Correlations between Magnetic and Vibration Measurements on Hydro Generators

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Abstract: - An effective magnetic method of detecting rotor winding shorted-turns, broken damper bars and magnetic imbalance of hydro generators is described. Testing of generators vibration state was also performed. Magnetic and vibration measurements were done simultaneously, in order to find a correlation between the given measurements. This correlation will provide valuable information for understanding the causes of high measured vibration values.

Key-Words: - Magnetic monitoring, hydro generator, vibration, shorted-turns, magnetic imbalance.

1 Introduction

Magnetic monitoring is ON-LINE monitoring that involves measuring the magnetic flux in the air gap in hydro generators in order to determine if field winding shorts in the rotor poles, broken damper bars or magnetic imbalance have occurred.
In hydro generators, magnetic flux across each pole depends on the MW and MVAR loading of the machine. Any change in the magnetic flux within a pole at a given load must be due to shorted turns, magnetic imbalance or broken damper bars. If any of these faults occurs, bearing vibration level will increase. For this magnetic measurements, the National Instruments USB 6212 multifunction data acquisition module and LabVIEW application was used.
Testing of generators vibration state was performed using Brüel & Kjær PULSE system. Digital signal processing and data logging were done in time and frequency domain. The recorded waveform data was then analyzed.

2 Flux and Vibration Monitoring System for Hydro Generators

The basic elements that are part of flux monitoring system (Fig. 1) are flux probes, amplifiers, filters, acquisition system, PC and programs for signal processing and data logging.
Six air gap probes are permanently mounted to the stator tooth surface to determine if magnetic imbalance and turn-to-turn shorts have occurred.

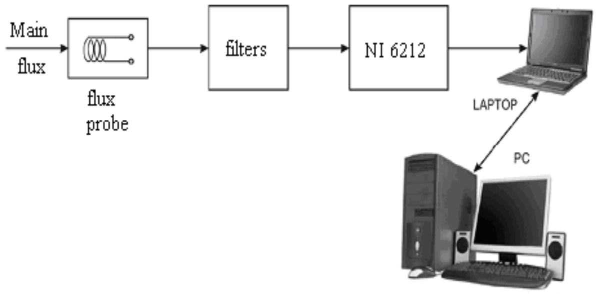

Fig.1 Flux monitoring system

Inductive sensors are placed evenly (every 60 degrees of scale, Fig. 2), where the first, third and fifth sensor are placed at the top of the stator and the second, fourth and sixth are at the bottom of the stator.

Fig.2 Detail of installed flux probes

As shown in figure 3a, testing of generators vibration state was performed using Brüel & Kjær PULSE system (30 channels). Software package that is used is PULSE Balancing Consultant 7790. Balancing is carried out in accordance with standard ISO 1940-1 and 2. Figure 3b shows flux monitoring system.

(a)

(b)

Fig. 3 Monitoring system a) vibration monitoring b) magnetic monitoring

3 Magnetic Measurements

During machine operation, the rotor flux from each pole will induce a current in the flux probe, since the rotor is moving past the flux probe. As each pole in the rotor passes, there will be a peak in the induced current caused by the magnetic flux of the pole. The peaks in the current can then be recorded and each peak of the waveform represents the "average" flux across one rotor pole. Shorted turns in a pole reduce the effective ampere turns of that pole and thus the peaks associated with that pole [1]. The recorded waveform data can then be analyzed to locate the poles containing the fault or to determine if magnetic imbalance has occurred. Presence of broken damper bars in the rotor also changes the air-gap flux.

3.1 Results of Magnetic Measurements

Data were taken under different load conditions ranging from no load to full load. Magnetic flux is proportional to induced voltage. Inductive sensors measure the electromotive force (1):

$$e = -N\frac{d\phi}{dt} \qquad (1)$$

Where e is the induced voltage, N is the number of turns and $\frac{d\phi}{dt}$ is the change in flux linking the coil. Figure 4 shows the change in signal characteristics vs. load condition (Fig. 4a - 0MW, 3VAR and Fig. 4b - 40MW, 17MVAR). Two adjacent poles with the change in flux (red color, normalized) and the total flux (white color) are shown. 40MW is full load for this machine.

