

VIBRATION MONITORING OF POWER GENERATION SYSTEMS, USING BUILT-IN MATLAB FUNCTIONS FOR DATA ANALYSIS

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Abstract. The objective of the paper was to enhance the theoretical analysis of vibration data by using contemporary programming tools and to investigate different methods of using built-in MATLAB functions in the National Instruments (NI) LabVIEW system design software. The data for analysis were obtained from vibrating systems under dynamic loading, and the MATLAB code was developed specifically for hydropower turbine vibration monitoring activities. The dynamic cyclic load conditions analyzed in the given paper were observed on a hydropower turbine resulting from the generator drive, hydraulic pressure and shock. Various data sets available for the analysis were experimentally obtained from the dynamically loaded object using the vibration monitoring system and specific rotor air gap measuring system. The given paper consists of description of the observed mechanical model and vibration equations included in the analysis of dynamic behavior of the hydropower turbine and subsections, aimed to integrate the MATLAB code into the existing monitoring system and compare the analysis accomplished thereof with the harmonics analysis obtained from LabVIEW without using the particular code.

Keywords: vibration, hydropower, hydro generator.

Introduction

The programming goal discussed in the paper was to establish the framework for power quality assessment of a hydropower generator. The suggested framework states that electric power quality is affected by mechanical faults of the power generator like rotor air gap eccentricity, rotor and stator vibration characteristics and unbalance [1; 2]. The power quality was analyzed based on harmonic components of every generator pole.

The air gap of the rotor should be evaluated at least once in 5 years, as well as before and after reconstruction of hydropower generation units [3; 4]. Evaluating the air gap and rotor form helps perform proper balancing of the unit and eliminate vibration [2].

The papers and projects addressing similar problems suggest different methods to integrate LabVIEW and MATLAB programs, for example, Mathscript tool, FPGA controllers etc. [5-11].

Materials and methods

To meet the objective of the study a set of measurements was performed on the hydropower generating unit with the following main instrumentation - power analyzer for three-phase electrical networks, laser tachometer kit, vibration measurement equipment, air gap measuring system. The data, acquired from the experiments, were analyzed through LabVIEW, MATLAB programming tools and Microsoft Office Excel.

LabVIEW interface has been designed to visualize data. The available data were analyzed and stored both in .lvm and.xls format. The ActiveX technology integrated in LabVIEW allowed to take the data in .xls files and to store them in devoted structures (array and cluster).

To evaluate both, centrifugal and electromagnetic forces effects on the air gap and rotor form, the measurements were performed in different idle and loaded work conditions (modes). Ten minutes long measurement was taken at idle mode with the load 13.8 kV and nominal rotational speed, 2,5 hours at nominal load. After the stator reached its normal operating temperature, measurements at reactive power at 0 MVar were taken and measurements of active power (10 MW, 45 MW, 90 MW) followed. The duration of each measurement was ten minutes. Then five minutes long measurements with active power 90 MW and following reactive power of +20, -10, -20, -30, -40, -50, -60, -70 MVar were performed. Finally, measurements at Synchronous Compensation with loads +20, 0, -10, -20, -30, -40, -50, -60, -70 MVar were performed.

The quantitative values of the air gap for the rotor were collected for the diagram of the rotor form, which were calculated as follows [3]:

$$\Delta_{rot.} = \frac{A_{rot.max} - \delta_{rot.avg}}{\delta_{rot.avg}} \cdot 100 \%, \tag{1}$$

where $A_{rot.max}$ – maximum value of measured air gap;
 $\delta_{rot.avg}$ – average value of all air gap measurements.

To evaluate the rotor air gap deviation statistically mean values of the obtained data set and standard deviation formula were used. For vibration data the root mean square (RMS, quadratic mean) values were used as common statistical measure of the varying vibration magnitude.

The MatLAB program code was developed to reduce the time for future investigation calculations. Please, refer to Figure 1 for the code example. The ready-to-use code also simplifies future data analysis and allows accomplishing graphical representation of data faster [12].

