Vibration analysis of a hydro generator for different operating regimes

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Abstract. Based on experimental measurements, this paper presents the vibration analysis of a hydro generator that equips a Kaplan hydraulic turbine of a Hydropower plant in Romania. This analysis means vibrations measurement to different operating regimes of the hydro generator respectively before installing it and into operation, namely putting off load mode (unexcited and excited) respectively putting on load mode. By comparing, through the experimental results obtained before and after the operation of hydro aggregates are observed vibrations improvements.

1. Introduction

The hydro-generator i.e. hydraulic turbines are the main active components from a Hydro Power Plant. The most used hydraulic turbines of a Hydro Power Plant are Kaplan, Francis and Pelton turbines [1], [2]. For Francis and Kaplan turbines are recorded, results on the rotor-stator interaction [3] and vibration analysis for different operating modes of hydro aggregates [4], [5].

This paper presents the results of measurements on experimental vibration analysis of a hydro-generator operating a Hydro Power Plant in Romania. This Hydro Power Plant is equipped with vertical Kaplan turbines respectively synchronous generators. Due to the large number of hours of operation, its rehabilitation is needed both in terms of mechanical and electrical point of view [6], [7]. It is very important that before dismantling hydro aggregates for rehabilitation, to evaluate the actual performance of operation of hydro aggregates in terms of mechanical and electrical, and will settle all the necessary measures in terms of constructive and functional in order to bring parameters nominal hydro aggregates respectively.

From a mechanical point of view when checking vibrations, desired bringing set points of hydro aggregates and to improve its operation and in terms of vibration [8], which over time can lead to big
problems in the functioning hydro-generators, have done research on experimental vibration rotor analysis vibration and temperature generator stator core [9] hydro aggregates vibration monitoring program using LabVIEW [10], namely research on vibration reduction [11]. Also, by measuring the vibration of hydro aggregates mechanical imbalance was followed, centering and focusing magnetic [12-14]. The signals were then analyzed using saved also LabVIEW software [15].

2. Used equipment and methods
For measuring the active power, tensions respectively currents across generator was used analyzer electrical parameters and process parameters that type VPA323 a laptop for data processing, as in Figure 1.

![Figure 1. Parameter analyzer of the VPA323 type](image1.png)

The revolution speed was measured by a laser speed, the type QS30LDQ (Figure 2), and the vibration in the bearing was measured three vibration sensors mounted on the top bearing of the generator as in Figure 3, with the sensitivity 533.3 mV / g, 546.1 mV / g or 497.5 mV / g.

![Figure 2. QS30LDQ laser speed](image2.png)  ![Figure 3. Vibration sensor](image3.png)

The vibration analysis of the hydro aggregates through experimental checkups and measurements before the dismantling hydro aggregates supposed to repair and putting into service.

For the two types of measurements, hydro aggregates requested various operating modes namely: idle mode (unexcited and excited) respectively regime under load.

At these operating modes using LabVIEW software for all experimental measurements were recorded the following sizes: n rotor speed; higher radial thrust bearing vibration in the horizontal direction + x VLRAG_X; radial thrust bearing vibration higher radial + y VLRAG_Y; lower radial bearing vibration direction + x VLAG_X.
Subsequently, the signals were analyzed taken in situations considered using LabVIEW software. To view, it was performed a Fourier transform in order to highlight the range of variation of speed (amplitude) in that order harmonic frequency.

3. Measurement before dismantling the hydro-generator
The measurement results starting in transitional and steady unexcited before the dismantling of hydro-generator to repair (Figure 4) were analyzed using the LabVIEW program.

