Unbalance influence on the rotating assembly dynamics of a hydro

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Abstract. The dynamics of the rotating parts of a hydro is characterized by the dynamic interaction between the rotor, the stator and the working fluid in order to operate the hydro. The main factors influencing the dynamics of the rotating parts of a hydro are: rotor unbalance, unbalanced magnetic pull, shaft misalignment and hydraulic flow regime. Rotor unbalanced is one of the most common factors influencing the dynamic stability of the rotating parts of a hydro. The unbalanced is determined by: uneven distribution of rotating masses, displacement of parts in the rotor during rotation, inhomogeneity of rotor component materials, expansion of the rotor due to heating, and rising speed during the transient discharge of the load. The mechanical imbalance of a rotor can lead to important forces, responsible for the vibration of the machine, which ultimately leads to a shorter operating time. Even a low unbalance can lead, in the case of high speed machines, to major unbalance forces that cause significant damage to the equipment. The unbalance forces cause additional vibrations in the bearings as well as in the foundation plate. To avoid these vibrations, it is necessary in the first stage to balance the static rotor in the construction plant and then to a dynamic rotation balancing.

1. Introduction

Considering the general tendency to reduce conventional energy resources, especially fossil fuel in the last period of time, there is a growing emphasis on the issue of increasing the efficiency of electricity production from unconventional resources [1].

The advantages of generating electricity by means of high power hydro, which typically exceed 100MW, are conditioned by the reliability of these equipments and the requirement of safe operation throughout their life [2-6].

The high power and high speed hydro power rotors have very large dimensions and weights, so they store huge amounts of kinetic energy during operation, which under certain conditions can lead to significant damage by shutting down.

Practice has shown that one of the major factors which determine the safety of operation is the rotating parts of hydro.

The dynamics of the rotating parts of a hydro is characterized by the dynamic interaction between the rotor, the stator and the working fluid in order to operate the hydro safely [7-12].

The main factors influencing the dynamics of the rotating parts of a hydro are: unbalance, unbalanced magnetic pull, shaft misalignment and hydraulic flow [13-15].
In this paper we present the factors that influence the dynamics of the rotating parts of the hydro-aggregates and the way they contribute to the instability of the position of the rotation axis of the hydro-aggregate. Also, some experimental procedures are set to highlight the causes that lead to inadequate functioning of the hydro-aggregate in terms of bearing vibrations due to the instability of the rotor dynamics.

2. Unbalance influence

Unbalance is one of the most common factors in practice, influencing the dynamic stability of the rotating parts of a hydro [16].

It is determined by: uneven distribution of rotating masses, displacement of parts in the rotor during rotation, inhomogeneity of rotor component materials, expansion of the rotor due to heating and rising speed during transient discharge from load.

The unbalance determines forces that produce radial beats and vibrations, the frequencies of which are determined by the rotor speed [16], [17]:

\[ f_d = k \frac{n}{60} \text{ (Hz)} \]  

The centrifugal force produced by the unbalance caused by the initial eccentricity is the expression:

\[ F_{em} = 11.2 \left( \frac{n}{1000} \right)^2 G_2 l_0 \]  

where:

- \( e_o \) is the initial static eccentricity of the rotor shaft;
- \( g_2 \) is the weight of the rotor between the two radial guide bearings expressed in kg.

Initial eccentricity \( e_o \) can be expressed as an amount of two eccentricities:

\[ e_o = \varepsilon_1 + \varepsilon_2 \]  

where:

- \( \varepsilon_1 \) is the eccentricity of the shaft to bearings caused by bearing play, bearing wear, or imoprection of the assembly;
- \( \varepsilon_2 \) is the eccentricity of the rotor axis relative to the stator axis due to ovality, deviation of the air gap, shaft line break;

The operation of a hydro with a large unbalance leads to high vibrations in the bearings or to an unsafe operation. For each machine, dynamic balancing is required in order to cancel the unbalance forces [17].

The balancing of the rotor is carried out first, statically, in the construction plant, followed by the dynamic rotation balancing [17].

