

SPECTRAL ANALYSIS METHODOLOGY FOR ACOUSTICAL AND MECHANICAL MEASUREMENTS RELATIVE TO HYDRAULIC TURBINE'S GENERATOR

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ABSTRACT

This paper presents a spectral analysis methodology for acoustical and mechanical measurements performed on hydraulic turbine's generator in the context of power increase diagnostic. The purpose of this analysis is to link the different excitation frequencies to the electromagnetic or mechanical sources. A multidisciplinary team was necessary to provide the necessary inputs and the specific workload for this analysis.

This methodology included a number of activities such as:

- Choice of measurements points and sensors (microphones, accelerometers, strain gages);
- Input of the generator's electromagnetic frequency analysis;
- Input of the rotor and stator's Finite Element Analysis (FEA) modes;
- Knowledge of the hydraulic turbine's generator operating frequencies;
- Measurement and recording of the different time based signals and computing their respective FFTs;
- Identifying peaks in the frequency domain from different mechanical signals;
- And several analyses that leads to identifying excitation sources and frequencies.

The methodology will be presented along with an example of an analysis performed on specific mechanical signals.

INTRODUCTION

In the context of a study of existing generators' power increase, full instrumentation was installed on high-power hydro-generators (> 60 MW). The main goal of this project is to assess the thermal limits of the stator in relation to the increase in power [1,2]. The mechanical limits are also accessed using vibration measurements performed on the generator's rotor and stator. The vibration measurements, combined with other mechanical measurements such as thermal dilatation of the stator, stress measurements on the rotor, and acoustic measurements, allow us to identify the forces acting on both structures. This paper will present the spectral methodology used in this project and will show preliminary results.

ALTERNATOR CHARACTERISTICS

A newly refurbished hydraulic power generator was instrumented and monitored. [Figure 1](#) shows the generator's rotor and stator during refurbishing. [Table 1](#) shows the generator's characteristics.

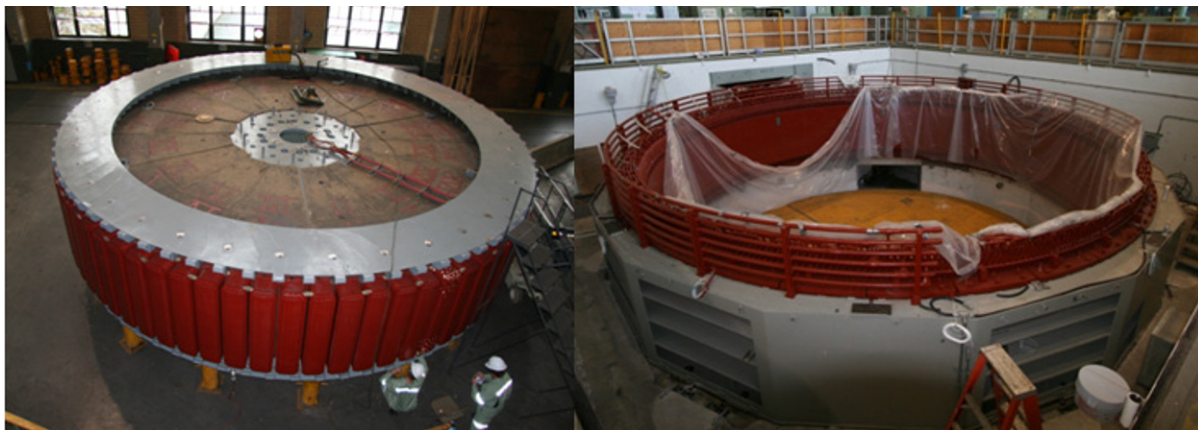


Figure 1: Rotor and stator of the hydraulic generator

Generator's characteristics	
Total power (Winter/Summer)	(75/65) MVA
Power factor	0,85
Real Power (Winter/Summer)	(64/55) MW
Rotation speed	94,7 rpm, 1,58 Hz
Number of poles on the rotor	76
Number of slots on the stator	396
Rotor External diameter	9,08 m
Stator Internal diameter	9,11 m
Gap	12,7 mm
Rotor height	1,6 m

Table 1: Generator characteristics

DESCRIPTION OF MEASUREMENTS

Performance measurements

Generator performance measurements were taken for several operating conditions, namely: Speed No Load (SNL), 0%, 70%, 85% and 100% of the nominal summer power specifications (55 MW).