![Figure 4](image)

The variation of the measured parameters in transitory starting mode and in stable unexcited functioning

The values of the parameters measured in the starting phase before the dismantling the hydro-generator to repair his regime stabilized idle unexcited are presented in Table 1, and the values of the parameters measured at steady idle unexcited in Table 2.

| Time (s) | Revolution (RPM) | Vibrations |
|---------|-------------------|------------|
|         |                   | v_{LRAG_x} (mm/s) | v_{LRAG_y} (mm/s) | v_{LAG_x} (mm/s) |
| 0       | 0                 | 0.33        | 0.35              | 0.11              |
| 1       | 71.67             | 0.22        | 0.15              | 0.08              |
| 2       | 86.73             | 0.17        | 0.19              | 0.09              |
| 3       | 97.09             | 0.29        | 0.18              | 0.08              |
| 4       | 110.8             | 0.25        | 0.26              | 0.13              |
| 5       | 110.8             | 0.25        | 0.26              | 0.13              |
| 6       | 128.28            | 0.26        | 0.22              | 0.11              |
| 7       | 131.71            | 0.31        | 0.21              | 0.11              |
| 8       | 141.81            | 0.3         | 0.17              | 0.08              |
| 9       | 150.24            | 0.28        | 0.21              | 0.1               |
| 10      | 158.23            | 0.34        | 0.23              | 0.09              |
| 11      | 162.47            | 0.36        | 0.25              | 0.13              |
| 12      | 167.18            | 0.4         | 0.31              | 0.1               |
| 13      | 167.23            | 0.3         | 0.28              | 0.13              |
| Max. Value | 167.23         | 0.4         | 0.35              | 0.13              |
Table 2. Measured parameters in a stable unexcited idle functioning mode

| Time (t) | Revolution (N) | Vibrations (vLRAG_x, vLRAG_y, vLAG_x) |
|----------|----------------|--------------------------------------|
|          | (s)            | (RPM)                                |
|          |                | (mm/s)                               |
|          |                | (mm/s)                               |
|          |                | (mm/s)                               |
| 1        | 167.2          | 0.65                                 |
| 2        | 167.2          | 0.68                                 |
| 3        | 167.2          | 0.68                                 |
| 4        | 167.2          | 0.67                                 |
| 5        | 167.19         | 0.65                                 |
| 6        | 167.19         | 0.61                                 |
| 7        | 167.19         | 0.57                                 |
| 8        | 167.2          | 0.53                                 |
| 9        | 167.21         | 0.49                                 |
| 10       | 167.21         | 0.44                                 |
| 11       | 167.22         | 0.38                                 |
| 12       | 167.22         | 0.38                                 |
| 13       | 167.22         | 0.42                                 |
| 14       | 167.23         | 0.46                                 |
| V. Average | 167.21        | 0.544                                |

The vibration spectrum of steady unexcited measured parameters is shown in Figure 5, i.e. the spectrum of variation of speed (amplitude) in that order harmonic frequency.

From Figure 5 is observed that maximum value is obtained for harmonic vibrations of order 1 axial- radial bearing higher along the horizontal direction + x, bearing higher axial-radial radial bearing lower respectively + y or + x direction.

It also notes that under unexcited idling vibration occurs due to sharp flow regimes and due to offsetting.

The regime idle excited, connecting the excitation voltage generator determines a nominal voltage stator, recorded the following parameters: rotor speed n, vibration thrust bearing radial upper horizontal direction + x vLRAG,X, vibration thrust bearing radial higher radial + y vLRAG,Y, lower radial bearing vibration direction + x vLAG,X.
Tables 3 and 4 present the values of the parameters measured at steady idle excited that variation measured quantities during transitory exciting process.

**Table 3.** Measured parameters during the stable excited idle functioning mode

| Time (s) | Revolution (RPM) | Vibrations |  |  |  |
|----------|------------------|------------|---|---|---|
|          |                  | \(VRAG_x\) (mm/s) | \(VRAG_y\) (mm/s) | \(VLAG_x\) (mm/s) |
| 1        | 167.2             | 0.82       | 0.8 | 0.31 |
| 2        | 167.2             | 0.82       | 0.8 | 0.31 |
| 3        | 167.2             | 0.82       | 0.8 | 0.31 |
| 4        | 167.2             | 0.81       | 0.8 | 0.33 |
| 5        | 167.19            | 0.81       | 0.8 | 0.34 |
| 6        | 167.19            | 0.81       | 0.8 | 0.34 |
| 7        | 167.19            | 0.81       | 0.8 | 0.34 |
| 8        | 167.2             | 0.81       | 0.8 | 0.35 |
| 9        | 167.21            | 0.81       | 0.8 | 0.35 |
| V. Average | 167.20          | 0.81       | 0.8 | 0.33 |