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1 %Example of code for generator vibration calculation
2 w=100; %frequency,Hz
3 v=2*w; %double value of the current, vibration of main wawe;
4 m1=0.4; %kg, example of mass for 1 cm^2 of stator cylindrical surface
13 B=0.87; %Tl, induction
14 lambda1=(12*R1^4/(1.2*H))*(10^7*2^2+1/(2*(2^2-1)));
15 lambda2=(12*R2^4/(1.2*H))*(10^7*2^2+1/(2*(2^2-1)));
16 z1=r*4*(10^-3)-1/(r*lambda1);
17 z2=r*4*(10^-3)-1/(r*lambda2);
18 p=20*B^2*(R1/R2); %Inducing power
19 L=20*lg(r*(p/(z1+z2))/3*10^-2); %vibration at housing
    
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Fig. 1. MATLAB code

Such simplified analysis was applicable for measurements where no extreme air gap deviation is expected.

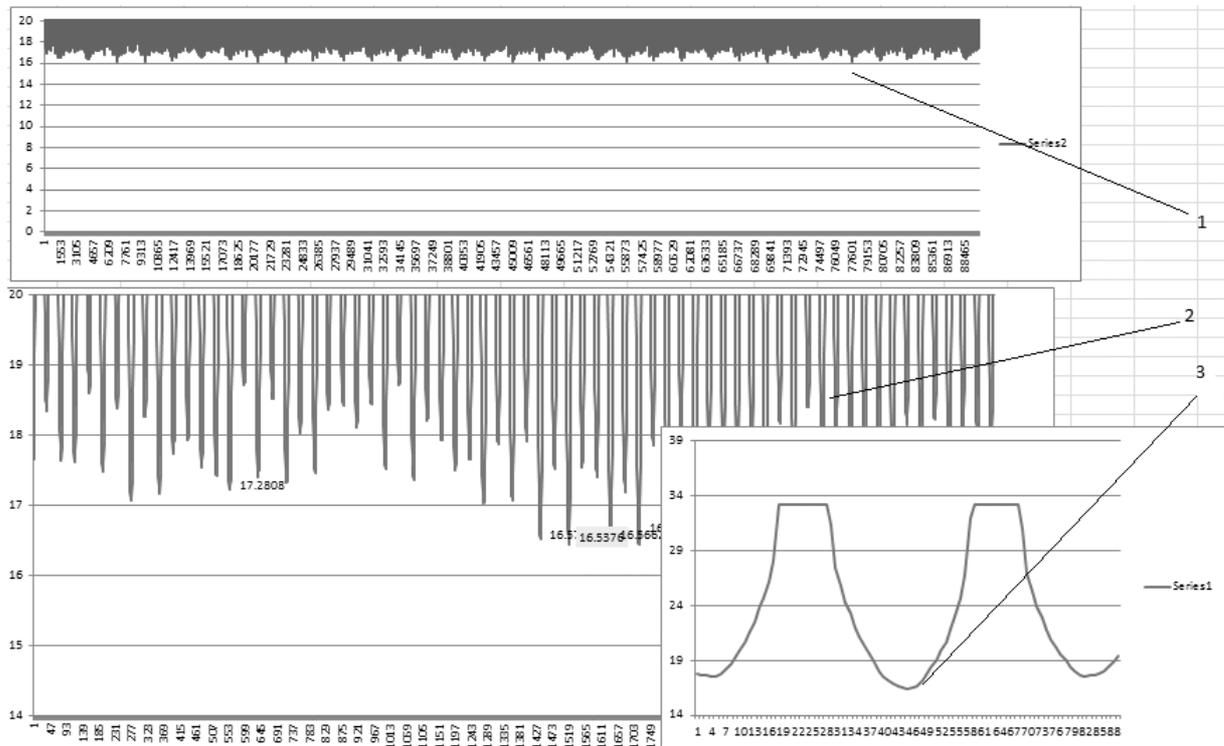


Fig. 2. Poles of rotor of hydro generator: 1 – overall data set for 1 mode with 90 MW active power; 2 – data limited to 1 rotation time; 3 – data for one rotor pole

Please, refer to Table 1 and Figure 4 for some main values of vibration obtained during the mode with 90 MW active power.

