electro-magnetic forces than it would have if all its coils had been intact. Even some of its counterparts, spread all around the rotor, produce less electro-magnetic forces due to structural differences. The resulting sum of all the forces involved would show that the relationship between compensated forces and non-compensated forces is negligible.

Finally, in many cases, a notable reduction in excitation current produces very little, if any, reduction in magnetic flux density. The actual magnetic flux level does not increase past its saturation point therefore; any additional excitation current does not produce more magnetic flux. When operating beyond the saturation point, when a notable reduction of excitation current is applied, the level of excitation current is sufficient to produce a level of magnetic flux that is still close to the point of saturation. Therefore; no significant variation in the magnetic field intensity in the air gap occurs. The same phenomenon is true with regards to the presence of a small number of shorted turns in that the remaining turns are still able to produce the required magnetic flux intensity beyond the saturation point.

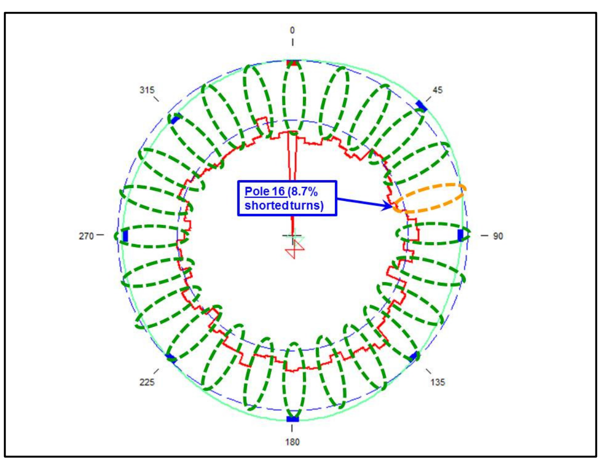
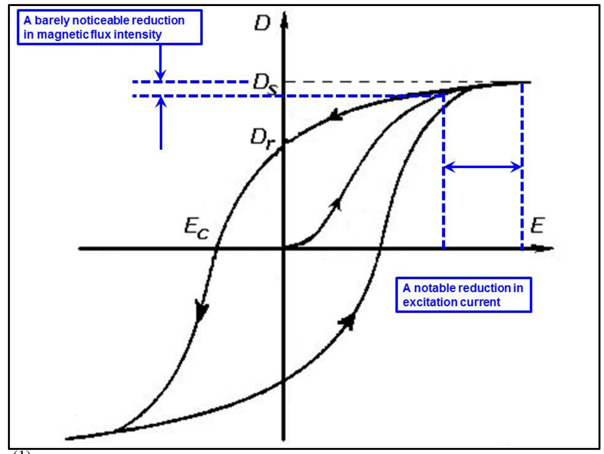


Fig. 7. Distribution of magnetic forces in the air gap.



(1) Fig. 8. Hysteresis loop (excitation current vs. magnetic flux intensity).

Fig. 8 above demonstrates the principle of the remanence properties of ferroelectric material. This property causes the total magnetic field intensity to remain high even after a certain reduction of excitation current occurs. In short, not only does a small decrease in magnetic flux intensity on one pole vs. a large number of poles (which is usually the case for large hydro-electric generators) produces very little variation in forces exerted on the rotor, a small amount of shorted turns will not even cause a decrease in the total amount of flux generated by the suspect pole.

III. VSM EXPERIENCE

It is a common belief in the industry that shorted turns create a magnetic unbalance in the air gap thus causing elevated vibration levels. However, our experience has shown that for this to be true, one of the two following conditions must be present.

Firstly, the total number of rotor poles needs to be quite low. For example, high speed vertical generators commonly have 10 to 16 poles (360 to 720 RPM). Shorted turns on these machines can create uncompensated magnetic forces which can increase vibration levels to some extent.

Secondly, the number of shorted turns must be significant. Otherwise, no variation in magnetic flux, or very little, will occur thus; the vibration levels will not be significantly affected.

The notion that shorted turns are the cause of increased vibration is often based on experiences on large turbo-generators. But their rotor designs are very different. It is true that shorted turns on these types of rotors do cause, in many cases, increases in a relative shaft vibration but for a very different reason. This situation causes variations in rotor temperature, where localized heating spots on the rotor create a thermal sensitivity reaction, causing the rotor to bend somewhat. The "rotor bowing" is the actual source of the increased vibration, not the variation in magnetic flux itself. Evidently, this is only true if the shorted turns are limited to a small number. Whether shorted turns are present or not can be determined using a stray flux monitoring system, as the shorted turns do show up on the signal patterns. In the past, before stray flux technology was available, the phenomenon was usually detected as increased shaft vibration levels when the excitation current was increased, or issues with the generators capacity to produce Vars.

This thermal sensitivity does not really apply to hydro-electric generators seeing that localized hot spots on one or more rotor poles, out of a large number of poles, is not relevant. Although poles with shorted turns do need to be repaired to prevent a deterioration, and eventually a more severe problem, they usually do not have an impact on rotor induced shaft vibration.

IV. CONCLUSION

The inspiration for this paper was the repeated cases where vibration increases were observed and actions undertaken to identify suspect poles (usually through voltage drop tests) and if present, to perform repairs on the defective poles. However, in most cases, the high vibration levels remained after the repairs. Further investigation showed that the generator suffered from abnormally shaped rotors/stators or rotor rim looseness due to the loss of rim original stiffness. Although magnetic flux monitoring technology is very useful to detect these anomalies (variations in magnetic flux intensity), monitoring of the air gap, correlated with the magnetic flux, correctly identifies the cause of the increase in vibration by clearly presenting the rotor/stator dynamics under all operating conditions, or eliminates the rotor/stator components as being part of the problem. In short, the combined use of air gap, magnetic flux intensity and of course, shaft vibration monitoring technology allows for the plant personnel to properly identify or eliminate the sources for this commonly found problem on large vertical hydro-electric generators.

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REFERENCES

(1) Graph courtesy of Wikipedia (www.wikipedia.org)