**Table 4.** The variation of the measured values during the transitory exciting process

| Time (s) | Revolution (RPM) | Vibrations |  |  |  |
|----------|------------------|------------|---|---|---|
|          |                  | \(VRAG_x\) (mm/s) | \(VRAG_y\) (mm/s) | \(VLAG_x\) (mm/s) |
| 1        | 167.2             | 0.4        | 0.31 | 0.11 |
| 2        | 167.2             | 0.39       | 0.37 | 0.15 |
| 3        | 167.2             | 0.37       | 0.31 | 0.13 |
| 4        | 167.2             | 0.39       | 0.39 | 0.14 |
| 5        | 167.19            | 0.49       | 0.52 | 0.17 |
| 6        | 167.19            | 0.63       | 0.67 | 0.24 |
| 7        | 167.19            | 0.7        | 0.74 | 0.28 |
| 8        | 167.2             | 0.74       | 0.77 | 0.29 |
| 9        | 167.21            | 0.78       | 0.73 | 0.29 |
| 10       | 167.21            | 0.73       | 0.77 | 0.3  |

In Figures 6 and 7 there are plotted variation of measured parameters in regime starting and idling excited stabilized waveform regime that stabilized idle excited.

**Figure 6.** The variation of the measured parameters in starting mode and in idle excited functioning mode
Figure 7. The wave form at stable idle excited functioning mode

Figure 8 represented the vibration spectrum of measured parameters i.e. unexcited steady speed variation spectrum (amplitude) in that order harmonic frequency. It is noted that the maximum value is obtained for harmonic vibrations of order 1 axial-radial bearing higher along the horizontal direction +x, bearing higher axial-radial radial bearing respective +y or +x lower direction.

Figure 8. The vibration spectrum of the measured parameters in a stable excited mode

Figure 9. The variation of the parameters at start and in a stable mode, functioning in charge P=5.6 MW
In Figure 9 there are shown also graphically electrical and mechanical parameters measure to start hydro aggregates for the mode under load, i.e.: the rotor speed \( n \), vibration thrust bearing radial upper horizontal direction + \( x \) \( V_{LRAG_X} \), vibration thrust bearing radial superior radial + \( y \) \( V_{LRAG_Y} \), lower radial bearing vibration direction + \( x \) \( V_{LAG_X} \).

The values that are presented in Table 5 are the parameters for mechanical loading of 5.6 MW, and Table 6 presents the variation parameters for different values of active power: \( P = 1.6 \div 5.6 \) MW.

**Table 5.** The variation of the measured parameters at stable functioning in charge mode \( V \), \( P=5.6 \) MW

| Time (s) | Revolution (RPM) | Vibration \( V_{LRAG_X} \) (mm/s) | Vibration \( V_{LRAG_Y} \) (mm/s) | Vibration \( V_{LAG_X} \) (mm/s) |
|----------|------------------|-----------------------------|-----------------------------|-----------------------------|
| 1        | 167.2            | 0.68                        | 0.71                        | 0.39                        |
| 2        | 167.2            | 0.72                        | 0.77                        | 0.33                        |
| 3        | 167.2            | 0.64                        | 0.7                          | 0.37                        |
| 4        | 167.2            | 0.66                        | 0.8                          | 0.36                        |
| 5        | 167.19           | 0.69                        | 0.71                        | 0.37                        |
| 6        | 167.19           | 0.69                        | 0.72                        | 0.33                        |
| 7        | 167.19           | 0.69                        | 0.73                        | 0.37                        |
| 8        | 167.2            | 0.73                        | 0.74                        | 0.4                          |
| 9        | 167.21           | 0.72                        | 0.75                        | 0.36                        |
| 10       | 167.21           | 0.63                        | 0.68                        | 0.36                        |
| V. average | 167.20        | 0.69                        | 0.73                        | 0.36                        |