Table 1

Values of Peak to Peak and Peak to Peak RMS vibration for 90 MW load

Location	P-P, μm	P-P RMS, μm
Generator bearing case in radial direction for right side of the unit	24	12
Turbine bearing case in radial direction for right side of the unit	183	82
Generator shaft, left side of the unit	135	98
Generator shaft, right side of the unit	102	69
Core of the stator, upper end, right side of the unit	119	58
Core of the stator, middle position, right side of the unit	90	51
Core of the stator, lower end, right side of the unit	61	45
Case of the stator, right side of the unit	76	37

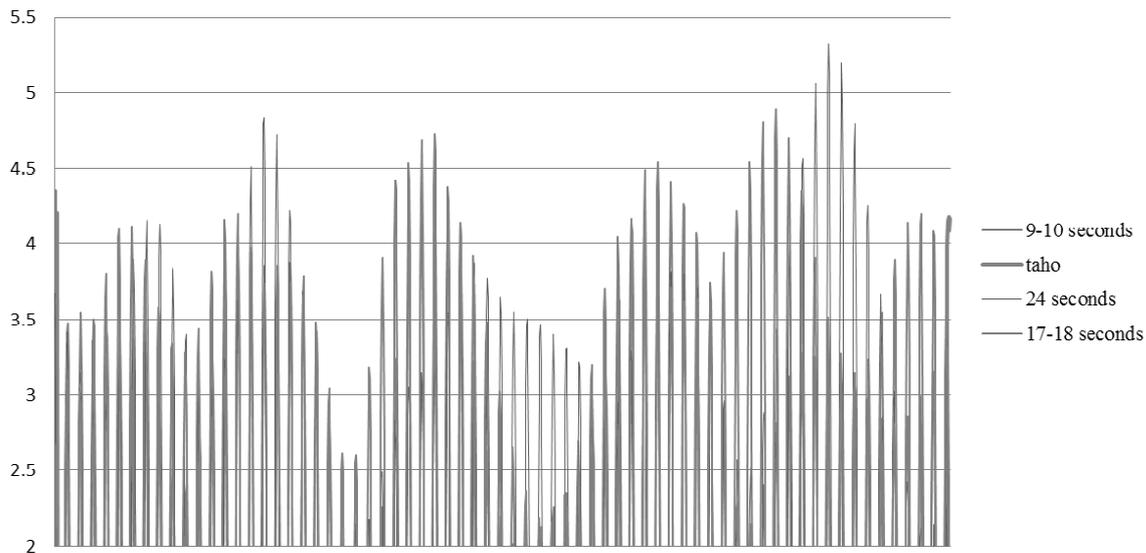


Fig. 3. Plotted values for 1 rotation cycle of hydro generator: vibration at 100 Hz, stator core, 90 MW

Results and discussion

It was found that vibration of the hydropower generator had significant effect on the output power quality. It was also discovered that the opposite effect takes place and power quality disruptions as harmonics and flicker increase vibration of the generator [13]. The framework for future similar measurements was developed.

After the actual measurements the numerical values were obtained through LabVIEW program application and for the simplicity plotted in MSC Excel. Please, refer to Figure 4 for illustration of the air gap in 90 MW mode.