The magnitude of flux density in air gap can be defined as [2]:

$$B(x) = \frac{\Delta bo}{\Delta b(x)}\mu_o\frac{Um,\delta}{\delta_o} \qquad (2)$$

where the δ_o is minimum air gap, μ_o is permeability of vacuum, Um,δ is magnetic potential in air gap, Δbo is predefined width on stator in front of pole and $\frac{\Delta bo}{\Delta b(x)}$ is relation that defines the impact of air-gap to changes of flux density. If we define width Δbo, in front of pole (air–gap is constant), where magnetic flux has some value, then we can define width $\Delta b(x)$ in part where air-gap is not constant so that flux value is the same as in case of Δbo.

Fig. 4a shows that air-gap flux is homogeneous in the middle of the pole ($\frac{\Delta bo}{\Delta b(x)} \approx 1$). The change in flux is symmetrical from pole to pole. Fig. 4b shows that when there is armature reaction (air-gap flux component caused by the armature current), air-gap flux is no longer uniformly distributed under the poles. The peak magnitude of the change in flux and the total flux varies little.

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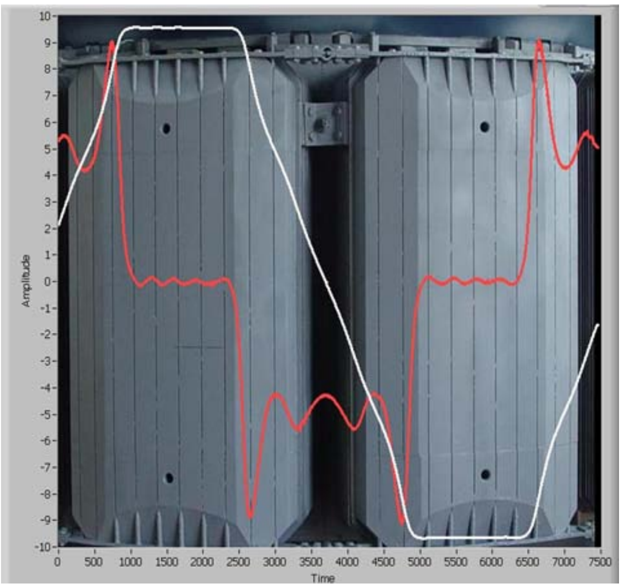
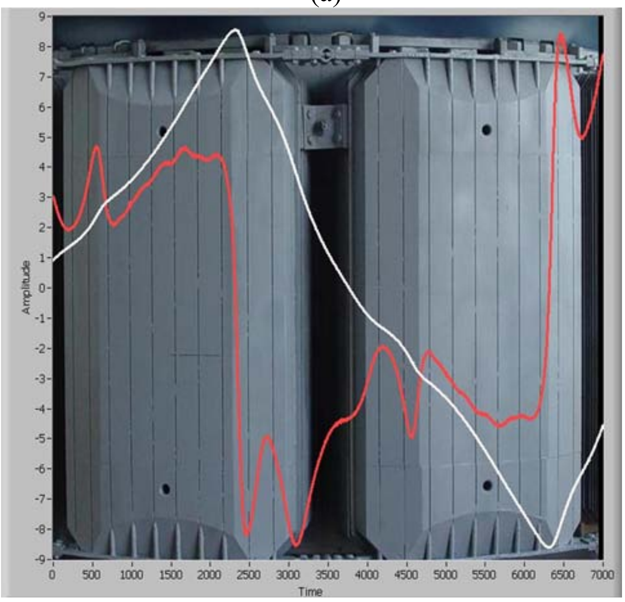