To achieve proper results, dynamic balancing is required in two planes, since the distribution of masses along the length of the rotor is not uniform.

Balancing is done by placing weights on the side surface of the rotor \( \Delta G_1 \) și \( \Delta G_2 \).

These weights determine the centrifugal forces:

\[ F_{c1} = 11.2 \left( \frac{n}{1000} \right) \Delta G_1 \cdot r_1 \]  

\[ F_{c2} = 11.2 \left( \frac{n}{1000} \right) \Delta G_2 \cdot r_2 \]  

where:

- \( r_1 \) și \( r_2 \) are the rays corresponding to the points where the two weights were placed \( \Delta G_1 \) și \( \Delta G_2 \).

The weights \( \Delta G_1 \) and \( \Delta G_2 \) are determined in such a way that the forces \( F_{c1} \) and \( F_{c2} \) balance the two forces of imbalance \( F_d_1 \) și \( F_d_2 \) at the two levels at which balancing is performed.
The unbalance forces $F_{d1}$ and $F_{d2}$ being spaced, with the length $l$, cause a moment that produces additional reaction forces in the radial guide bearings, which results in a further heating thereof.

Proper balancing implies:

$$F_{c1} = 11.2 \left( \frac{n}{1000} \right)^2 \Delta G_1 \cdot r_1 = -F_{d1}$$

$$F_{c2} = 11.2 \left( \frac{n}{1000} \right)^2 \Delta G_2 \cdot r_2 = -F_{d2}$$

(5)

In this way, the unbalance forces are canceled at the level of the two planes as in Figure 1, which determines that the hydro-aggregate operation is appropriate from this point of view.

![Figure 1. Dynamic balancing in 2 planes](image)

It is worth noting that the balancing of the rotating assembly of a hydro is performed at the level of the rotor which has a very large mass and allows the balancing weights to be arranged on the rotor hub or on the fan discs [17].

3. **Experimental results**

Experimental tests have been carried out on different hydro of different sizes [18]:

- Hydro no.2 from Hydro power plant Cărinești I, max power: 5.4 MW
- Hydro no.1 from Hydro power plant Mâncești, max power: 6.1 MW
- Hydro no.1 from Hydro power plant Totești I, max power: 8.4 MW
- Hydro no.1 from Hydro power plant Lerești, max power: 20 MW

The following were measured on these hydro [19]:

- Vibration in the upper generator guide bearing on the +x axis ($V_{LRAG}+x$)
- Vibration in the upper generator guide bearing on the +y axis ($V_{LRAG}+y$)
- Vibration in the lower generator guide bearing on the –x axis ($V_{LRI}-x$)
- Rotor speed ($n$)

3.1. **Experimental results from Hydro no.2 at Hydro power plant Cărinești**

Values obtained before maintenance are given in Table 1.

| No | n [rpm] | Vibration [mm/s] |
|----|---------|----------------|
|    |         | $V_{LRAG}+Y$  | $V_{LRAG}+X$  | $V_{LRI}-X$  |

3
A high level of vibration is observed in upper generator guide bearing on the +y axis. To reveal the causes of these vibrations we proceed to decompose the harmonic vibration signals. Figure 2 shows the frequency spectrum of the vibration.

![Figure 2. Spectrum frequency of vibrations](image)

The frequency spectrum highlights a very large amplitude of the no. 3 harmonics and a very small amplitude of the fundamental, indicating a negligible mechanical imbalance, so no dynamic balancing of the rotating assembly is required. After completion of the repair work on the hydro the results are as follows:

| No | Vibration Value |
|----|-----------------|
|    | V_LRAAG +Y | V_LRAAG +X | V_LRI -X |
| 1  | 0.32        | 0.28        | 0.18     |
| 2  | 0.32        | 0.3         | 0.18     |
| 3  | 0.32        | 0.3         | 0.2      |