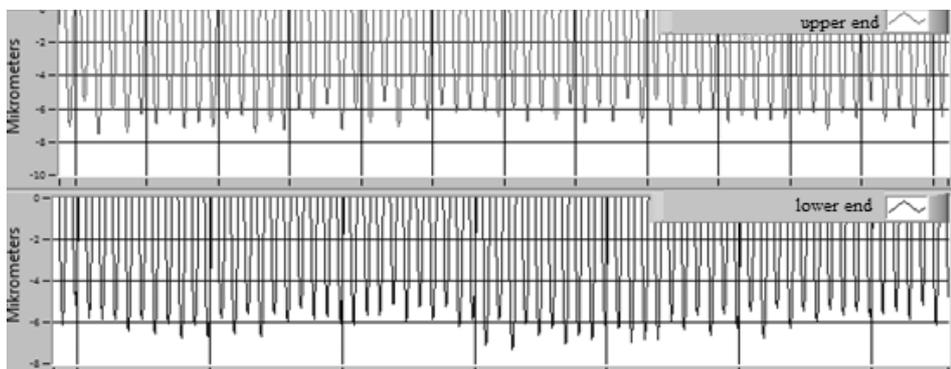


Fig. 4. Air gap graphical representation in LabVIEW in 90 MW mode

It was observed that the upper sensor measurements differ from the lower sensor measurements for the air gap. Figure 5 represents two upper and two lower rotor pole air gaps. The same behavior was observed for electromagnetic force measurements. Putting both facts together, conclusion could be made that the stator wall is not perfectly vertical; therefore, constant discrepancy between any two or more lower and any two or more upper end values appeared. Nevertheless, also discrepancies between the rotor poles on the upper end only exist. The example of discrepancies of rotor pole characteristics, compared to the sine wave could be seen also in Figure 5, which means that the rotor poles are indeed different.

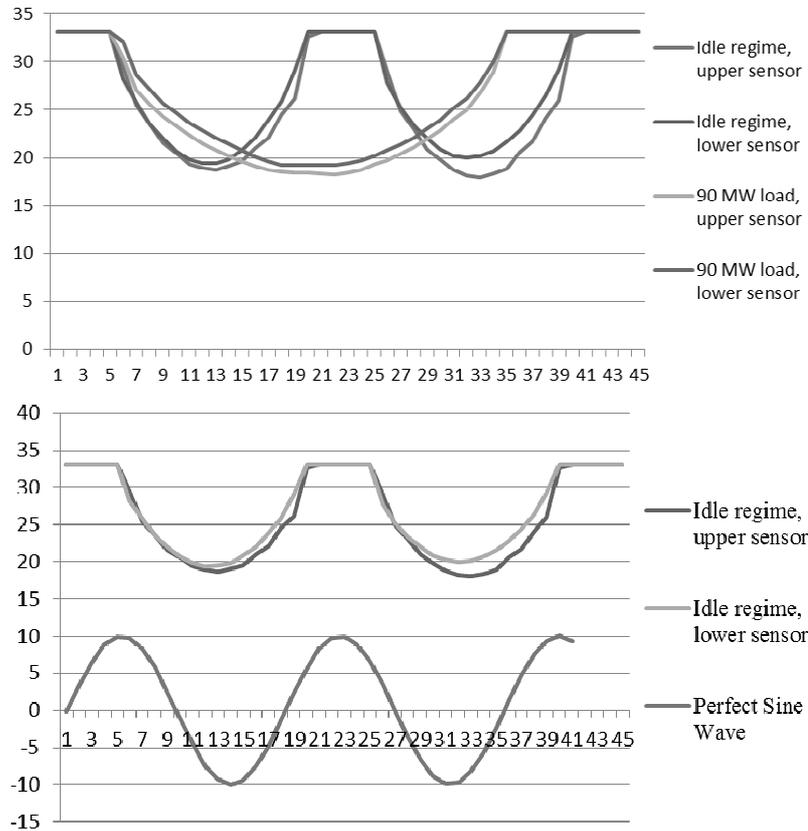


Fig. 5. Air gap on 2 rotor poles compared to perfect sine wave

The deviation of the rotor air gap, illustrated in Figure 6 was calculated to be 2.7 %, which was less than 3 % and therefore compliant to the standard [3]. The deviation of the air gap from perfect sine wave in Figure 5 illustrates the vibration effect on the power quality, but further analysis should reveal which particular bearing vibration has to be eliminated or which rotor pole has to be fixed.