**Table 6.** The variation of the measured parameters in charged functioning at different power levels

| Active power \( P \) (MW) | Revolution (RPM) | Vibration \( V_{LRAG_X} \) (mm/s) | Vibration \( V_{LRAG_Y} \) (mm/s) | Vibration \( V_{LAG_X} \) (mm/s) |
|---------------------------|------------------|-----------------------------|-----------------------------|-----------------------------|
| 1.6                      | 167.2            | 0.68                        | 0.81                        | 0.38                        |
|                          | 167.2            | 0.74                        | 0.7                          | 0.32                        |
| \( \div \) 5.6           | 167.19           | 0.57                        | 0.71                        | 0.34                        |
|                          | 167.19           | 0.73                        | 0.83                        | 0.42                        |
|                          | 167.19           | 0.66                        | 0.7                          | 0.43                        |
|                          | 167.2            | 0.72                        | 0.66                        | 0.36                        |

**Figure 10.** The vibration spectrum of the measured parameters stable charge
In Figure 10 is the vibration spectrum of parameters measured under load regime stabilized and the maximum value is obtained for harmonic vibrations of order 1.

4. Measurement upon starting the hydro-generator
The commissioning of hydro-generator were performed vibration measurements and checks for the following modes: idle (unexcited and excited) or under load.

By this test determines the performance of the hydro-generator mechanical assembly vibration measurements both in the transitional arrangements starting and steady idle. There have been following sizes: n rotor speed, vibration higher radial thrust bearing in the horizontal direction $+x V_{LRAG_X}$, higher radial thrust bearing vibration radial $+y V_{LRAG_Y}$, lowers radial bearing vibration direction $+x V_{LAG_X}$.

The measurement results in transitional and steady start after dismantling hydro-generator unexcited and operation are given in Figure 11. The commissioning of hydro-generator were performed vibration measurements and checks for the following modes: idle (unexcited and excited) or under load.

![Figure 11. The variation of the parameters measured in transitory starting mode and idle unexcited functioning](image)

| Time (s) | Revolution (RPM) | $V_{LRAG_X}$ (mm/s) | $V_{LRAG_Y}$ (mm/s) | $V_{LAG_X}$ (mm/s) |
|----------|------------------|---------------------|---------------------|-------------------|
| 1        | 76.31            | 0.19                | 0.16                | 0.13              |
| 2        | 98.82            | 0.19                | 0.14                | 0.17              |
| 3        | 121.33           | 0.47                | 0.21                | 0.17              |
| 4        | 140.71           | 0.23                | 0.13                | 0.11              |
| 5        | 143.78           | 0.24                | 0.21                | 0.15              |
| 6        | 148.16           | 0.42                | 0.15                | 0.14              |
| 7        | 150.76           | 0.37                | 0.19                | 0.14              |
| 8        | 154.29           | 0.56                | 0.24                | 0.16              |
| 9        | 166.3            | 0.37                | 0.29                | 0.22              |
| 10       | 166.46           | 0.34                | 0.26                | 0.18              |
| 11       | 166.96           | 0.36                | 0.23                | 0.21              |
| 12       | 166.96           | 0.31                | 0.23                | 0.19              |
| 13       | 166.95           | 0.31                | 0.23                | 0.18              |
| 14       | 166.95           | 0.43                | 0.22                | 0.21              |
The values of the parameters measured in the starting phase after dismantling the hydro aggregate and commissioning of the regime idle unexcited stabilized are shown in Table 7, and the values of the parameters measured at steady idle unexcited in Table 8.

### Table 8. Parameters measured in a stable mode of idle unexcited functioning

| Time (s) | Revolution (RPM) | Vibrations |
|----------|------------------|------------|
|          |                  | \( \text{LRAG}_x \) | \( \text{LRAG}_y \) | \( \text{LAG}_x \) |
| 1        | 166.7            | 0.59       | 0.21       | 0.18       |
| 2        | 166.95           | 0.34       | 0.26       | 0.17       |
| 3        | 166.79           | 0.32       | 0.24       | 0.2        |
| 4        | 166.95           | 0.37       | 0.25       | 0.19       |
| 5        | 166.95           | 0.44       | 0.23       | 0.2        |
| 6        | 189.91           | 0.36       | 0.25       | 0.19       |
| 7        | 166.95           | 0.48       | 0.27       | 0.17       |
| 8        | 166.95           | 0.43       | 0.22       | 0.21       |
| 9        | 166.95           | 0.39       | 0.23       | 0.2        |
| 10       | 166.95           | 0.42       | 0.25       | 0.24       |
| 11       | 166.7            | 0.41       | 0.27       | 0.19       |
| 12       | 166.95           | 0.37       | 0.28       | 0.22       |
| 13       | 166.78           | 0.49       | 0.23       | 0.2        |
| 14       | 166.78           | 0.49       | 0.23       | 0.2        |
| V. average | 168.52         | 0.421     | 0.244     | 0.197     |

The spectrum of vibration parameters measured at steady unexcited after dismantling of hydro aggregate and commissioning of are presented in Figure 12, and the maximum value is obtained for harmonic vibrations of order 1.