Acoustical and Mechanical measurements

The mechanical measurements performed on the generator's rotor and stator include sound pressure level, vibration and stress for each of the abovementioned operating condition. Acoustic measurements were performed at 8 different locations on the alternator floor. These measurements were used to evaluate the overall noise level for monitoring the working environment and machinery by non-contact sensing. Frequency analyses (FFT 0-2 kHz and 0-10kHz) were also performed to correlate the acoustic signals to the operating conditions.

Mechanical (vibration and strain gages) instrumentation was installed on the rotor and stator. The rotor instrumentation includes 3 accelerometers installed in the axial, radial, and tangential directions and 16 strain gages (one per cross arm, with their position optimized by finite-element analysis and previous measurements) (Figure 2). The signals coming from the rotor instrumentation were transferred to the acquisition system by RF transmission. The stator's instrumentation allows for acceleration measurements (radial and tangential) of the stator core and stator frame (Figure 3). These mechanical measurements, combined with a thorough frequency analysis, were used to investigate the results obtained during different operating conditions.



Figure 2: Rotor instrumentation

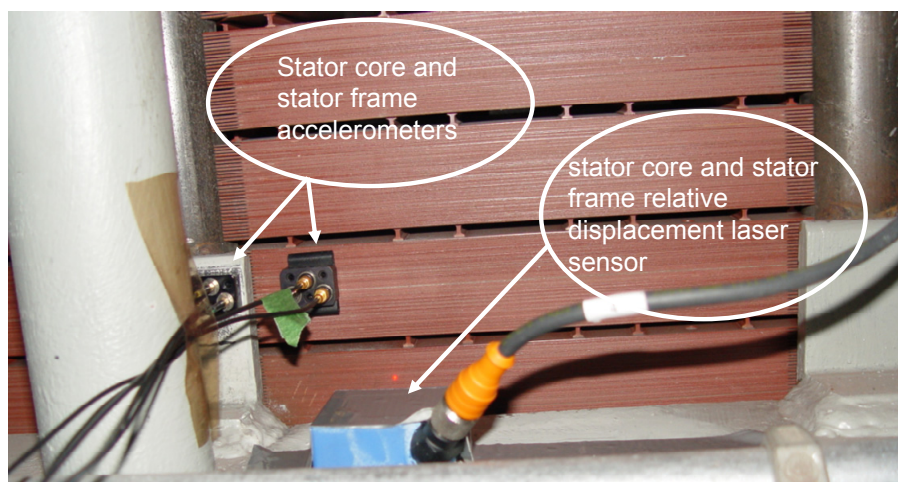


Figure 3: Stator instrumentation

SPECTRAL ANALYSIS METHODOLOGY

A spectral analysis methodology was developed for the various mechanical signals. [Figure 4](#) presents the various steps of this methodology in the form of a logical diagram. The analysis allows the identification of the hydro generator excitation sources using the different sensor inputs (accelerometers, strain gages and microphones). This methodology consists of several steps and has two key goals that can be found at the bottom line of the logical diagram of [figure 4](#). The first goal is to determine the source of the various frequencies detected by comparing those with the spectral contents coming from the stator and rotor. The second goal is to ensure the follow-up of the evolution of a spectral component on a particular signal for the various operating conditions. There are two types of inputs for this analysis which can be found at the top line of the logical diagram ([figure 4](#)). Firstly, the output generated by the various sensors is recorded as a time based signal. These signals, representing acceleration and stress endured by the generator rotor and stator, are analyzed in the frequency domain using a FFT transformation over a frequency range of 0-2kHz. We also use other types of data sets which allow us to identify the excitation frequencies and their causes. These data sets include the knowledge of the operational and mechanical characteristics of the hydraulic generator, the FEA and analytical analysis of the rotor/stator and electromagnetic simulations of the system. These data set allows the identification of the synchronous frequency, the vibration modes and the electromagnetic excitation. These are then compared to the peaks found in the frequency domain of the different mechanical signals. There are three types of comparison which can be made:

- For a specific sensor and a specific operating condition to find the equivalent peaks from the mechanical signal and excitation frequencies.
- Between the peaks of different sensors for the same operating condition to find the common excitation frequencies.
- For a specific sensor and a specific and different operating condition to follow the evolution of one or more excitation peak.

The logical diagram of [figure 4](#) shows the overall process performed during this analysis. Each box of the logic diagram is an action on the input data or on the intermediate results that helps achieve the two key goals described above.

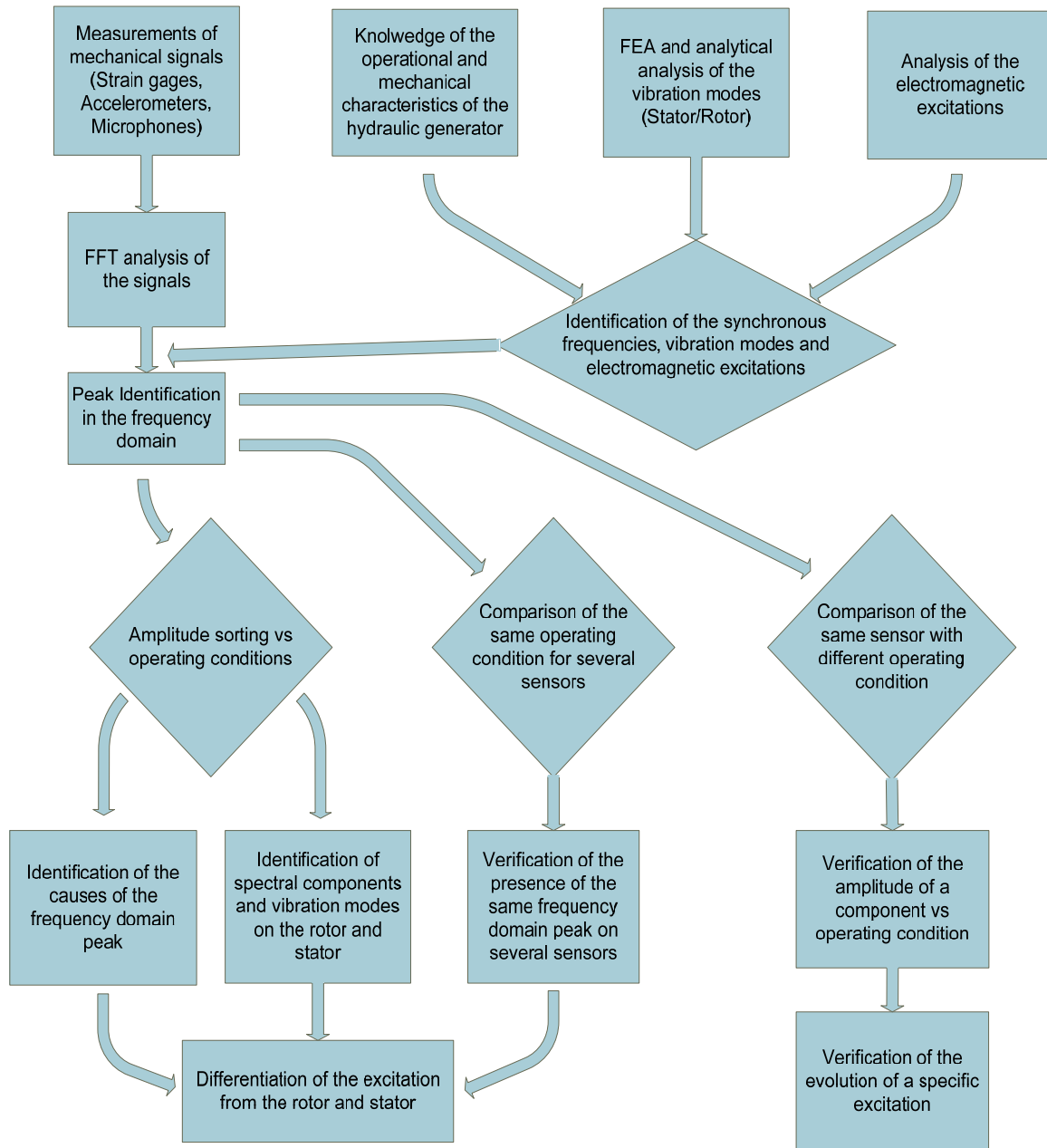


Figure 4: Spectral analysis methodology

TYPICAL SPECTRAL ANALYSIS RESULTS

The typical results of the analysis show that the signals coming off the rotor and the stator have different spectral contents. Figure 5 and 6 respectively show the spectra of the generator's rotor and the stator radial acceleration with an aim of comparing the frequencies content in each signal (the amplitude of the graphs is adjusted to the maximum of each signal). The vibration content of the stator consists principally of harmonics of the even multiple of the electric fundamental frequency (120 Hz, 240 Hz...). Table 2 presents a list of the rotor's main frequencies of vibration as well as their associated causes.

Figure 7 presents the stress spectrum measured on a cross arm of the generator's rotor. We notice that the maximum stress is reached at a frequency of 94.8 Hz, which is similar to the rotor radial acceleration. Another stress peak is reached at a frequency of 1.58 Hz, which corresponds to the actual rotor rotational speed. The stress level at the rotation speed of the rotor (1.58 Hz) is also comparable with the one at the principal frequency, which corresponds to the actual rotor rotational speed.