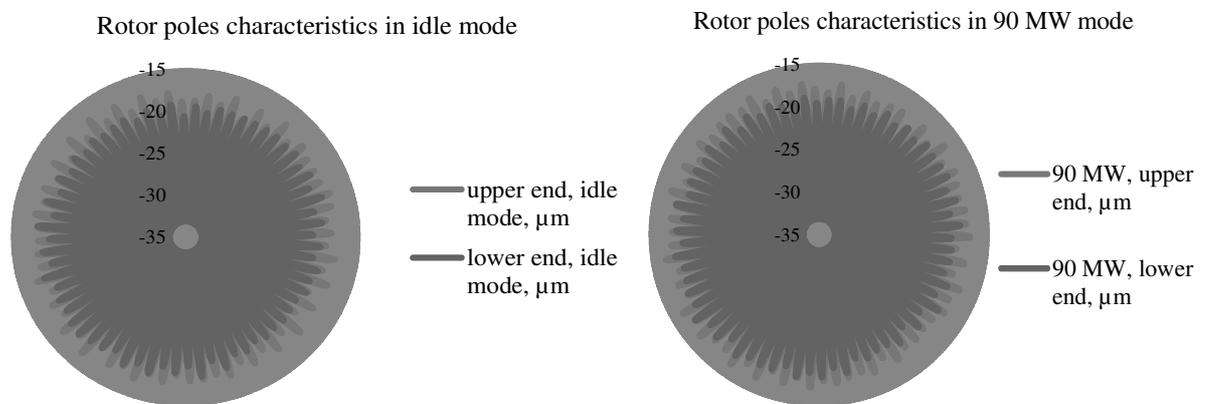


Fig. 6. Plotted values of rotor air gap

Some abnormal behavior was observed during vibration measurements, particularly at 100 Hz rate. The data about vibration at 100 Hz rate have been collected since 1998. The data are a useful

material for future investigations, because it is still not clear what mechanical faults exactly cause the flicker at the particular rotation speed.

Normally by observing increasing phase shift per harmonic, the phase shift gets greater the higher the frequency [13], but for particular measurements done during the study (specifically at frequency 100 Hz) the effect was just the opposite.

In the methodology section it was shown that simplified air gap analysis by equation (1) was applicable for particular measurements, because no extreme air gap deviation was expected. However, for further analysis Fourier transformation should be used. Thus, the first harmonic component will describe eccentricity of the rotor, the second – elliptic form and higher harmonics will show if the rotor has more complicated air gap deviation [3; 13]. Defining harmonics through Fourier analysis should be a good way to quantify non-linear load and is suggested for further investigations.

During further investigation it should be considered that the major producers of harmonics could be large converter-controlled electric motor drives. Such harmonics (as well as harmonics from miscellaneous equipment like computers) do not inject a harmful level of harmonic currents into the public electricity supply system if filtered on site [13].

For future measurements the following framework is suggested [4-6].

1. The working program with modes similar to those listed in the materials and methods section should be composed.
2. The numerical values of the expected vibration should be obtained through MATLAB code developed in the materials and methods section for the particular study [7-8].
3. The information, which could be useful for further investigation, should be collected. The suggested information should include (but is not limited to) the following characteristics:
 - the characteristics of the iron of the transformer core;
 - the designed flux level of the transformer;
 - the level of the supply voltage compared to the nominal;
 - the inductance of the relevant transformer winding when saturated;
 - the load on any other windings on the transformer, and the coupling between the windings.
 - the Total Harmonic distortion calculated and high order harmonics analyzed if percentage of the rotor gap deviation from the average value is larger than 3 % [13].

For further studies three other hydropower generating units will be chosen. Knowing the specifics of each unit, the measurement results of the power quality and vibration could be compared, and correlation between the values and defects could be found. For the forthcoming measurements it is suggested to use the proposed framework and the same LabVIEW program. For further studies it would be also beneficial to use the real-time machine containing FPGA chipset which can be configured directly from the NI LabVIEW environment. The main advantage of the device would be saving of computational time and reliable timing [5; 12].

