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# VIBRATIONS LEVEL ANALYSIS DURING THE OPERATION OF A HIGH HEAD HYDROPOWER PLANT

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*In the testing campaign carried out in July 2010 at a high head hydropower plant equipped with four 25 MW units and two 50 MW units, there were performed vibration and noise level measurements, in addition to the hydraulic and electric parameters (flow rate, pressures and electric power).*

*The final object of this study was to analyze the vibration and noise levels as a function of the generated power.*

**Keywords**: vibration level, FFT, amplitude spectrum, and high head hydropower plant.

## 1. Introduction

Vibration is one of the most vexing problems with hydraulic machinery, and it is the cause of considerable altercation and litigation. Noise can also become a significant, annoying problem [1]. Excessive vibration from primary equipment can be transmitted directly to the building structure, which causes uncomfortable (and sometimes dangerous) structural vibration levels. Excessive vibration of equipment and piping can destroy portions of the equipment (such as drive shafts and seals), loosen or break pipe anchors, and even cause pipes to burst under certain conditions. Unlike the cavitation problems, the unsteady fluids flow in turbo machinery does not have a long research history.

The diagnose of the operating systems, machinery and equipment based on limited information in quantity and quality is one of the current issues not only for exploitation but also for design and conception.

Therefore, since noise and vibration of machines in operation can be considered as significant parameters in defining the state of operation, the analysis

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and interpretation of diagnostic through vibration and noise involves the use of specific methods and recommendations of probabilistic nature.

### 2. Vibration and noise measurement

The analyzed hydro units equip a high head hydro power plant [2]. The vibrations level during the operation of the hydro units was measured with vibration transducers. The transducers were placed in four different positions, according to the standard's recommendations (see Fig. 1).

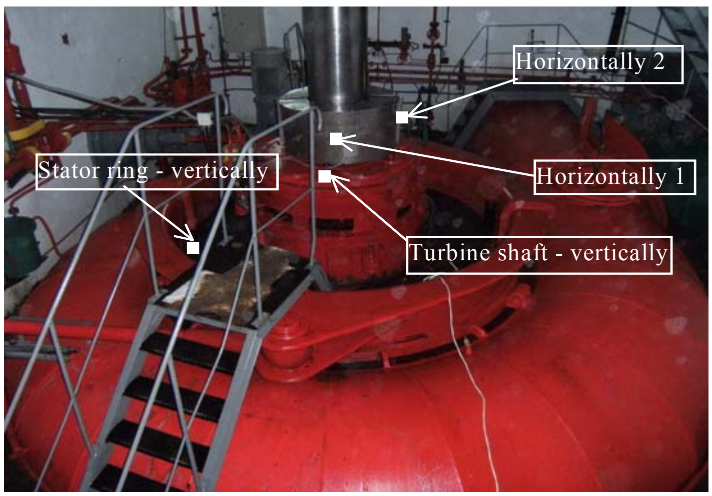


Fig. 1 – Vibration transducer setting

Noise level measurements carried out at the suction elbow level were added to the vibration measurements for each hydro unit. These measurements were realized by means of a portable sound level meter [2].

### 3. Vibration signal processing

In order to identify the possible operating disorders, as well as their causes, the signal for each vibration measurement was processed.

These electric signals acquired were transformed in acceleration units with the transducer calibration equation.

For each acquired vibration signal the frequency domain response was analyzed in order to identify the possible dangerous amplitudes.

The spectral analyze was made on 512 ($2^9$) test samples taken from the acquired signals. The Fast Fourier Transform (FFT) was used to decompose the signal and to obtain the components amplitudes and frequencies.

The spectral analysis results are synthetically presented in the following figures. In the present paper, are presented the analysis for two 25 MW units (U1 and U2) and for one 50 MW unit (U3).