(a)



(b)

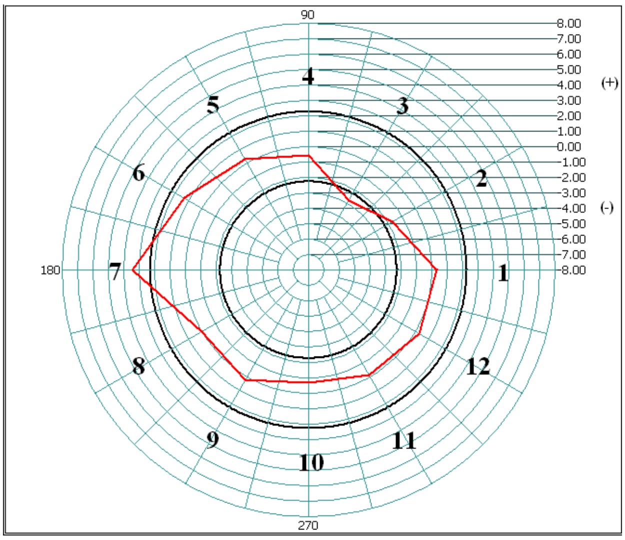
Fig. 4 Flux change (red color, normalized) and total flux (white color) a) 0MW, 3VAR b) 40MW, 17MVAR

3.2 Analysis of the Results of Magnetic Measurements

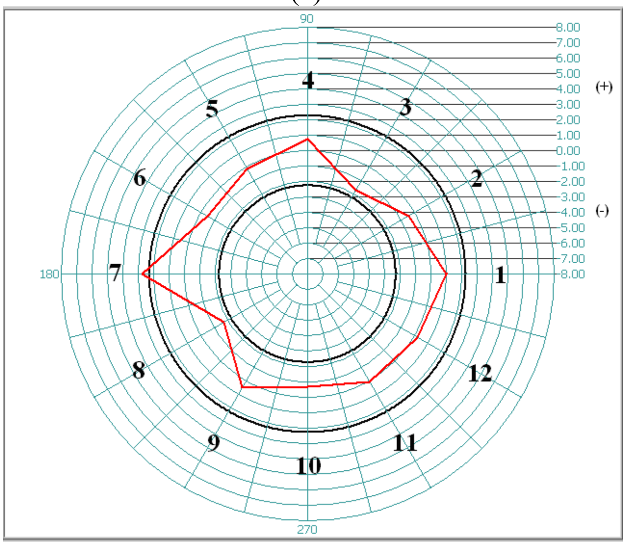
Algorithm to be used is to plot the peak integrated signal (total flux) for each pole compared with the value of the average of all the poles (Fig. 5a) and to the average of the two adjacent poles (Fig 5b) [3]. Figure 5a shows magnetic imbalance, which is not critical. This was confirmed by testing of generators vibration state.

Variations in flux (Fig. 5a) may be due to changes in gap due to an out of round rotor due to poles mounting on the rotor [4]. We can consider that in all cases of load condition the natural variation in comparison of pole to average of adjacent poles or to average of all the poles is 2.2 % or less.

The total flux is proportional to the number of turns of the pole and if one turn is short then the total flux would decrease by 1/number of turns. In our case the total flux would decrease 2.2 % (compared to the average of two adjacent poles) if there is one short turn. Figure 5b shows that there were no pole shorts in this case. Pole 7 had total flux that is little higher than the value of the average of the two adjacent poles. There are 12 poles on the rotor. The higher load and more positive VARS are most sensitive to shorted turns.



(a)



(b)

Fig.5 Radial plot of difference in peak integrated signal (40MW, 17MVAR) a) average of all the poles b) average of the two adjacent poles

Numerical data from Fig. 5 are shown in Table 1. Presence of broken damper bar will amplify the flux probe signal considerably [5].