Conclusions

The developed framework described how the stator and the rotor vibration amplitudes were affected by the value of the eccentricity, the internal power-angle of the generator and the exciting current under the air gap eccentricity fault. Combination of MATLAB and LabVIEW programming languages allowed processing data from different measurement devices simultaneously, optimizing the data processing time and making the code appearance more user-friendly.

The framework is beneficial for diagnosis of hydropower units since it relates electrical and mechanical analysis and provides an example of data acquisition program suitable for further investigations.

Procedures described can be applied on a yearly based dataset of corporate vibration severity reports. Built-in MatLAB codes require minimum space, but have similar functionality as LabVIEW elements. Since LabVIEW block diagrams do not have zooming options, built-in MATLAB codes provide an opportunity to build leaner block diagrams. As a result, one could make improvements and find mistakes in the codes faster. Moreover, MATLAB has plenty of additional libraries and the Simulink add-ons, which could help to develop advanced application for FFT analysis of harmonics.

Analysis of FFT in MATLAB could be used as a complementary tool for built-in spectrum analysis available in LabVIEW, which would increase reliability of the data obtained.

References

1. Rosenberg, L.T. Eccentricity, vibration, and shaft currents in turbine generators. Transactions of the American Institute of Electrical Engineers, vol. 74, No. 1, 1955, pp. 38-41.
2. Воробьёв, В. Е., Кучер В.Я. Прогнозирование срока службы электрических машин: Письменные лекции (Forecasting the service life of electrical machines). Санкт-Петербург, СЗТУ, 2004, 56 p. (In Russian).
3. Методики оценки технического состояния основного оборудования гидроэлектростанций: СТО 17330282.27.140.00-2006 (Evaluation methods for technical conditions of main equipment in hydropower plants), Дата введения: 2006-08-01, М. : ОАО РАО «ЕЭС России», 2006, 120 с. (In Russian).
4. Каплин, А. И., and М. Ю. Либерман. О новых стандартах МЭК по нормированию акустического шума и вибрации электрических машин (The new IEC standards for standardization of sound and vibration of electrical machines). Электротехника 5, 2009, Санкт-Петербург, pp. 35-40. (In Russian).
5. Vergura, S., and E. Natangelo. "Labview-Matlab integration for analyzing energy data of PV plants." International conference on renewable energies and power quality, Granada, 2010.
6. Březina, Lukáš, Ondřej Andrš, and Tomáš Březina. NI LabView-Matlab Sim. Mechanics Stewart platform design, Applied and Computational Mechanics 2 journal, 2008, pp. 235-242.
7. Xing, Xuening, and Shijin Jiang. The realization of Automatic Control Theory virtual experiment system based on LabVIEW and MATLAB. 2010 International Conference On Computer Design and Applications, Vol. 3, 2010.
8. Horng, Jui-Hong. Hybrid MATLAB and LabVIEW with neural network to implement a SCADA system of AC servo motor. Advances in Engineering Software 39.3, 2008, pp. 149-155.
9. Tekin, Raziye. MATLAB and LabVIEW in modeling, analysis and real time control of a motion control system. Control and Automation (ICCA), 2010 8th IEEE International Conference, 2010.
10. CHEN, Fei, and Hui-xia CHEN. Automatic Control Theory Virtual Experiment System Based on LabVIEW and Matlab [J]. Experiment Science & Technology 1, 2009, 034 p.
11. YAO, Shi-feng. Method of Hybrid Programming with LabVIEW and Matlab. Ordnance Industry Automation 6 journal, 2005, 073 p.
12. Смоленцев Н.К. MATLAB Программирование на Visual C# Borland JBuilder, VBA (MATLAB Programming on Visual C# Borland JBuilder, VBA). Москва, ДМК Пресс, 2012.- 454 с. (In Russian).
13. Shmilovitz, Doron. On the definition of total harmonic distortion and its effect on measurement interpretation. IEEE Transactions on Power delivery 20.1 journal, 2005, pp. 526-528.