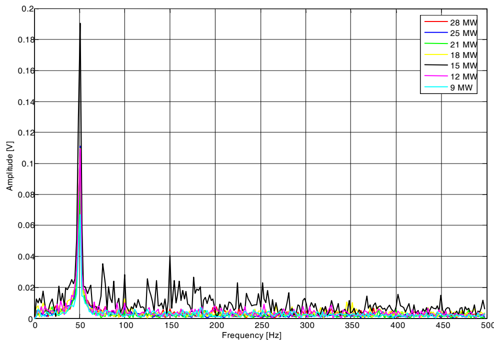


Fig. 2 – Frequency spectrum on turbine shaft, in vertical position for U1

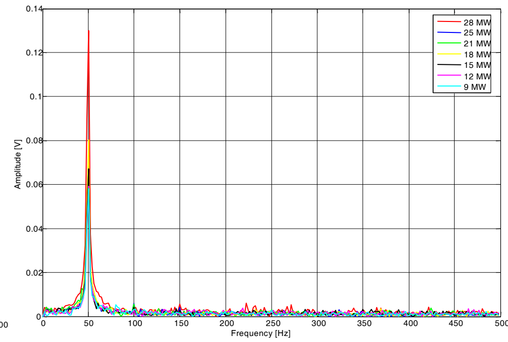


Fig. 3 – Frequency spectrum on stator ring, in vertical position for U1

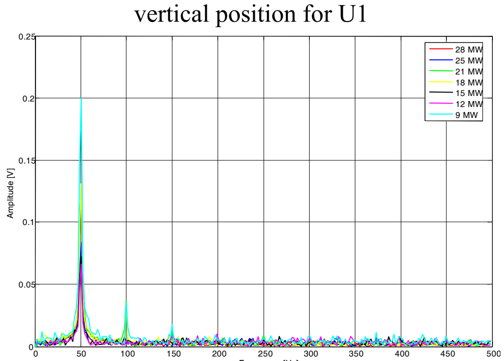


Fig. 4 – Frequency spectrum on turbine shaft, in the first horizontal position for U1

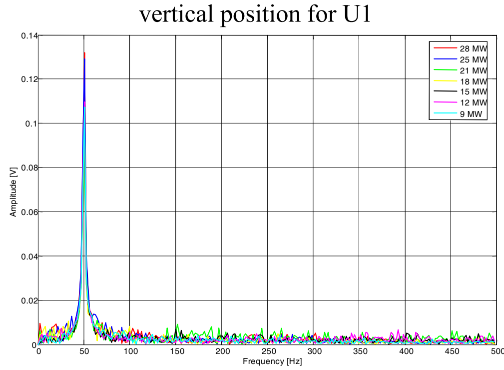


Fig. 5– Frequency spectrum on turbine shaft, in the second horizontal position for U1

The frequency corresponding to the synchronous speed for U1 is

$$f_s = \frac{428.6}{60} = 7.14 \text{ Hz} \tag{1}$$

Thus, the fundamental frequency is close to 100 Hz, which corresponds to the synchronous frequency multiplied to the runner number of blades (14 blades)

$$f = \frac{n}{60} \cdot N = \frac{428.6}{60} \cdot 14 = 99.96 \text{ Hz} \tag{2}$$

In all frequency spectra there is a dominant component of the signal located at 50 Hz, corresponding to the generator frequency (system frequency).

In the frequency spectra corresponding to the signals recorded in different positions of the transducer vibration setting and for different values of electrical power it can be seen a component corresponding to the fundamental frequency of the rotor of approximately 100 Hz, but it has an amplitude lower than the one at 50 Hz.

In the vertical direction it can be seen an increase in the vibration level for the signal acquired below 18 MW (Fig. 2), the frequency spectrum of vibration signal corresponding to 15 MW electric power being rich in high amplitudes, which indicates relatively strong vibration.

In the horizontal direction the signals are relatively clean, with a slight increase in vibration level at low power (Figs. 4, 5).