**Figure 12.** The vibration spectrum of the measured parameters in unexcited stable functioning mode
From Figure 12 it is observed that the maximum vibration along the axial-radial bearing higher radial + y respectively lower bearing radial direction + x is greater than before dismantling and axial-radial bearing higher along the horizontal direction is smaller.

In idle excited mode, connecting the generator excitation voltage determines a nominal voltage stator, rotor speed and registering vibrations in the chambers.

Figure 13 are plotted variation of measured parameters in regime starting and idling excited stabilized and is represented in Figure 7 wave-form stabilized and /or idle excited modes.

![Figure 13. Parameter variation measured in the starting process and the idle stabilized excited mode](image)

Parameters measured values steady idle excited are shown in Table 9 and the variation of measured values during transient excitation in Table 10.

### Table 9. Parameters measured in stable idle functioning mode

| Time (s) | Revolution (RPM) | VLRAG \_x (mm/s) | VLRAG \_y (mm/s) | VLAG \_x (mm/s) |
|----------|------------------|-----------------|-----------------|----------------|
| 1        | 166.69           | 0.33            | 0.39            | 0.32           |
| 2        | 166.61           | 0.79            | 0.42            | 0.38           |
| 3        | 166.78           | 0.48            | 0.39            | 0.36           |
| 4        | 166.61           | 0.5             | 0.4             | 0.36           |
| 5        | 166.69           | 0.41            | 0.38            | 0.36           |
| 6        | 166.61           | 0.35            | 0.4             | 0.37           |
| 7        | 166.61           | 0.45            | 0.42            | 0.38           |
| 8        | 166.61           | 0.76            | 0.38            | 0.36           |
| 9        | 166.7            | 0.39            | 0.44            | 0.32           |
| 10       | 166.45           | 0.48            | 0.4             | 0.34           |
| 11       | 166.61           | 0.6             | 0.4             | 0.4            |
| V. Average | 166.63       | 0.50            | 0.40            | 0.36           |
Table 10. Variation of the measured values during the transitory exciting process

| Time (s) | Revolution (RPM) | Vibrations (mm/s) |
|----------|------------------|------------------|
| T        | n                | \(V_{LRAG_x}\)   | \(V_{LRAG_y}\)   | \(V_{LAG_x}\)   |
| 1        | 0.4              | 0.26             | 0.21             | 0.4             |
| 2        | 0.41             | 0.23             | 0.24             | 0.41            |
| 3        | 0.4              | 0.25             | 0.22             | 0.4             |
| 4        | 0.47             | 0.27             | 0.22             | 0.47            |
| 5        | 0.45             | 0.28             | 0.25             | 0.45            |
| 6        | 0.55             | 0.31             | 0.27             | 0.55            |
| 7        | 0.55             | 0.4              | 0.3              | 0.55            |
| 8        | 0.48             | 0.31             | 0.35             | 0.48            |
| 9        | 0.43             | 0.4              | 0.37             | 0.43            |
| 10       | 0.61             | 0.39             | 0.38             | 0.61            |
| 11       | 0.43             | 0.41             | 0.33             | 0.43            |
| 12       | 0.43             | 0.33             | 0.32             | 0.43            |
| 13       | 0.48             | 0.39             | 0.36             | 0.48            |

Vibration spectrum parameters are measured at steady excited represented in Figure 14.

Figure 14. The vibration spectrum of the measured parameters at stable excited mode

From Figure 14 is observed that the maximum vibration along the axial-radial bearing higher radial + y respectively axial-radial bearing upper horizontal direction + x is less than before disassembly and lower radial bearing along the direction + x is bigger.