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Pole	Algorithm 1	Algorithm 2
1	0.281	1.004
2	-1.685	-0.426
3	**-2.809**	-1.719
4	-0.534	0.746
5	0.267	-0.132
6	1.334	-0.502
7	**3.425**	**2.726**
8	0.026	-1.753
9	0.199	0.526
10	-0.677	-0.712
11	-0.127	0.061
12	0.299	0.248

Table 1 Numerical data (in %) showing results of magnetic measurements

4 Testing of Generators Vibration State

Testing of generators vibration state includes testing of upper and lower generator guide bearings, and a turbine guide bearing in different measurement directions [6].

Magnetic imbalance changes vibration signals in cases of no load – not excited (Fig. 6) / excited generator (Fig. 7). Fig. 6 and fig. 7 show two different measurement directions (MM10 and MM11), which are 90 degrees apart. Component of interest is $A_{o-peak}(f_o)$, where

$$f_o = n/60 = 500/60 = 8.33Hz \qquad (3)$$

It is obvious that the magnetic imbalance was detected. Vibration amplitudes and magnetic imbalance usually increased with higher loads (Fig. 8). Vibrations that are recorded in case of no load (not excited generator) are indicators of the presence of mechanical imbalance [7]. Measured vibration values were not too high and their correcting wasn't necessary.

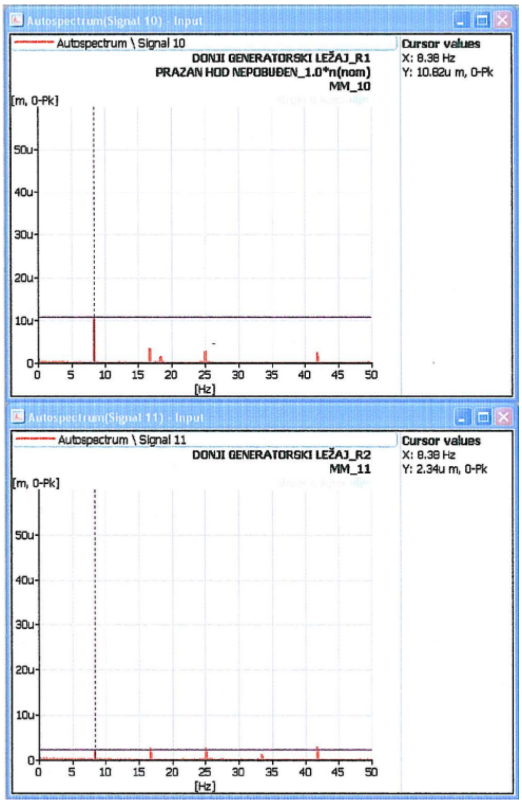

Fig. 6 Absolute bearing vibration / lower generator guide bearing / no load – not excited / frequency domain

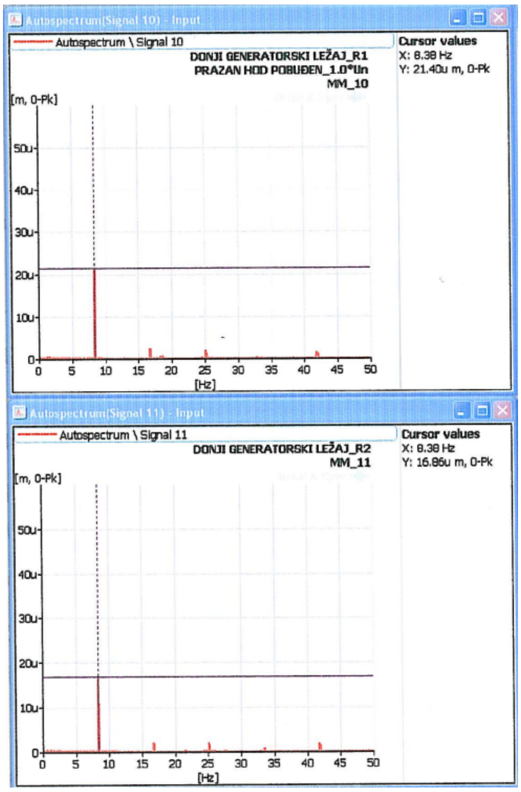

Fig. 7 Absolute bearing vibration / lower generator guide bearing / no load – excited / frequency domain