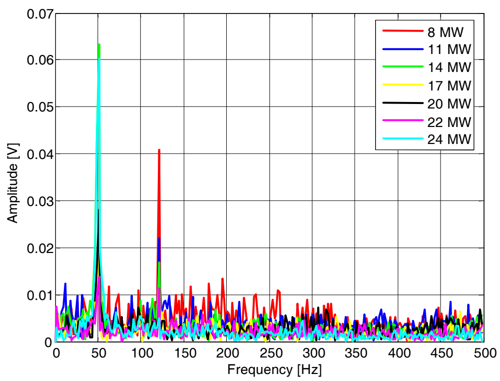


Fig. 6 – Frequency spectrum on turbine shaft, in vertical position for U2

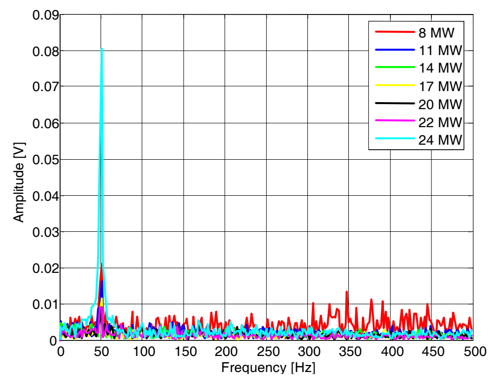


Fig. 7 – Frequency spectrum on stator ring, in vertical position for U2

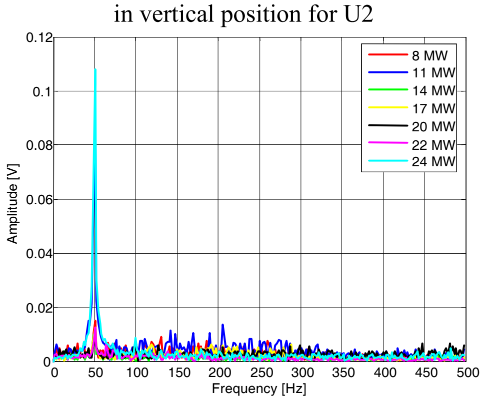


Fig. 8 – Frequency spectrum on turbine shaft, in the first horizontal position for U2

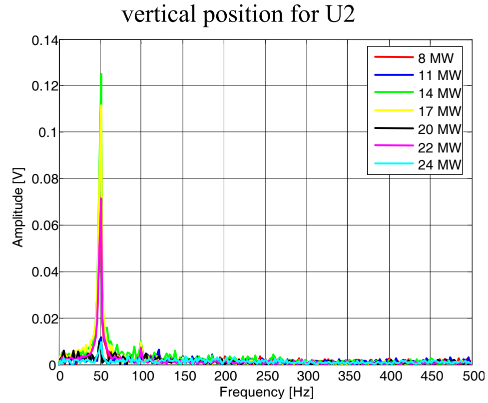


Fig. 9 – Frequency spectrum on turbine shaft, in the second horizontal position for U2

The frequency corresponding the synchronous speed of the other 25 MW unit is the same as for U1

$$f_s = \frac{428.6}{60} = 7.14\ \text{Hz} \tag{3}$$

In this case, because the turbine runner has 17 blades, the fundamental frequency is close to 120 Hz, corresponding to the synchronous frequency multiplied to the runner number of blades

$$f = \frac{n}{60} \cdot N = \frac{428.6}{60} \cdot 17 = 121.44\ \text{Hz} \tag{4}$$

For the second analyzed unit the runner fundamental frequency of 121 Hz is present in the spectrum of vibration signal acquired on the vertical position of the turbine shaft (Figure 6). In the other three positions of the transducer it is not significant (Figs. 7, 8, 9).

In all frequency spectra it can be seen the generator component and also an increase of the signal amplitude proportional to the generator power decrease.