Attempts are considering establishing performance operation of the hydro vibration measurements regime under load. In Figure 15 are presented graphically electrical and mechanical parameters measured at the start hydro regime under load.
Figure 15. Variation of the parameters in excited and stable modes at charged functioning for $P=1.77$ MW

The values are presented in Table 11 parameters for electrical and mechanical loading of 5.6 MW, and Table 12 presents the variation parameters for different values of active power: $P = 1.6 \div 5.6$ MW.

Table 11. Variation of the measured parameters at charged stable functioning for $P=5.6$ MW

| Time (s) | Revolution (RPM) | Vibrations |
|----------|------------------|------------|
|          |                  | $v_{LRAG_x}$ | $v_{LRAG_y}$ | $v_{LAG_x}$ |
| 1        | 166.63           | 0.48        | 0.46         | 0.4         |
| 2        | 166.71           | 0.52        | 0.49         | 0.36        |
| 3        | 166.71           | 0.39        | 0.46         | 0.37        |
| 4        | 166.63           | 0.43        | 0.37         | 0.37        |
| 5        | 166.63           | 0.46        | 0.4          | 0.4         |
| 6        | 166.63           | 0.44        | 0.39         | 0.4         |
| 7        | 166.47           | 0.6         | 0.4          | 0.43        |
| 8        | 166.46           | 0.36        | 0.47         | 0.36        |
| 9        | 166.63           | 0.4         | 0.36         | 0.39        |
| 10       | 166.79           | 0.68        | 0.43         | 0.39        |
| 11       | 166.46           | 0.46        | 0.38         | 0.36        |
| 12       | 166.46           | 0.46        | 0.44         | 0.43        |
| 13       | 166.63           | 0.45        | 0.38         | 0.36        |
| 14       | 166.79           | 0.6         | 0.4          | 0.34        |
| 15       | 166.63           | 0.51        | 0.42         | 0.37        |
| 16       | 166.46           | 0.75        | 0.41         | 0.36        |
| 17       | 196.21           | 0.61        | 0.43         | 0.38        |
| 18       | 166.63           | 0.41        | 0.44         | 0.39        |
| 19       | 166.17           | 0.37        | 0.4          | 0.37        |
| 20       | 166.71           | 0.49        | 0.41         | 0.42        |
| V. Average | 168.07         | 0.49        | 0.42         | 0.38        |
Table 12. Variation of the measured parameters at charged functioning at different power stages

| Active power (MW) | Revolution (RPM) | Vibrations | | | |
|------------------|------------------|------------|------------|------------|------------|
| P                | N                | VLRAG_x    | VLRAG_y    | VLAG_x     |
| 1.6              | 167.8            | 0.54       | 0.48       | 0.41       |
| ÷                | 166.7            | 0.39       | 0.33       | 0.31       |
| 5.6              | 166.6            | 0.41       | 0.38       | 0.39       |
|                  | 166.7            | 0.55       | 0.42       | 0.34       |

Figure 16 represents the spectrum of vibration parameters measured under load regime stabilized and the maximum value is obtained for harmonic vibrations of order 1.

Figure 16 shows that the maximum vibration along the axial-radial bearing higher radial + y respectively axial- radial bearing upper horizontal direction + x is less than before disassembly and lower radial bearing along the direction + x is bigger.

Based on experimental measurements made before and after repair the hydro aggregate is seen:
- At the level of the thrust bearing, vibration in the radial direction + y reaches the value of 0.8 mm/s to 0.385 mm/s in the empty unexcited;
- After repair maximum level of vibration in idle mode excited is 0.5 mm/s radial + x, to 0.421 mm/s value recorded under idle unexcited;
- The system under load is the tendency to standardize the level of vibration to the value of 0.49 mm/s;

5. Conclusions

In this paper based on experimental measurements performed, shows the following: vibrations in idle mode in the three camps are influenced largely by the state of magnetization of the rotor, the system under load is the tendency to standardize the level of vibration, under a throw of pregnancy there is a proper behavior in dynamic rotor over-speed during the transitional arrangements, observed that under unexcited idling vibration occurs due to sharp flow regimes and due to offsetting.
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