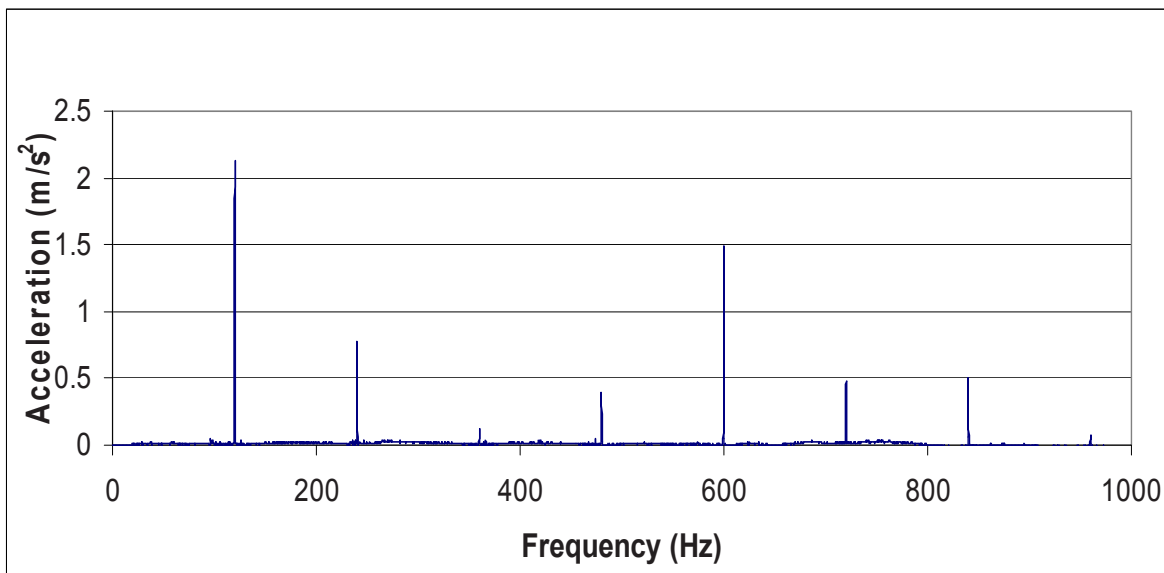


Figure 5: Radial acceleration spectrum of the stator

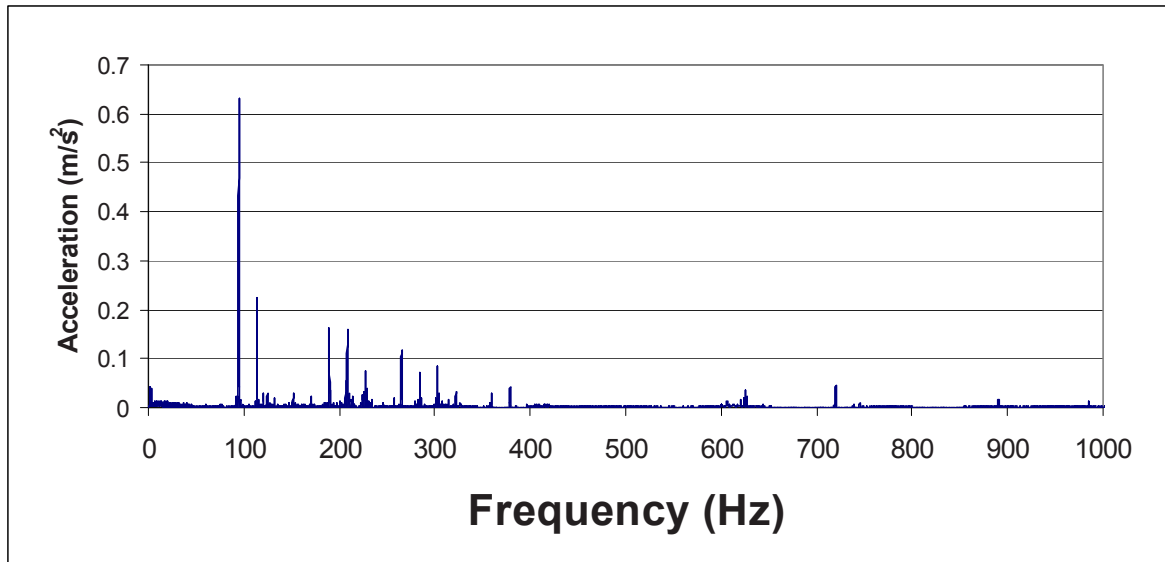


Figure 6: Radial acceleration spectrum of the rotor

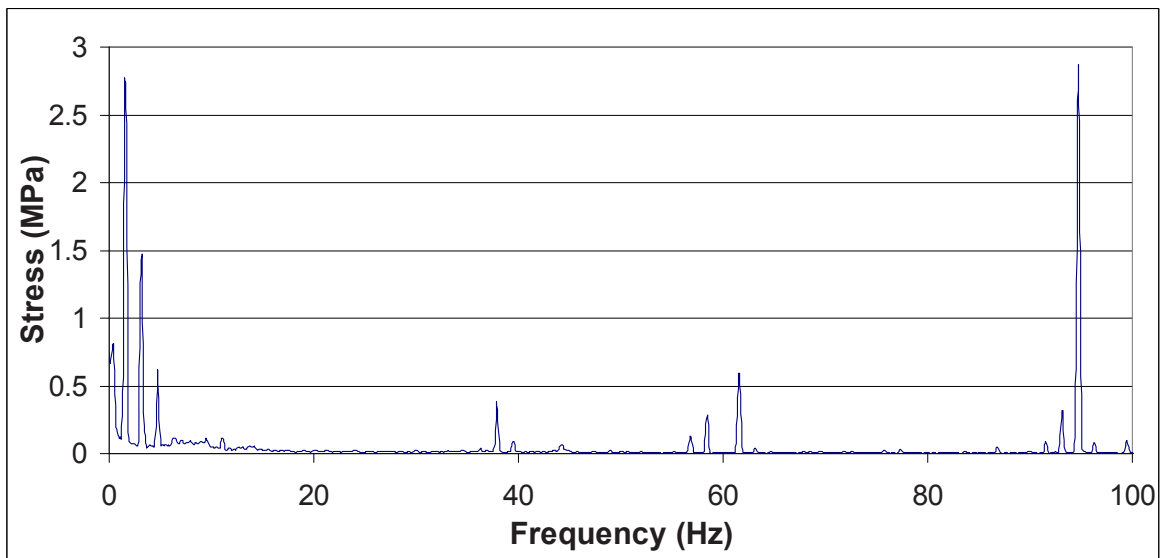


Figure 7: Strain gage spectrum of the rotor cross arm

Frequency (Hz)	Associated causes
94.8	Magneto motive force harmonic Rotation frequency harmonic
113.7	Magneto motive force harmonic Blade passing frequency harmonic
189.5	Magneto motive force harmonic Blade passing frequency harmonic
208.4	Blade passing frequency harmonic
265.2	Magneto motive force harmonic Blade passing frequency harmonic
303.2	Magneto motive force harmonic Blade passing frequency harmonic
227.4	Magneto motive force harmonic Blade passing frequency harmonic
1250.3	Magneto motive force harmonic
284.1	Magneto motive force harmonic
206.8	Rotation frequency harmonic
720.0	harmonics of the even multiple of the electric fundamental frequency
378.9	Rotation frequency harmonic
1.58	Rotation frequency harmonic
191.0	Coincidence with a mode of the rotor (analytical calculation)
625.2	Slot passing frequency

Table 2: Main rotor vibration frequencies and their associated causes

The end result obtained from the study of the frequency versus the operating condition evolution is used in the diagnosis of power increase. The spectral analysis methodology allows us to compare the amplitude of the major spectral components or principal excitations variation against the operating condition for the stator (figure 8) and rotor (figure 9). We notice that the various excitation components do not respond in the same manner when subjected to a power increase. For this type of analysis, we look at the tendency (rising, stable or falling) of a particular excitation according to the increase in power. The tendency informs us on the types of extrapolation of the levels of excitation according to the increase of power beyond the nominal output. The tendency cues us that a specific excitation might rise or fall when the generator's power is increased beyond its nominal output, which helps us determine the main mechanical limiting factors.