| 1  | 215.2       | 0.63        | 0.53      | 0.77      |
| 2  | 215.14      | 0.69        | 0.53      | 0.51      |
| 3  | 215.1       | 0.61        | 0.49      | 0.49      |
| 4  | 215.1       | 0.65        | 0.55      | 0.4       |
| 5  | 215.15      | 0.73        | 0.54      | 0.27      |
| 6  | 215.22      | 0.75        | 0.53      | 0.27      |
| 7  | 215.28      | 0.77        | 0.56      | 0.46      |
| 8  | 215.3       | 0.61        | 0.53      | 0.28      |
| 9  | 215.27      | 0.69        | 0.53      | 0.57      |
| 10 | 215.28      | 0.68        | 0.5       | 0.51      |
| 11 | 215.25      | 0.77        | 0.59      | 0.43      |
| 12 | 215.23      | 0.72        | 0.46      | 0.29      |
| 13 | 215.2       | 0.68        | 0.48      | 0.23      |
| 14 | 215.21      | 0.73        | 0.5       | 0.26      |
| 15 | 215.21      | 0.81        | 0.5       | 0.28      |

The average values are:

- **Average value**: 0.73 mm/s, 0.51 mm/s, 0.33 mm/s
Figure 3 shows the frequency spectrum of the vibration signals, where there is an almost complete reduction of the 3rd order harmonics and some reduction of the fundamental amplitude compared to the situation before the repair.

3.2. Experimental results from Hydro no.1 at Hydro power plant Manicești

Values obtained before maintenance are given in Table 3.

Table 3. Vibration Value

| Time [s] | Speed [RPM] | LRA_x_rad [mm/s] | LRA_y_rad [mm/s] | LRI_x_rad [mm/s] |
|----------|-------------|------------------|------------------|------------------|
| 0        | 166.7       | 1.87             | 0.39             | 0.11             |
| 1        | 166.61      | 2.02             | 0.28             | 0.15             |
| 2        | 166.69      | 1.67             | 0.39             | 0.12             |
| 3        | 166.53      | 2.08             | 0.41             | 0.16             |
| 4        | 166.53      | 1.93             | 0.4              | 0.13             |
| 5        | 166.36      | 1.94             | 0.4              | 0.14             |
| 6        | 166.61      | 1.7              | 0.33             | 0.21             |
| 7        | 166.53      | 1.84             | 0.38             | 0.13             |
It is noted that the vibration level is very high, the maximum being in upper generator guide bearing on the +x axis, 1.83 mm / s.

![Figure 4. Spectrum frequency of vibrations](image)

The very high amplitude of the fundamental, 1,946 mm / s indicates a pronounced unbalance, but the presence of higher harmonics with very large amplitudes of order 2, 3 and 5 indicates the presence of other factors that influence the rotor dynamics.

For this reason, it is necessary that the repair work program eliminates these factors before dynamic balancing. When checking the vibrations after balancing, it was found that the vibration level dropped a lot, the results being given in Table 4.

The maximum vibration level in radial direction + x in upper generator guide bearing on the +x axis decreased from 1.83 mm / s to 0.58 mm / s, which justifies the efficiency of maintenance work on the hydro-aggregate.

| Time [s] | Speed [RPM] | LRA_x_rad [mm/s] | LRA_y_rad [mm/s] | LRI_x_rad [mm/s] |
|----------|-------------|------------------|------------------|------------------|
| 0        | 166.7       | 0.17             | 0.31             | 0.51             |
| 1        | 166.61      | 0.16             | 0.47             | 0.56             |
| 2        | 166.69      | 0.12             | 0.38             | 0.54             |
| 3        | 166.53      | 0.14             | 0.31             | 0.7              |
| 4        | 166.53      | 0.21             | 0.34             | 0.72             |
| 5        | 166.36      | 0.16             | 0.63             | 0.5              |
| 6        | 166.61      | 0.17             | 0.38             | 0.48             |
| 7        | 166.53      | 0.18             | 0.36             | 0.51             |
| 8        | 166.69      | 0.12             | 0.47             | 0.47             |
| 9        | 166.53      | 0.14             | 0.37             | 0.5              |
| 10       | 166.36      | 0.2              | 0.36             | 0.48             |
| Average  | 0.18        | 0.38             | 0.58             |