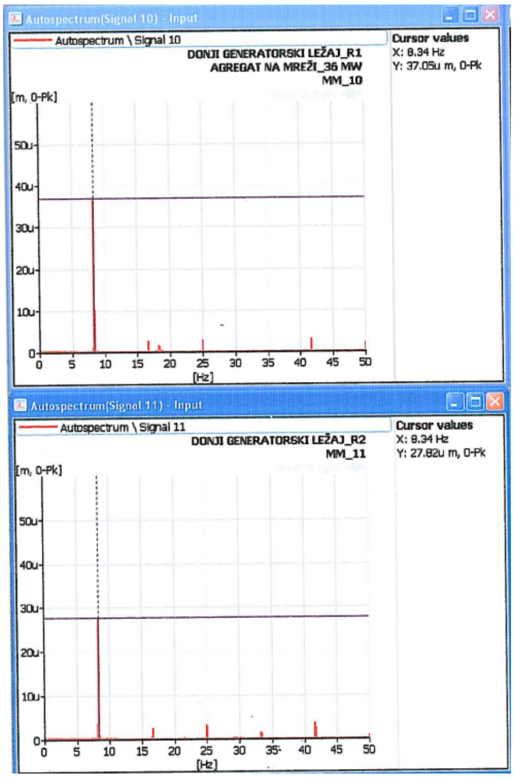

Fig. 8 Absolute bearing vibration / lower generator guide bearing / 36 MW / frequency domain

5 Conclusion

In this paper, special attention was given to detection of rotor winding shorted-turns, broken damper bars and magnetic imbalance. Magnetic and vibration measurements were done simultaneously. Results from all six sensors were similar.

There were no shorted turns and broken damper bars found on the rotor poles. Presence of magnetic imbalance, that is not critical, was detected. This is confirmed by testing of generators vibration state. Measured vibration values were not too high. Correlations between the given measurements are extremely important. Using magnetic measurements it is possible to detect the causes (changes in air gap, physical differences in the poles…) ,of the magnetic imbalance. Periodic magnetic monitoring (once or twice per year) is recommended to catch any changes in the rotor winding insulation condition and rotor balance.

References:

[1] Greg C. Stone, Edward A. Boutler, Ian Culbert, Hussein Dhirani, *Electrical Insulation for Rotating Machines*, IEEE Press Series on Power Engineering, 2004.

[2] A.E.Fitzgerald, Charles Kingsley, Jr., Stephen D. Umans, *Electric Machinery*, McGraw-Hill, Boston, 2003.

[3] N. Kartalovic, B. Babic, *Magnetic Monitoring of Generators in EPS*, Collected papers, Electrotechnical Institute "Nikola Tesla", 2011, Volume 21, pp. 247-267

[4] B. Babic, N. Kartalovic, *Magnetic Monitoring of Hydro Generators in Hydro-Plant Pirot*, CIGRE 2013 Conference Proceedings.

[5] H.C.Karmaker, *Broken Damper Bar Detection Studies Using Flux Probe Measurements and Time-Stepping Finite Element Analysis For Salient-Pole Synchronous Machines*, Power Electronics and Drives, 2003, SDEMPED 2003, 4th IEEE International Symposium on Diagnostics for Electric Machines

[6] J.Pirhonen, T. Jokinen, V. Hrabovcova, *Design of Rotating Electrical Machines*, UK, 2008

[7] P.Tavner, L. Ran, J. Penman, *Condition Monitoring of Rotating Electrical Machines*, The Institution of Engineering and Technology, London, 2008

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