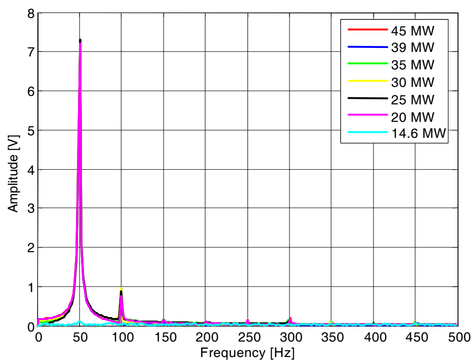


Fig. 10 – Frequency spectrum on turbine shaft, in vertical position for U3

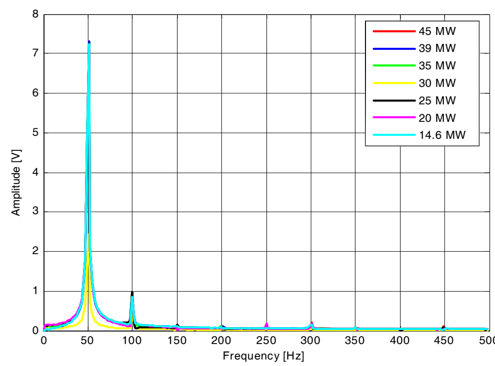


Fig. 11 – Frequency spectrum on stator ring, in vertical position for U3

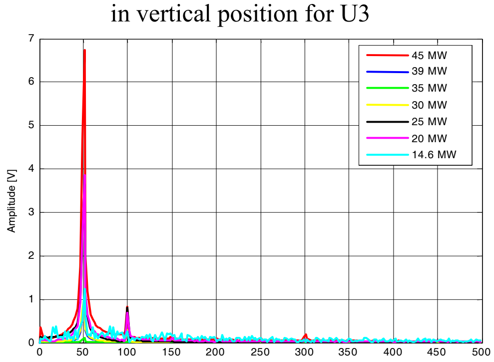


Fig. 12 – Frequency spectrum on turbine shaft, in the first horizontal position for U3

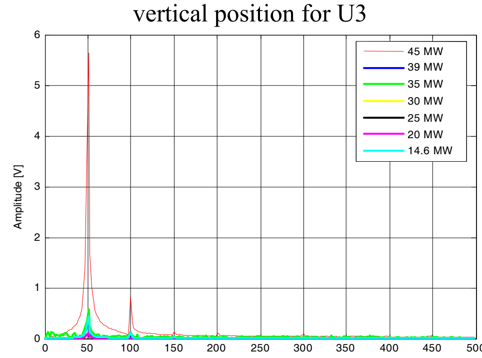


Fig. 13 – Frequency spectrum on turbine shaft, in the second horizontal position for U3

The frequency corresponding to the synchronous speed for the 50 MW unit is

$$f_s = \frac{300}{60} = 5 \text{ Hz} \tag{5}$$

The fundamental frequency is close to 85 Hz, which corresponds to the synchronous frequency multiplied to the runner number of blades (17 blades).

$$f = \frac{n}{60} \cdot N = \frac{300}{60} \cdot 17 = 85 \text{ Hz} \tag{6}$$

For the 50 MW unit it can be seen the presence of a component with significant amplitude at the runner fundamental frequency of 85 Hz (Figures 10 - 13). In the vertical direction the vibration signals amplitude increases with the generator power decrease, but in the horizontal direction the vibration amplitude was recorded at maximum acquired electrical power [3, 4].

## 4. Noise signal processing

The noise signals were also analyzed in frequency domain. Numerous experimental and theoretical studies show that there are correlations between the level of vibration and noise, between the characteristics of vibration and noise (peak areas and dominant frequency) for machinery parts and machines in operation.

Diagnosing the state of operation by noise appears as an immediate solution, especially in subjective assessments, on one hand due to the simplicity and productivity and on the other hand due to the particular sensitivity compared with the auditory organ. In other cases, the noise is a parameter preferred by the customer in consideration of quality, on certain conditions.

The recordings for the studied hydro units are presented in Figs. 13, 14 and 15.