Table 4. Vibration Value
3.3. Experimental results from Hydro no.1 at Hydro power plant Totești I

Values obtained before maintenance are given in Table 5.

| No | n [rpm] | Vibration Value | Vibration [mm/s] |
|----|--------|-----------------|------------------|
|    |        | V_LRAG_+Y | V_LRAG_+X | V_LRI_-X |
| 1  | 215.2  | 0.79     | 0.66    | 0.65    |
| 2  | 215.14 | 0.82     | 0.65    | 0.62    |
| 3  | 215.1  | 0.98     | 0.71    | 0.51    |
| 4  | 215.1  | 0.83     | 0.67    | 0.5     |
| 5  | 215.15 | 0.82     | 0.67    | 0.49    |
| 6  | 215.22 | 0.82     | 0.67    | 0.56    |
| 7  | 215.28 | 0.87     | 0.66    | 0.47    |
| 8  | 215.3  | 0.8      | 0.7     | 0.54    |
| 9  | 215.27 | 0.78     | 0.74    | 0.48    |
| 10 | 215.28 | 0.84     | 0.72    | 0.61    |
| 11 | 215.25 | 0.91     | 0.69    | 0.5     |
| 12 | 215.23 | 0.82     | 0.69    | 0.44    |
| 13 | 215.2  | 0.85     | 0.7     | 0.54    |
| 14 | 215.21 | 0.72     | 0.64    | 0.55    |
| 15 | 215.21 | 0.88     | 0.65    | 0.04    |

Average value 0.83 0.67 0.51

Figure 5. Spectrum frequency of vibrations

A high level of vibrations can be noticed in upper generator guide bearing on the +x axis 0.83 mm/s.

From the frequency spectrum of the vibrations shown in Figure 5, there are observed the existence of the order 3 and 5 harmonics with higher amplitudes than the fundamental.

After repair, the following results were registered:

| No | n [rpm] | Vibrații [mm/s] |
|----|--------|-----------------|
|    |        | V_LRAG_+Y | V_LRAG_+X | V_LRI_-X |
| 1  | 212.22 | 0.56     | 0.34    | 0.85    |
It is noticed that after the repair the vibration level increased in lower generator guide bearing on the -x axis.

The frequency spectrum shown in Figure 6 that harmonics of the order 3, 4 and 5 have not been completely reduced and indicates the presence of rotor oscillations but of lesser amplitude. The presence of these harmonics leads to the conclusion that all the conditions for proper operation have not been ensured through the maintenance work.

Since the maximum vibration level on the base is high, it is advisable to dynamically balance the rotating assembly.

3.4. Experimental results from Hydro power plant Lerești
After repair, the following results were registered in Figure 7.
Figure 7. Spectrum frequency of vibrations

The vibration spectrum shown in Figure 7 highlights the existence of the 2nd order harmonics whose amplitude is very high, 2.44 mm / s. The existence of this harmonics reveals a shaft misalignment. Balancing is possible after shaft misalignment is resolved.

4. Conclusions

The NAR neural network can be used to predict a time series from the same series past values. This network is a dynamic network with feedback that can be transformed between open-loop and close-loop.

At hydro no.2 at Hydro power plant Cârnești I from the measurements made before the repair showed that dynamic balancing is not necessary and after the repair the vibrations decreased from 0.73 mm / s to 0.32 mm / s, the repair works being efficient.

At hydro no.1 at Hydro power plant Mânicăști there was a mechanical imbalance, but for its correction it is necessary that the maintenance program eliminates the other factors that influence the rotor dynamics. After repair and balancing, vibrations decreased from 1.83 mm / s to 0.58 mm / s.

At hydro no.1 at Hydro power plant Totești I after completion of maintenance work on the frequency spectrum, a dynamic balancing is required.

At hydro no.1 at Hydro power plant Lerești high vibrations caused by the shaft misalignment in the rotary assembly prevent proper balancing.

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