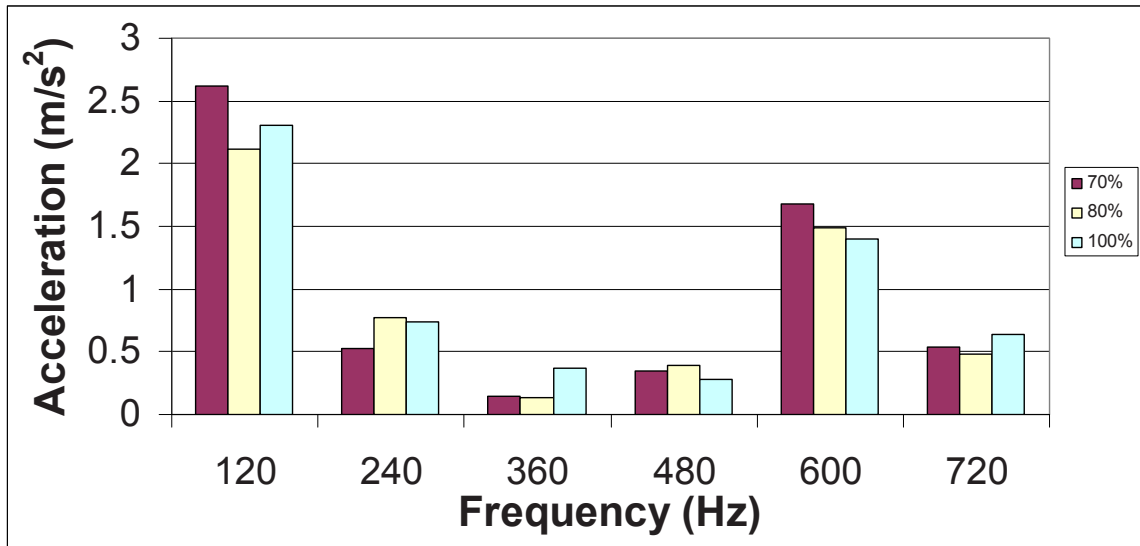


Figure 8 : Acceleration level at the stator vs. operating condition

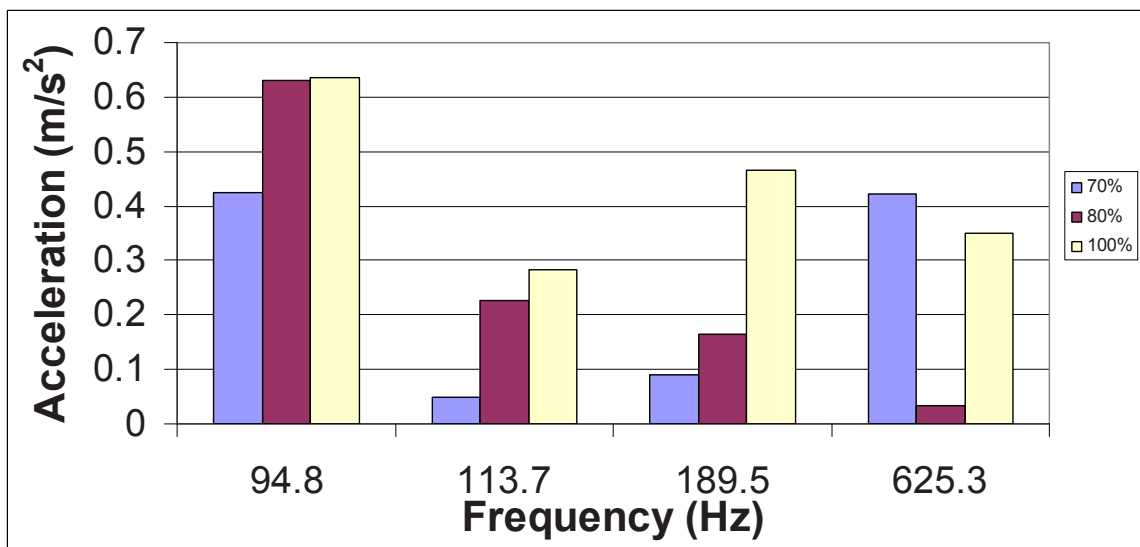


Figure 9 : Acceleration level at the rotor vs. operating condition

CONCLUSION

A spectral methodology analysis of the mechanical signals (accelerometers, strain gauges, microphones) was applied to the diagnostic of power increase of hydroelectric generators. This methodology allows us to better understand the excitation forces on the various parts of the generator. The methodology also allows the understanding of the evolution of a particular excitation in relation to the operating conditions. The complete analysis of the data obtained will enable us to refine the analysis methodology and to obtain a more complete mechanical diagnostic in the power increase of hydro generator.

ACKNOWLEDGMENTS

The authors acknowledge the technical staff of the Hydro-Québec research institute (IREQ) for the quality of their work. This team includes Luc Martell and Mathieu Soares.

REFERENCES

- [1] C. Hudon, M. Chaaban, J. Leduc and D.N. Nguyen, Use of distributed Temperature Measurements to Explain a Generator Winding Faillure, CIGRE 2005, Lausanne, 6 pages.
- [2] F. Lafleur, S. Bélanger, L. Marcouiller and A. Merkouf, Acoustic and mechanical measurements of an hydraulic turbine's generator in relation to power levels and excitation forces, IMAC 2009, Jacksonville, FL, 7 pages.

Rotating Machinery, Structural Health Monitoring,
Shock and Vibration, Volume 5
Proceedings of the 29th IMAC, A Conference on
Structural Dynamics, 2011
Proulx, T. (Ed.)
2011, X, 554 p., Hardcover
ISBN: 978-1-4419-9427-1