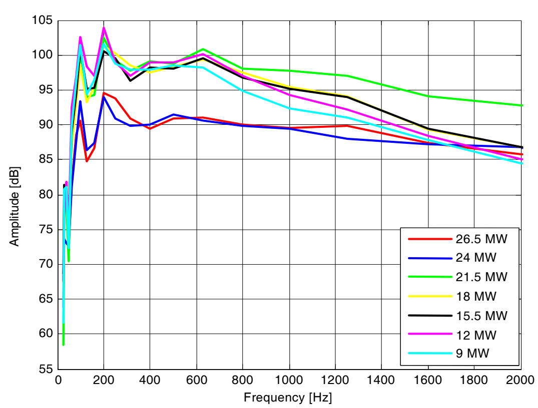


Fig. 13 – Noise signal spectrum recorded at U1, for seven levels of power output

The sound signals were decomposed into amplitudes at characteristic frequencies. Measurements were made for each of the analyzed hydro units for different values of generator electric power. In order to have an easier interpretation, the curves corresponding to different levels of output for each hydro unit were analyzed and compared on the same graph.

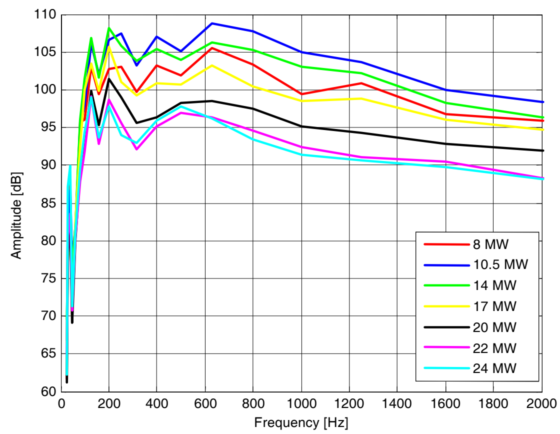


Fig. 14 – Noise signal spectrum recorded at U2, for seven levels of power output

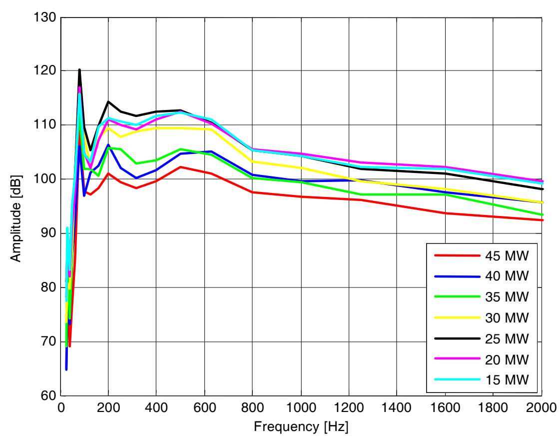


Fig. 15 – Noise signal spectrum recorded at U3, for seven levels of power output

The noise level increases with the decrease of the generator power, thus is higher for lower generator power values.

For the first 25 MW unit it can be seen that below 24 MW the noise level increases fast, so taking into account the noise level it is recommended to operate at a power close to maximum output (Fig. 13).

For the second 25 MW analyzed unit (Fig. 14) it can be seen the same noise level increases when the generator power decreases, the signal spectra being quite rich on a large frequency domain.

Analyzing the results obtained for the 50 MW unit (Fig. 15) it can be seen that noise power variation with the generator power is not very significant. Yet it can be observed that the signals spectrum is rather rich, with relatively high amplitudes for a large domain of frequencies.

## 6. Conclusions

Analyzing the vibration levels it can be recommended to avoid operation at partial load, close to minimum values, but not over maximum, in order to keep relatively low levels of vibration.

The hydro units don't have problems in normal operation, in the vibration signals frequency spectra being observed remarkable amplitudes at frequencies identified as runner fundamental frequency and network frequency. Otherwise the signals are relatively clean.

In all cases of the noise analysis the significant amplitudes are at frequencies above 50 Hz. Their causes may be, according to the literature, the flow hydrodynamics [5, 6]. The same is indicated by the fact that the noise level increases at partial load of the turbines, when there are strong pressure variations in the draft tube cone.

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