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CRITICAL ANALYSIS OF VIBRATION SOURCES OF HYDRO AGGREGATES IN OPERATING REGIME

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Abstract - The paper makes a critical analysis by evaluating the vibration frequency of hydro aggregates, the vibration amplitude and the direction of propagating, directly correlated with the vibration possible cause.

Keywords: vibration sources, fundamental harmonics, pulsations, excitation, cavitation

1. INTRODUCTION

Having in view that the hydropower aggregate of hydroelectric machines composition are considered as critical, with most expensive value, it is essential that their operation should be carried out in both higher yield and reliability. Taking into account the multitude of parameters (hydraulic, mechanical, electrical, thermal, etc.) characterizing a hydropower aggregate operation and, as well, the interdependence between them, the providing of the above conditions is performed by the following steps:

- at design level, considering the requirements of quality, performance and safety;
- at implementation level by compliancing the technologycal and quality procedures;
- at exploitation level, with regard to preventive and corrective maintenance requirements.

If the hydropower aggregate has run over the design and technological manufacturing steps, follow-up installing, it is delivered to the operating and exploiting circuit wherein shows its capacity of fulfilling the function for which it was made. At this stage, the most difficult problems arise because the operating conditions may introduce new elements, neglected or unknown in the design and technological manufacturing steps. First, in operational phase, as following the comitted complex loads, the hydro aggregate is subject to:

- deformation of components;
- imbalance of the shafts, bearings;
- mass imbalances;
- attritions of the parts;
- variable duties such as hydraulic, mechanical, electromagnetic, thermal, etc..

Under these circumstances, the actual condition of the operating hydro aggregate differs in terms of the ideal dynamic functioning. This difference of condition manifests itself in various ways, but primarily manifesting in the vibration and noise level.

2. SOURCES OF VIBRATIONS IN HYDRO AGGREGATE

The main sources de vibrations which interest the group are: the misalignment from the line of shafts, mass imbalances, bearing defects, mechanical games, hydrodynamic, electrical, magnetic forces, etc.

The components of the shaft are connected through flanging. Regardless of whether they fit or not, in the admitted tolerances, deviations from perfect line generates excitation forces that manifest themselves in the vibrations through components having the frequency of rotation accompanied by harmonics and sub-harmonics, of which the most significant are those of the order 2 and ½.

Defects in bearings and mechanical games may occur due to normal wear during use, or as a consequence of the destruction or turbulence of the oil film, in the case of unsuitable parameters of the lubrication system.

Imbalances can be caused by the weakening of the various components of the rotating assembly or resettlement of components.

Other types of defects that interested specific coupled equipment, mainly the electric generator and turbine, are listed in general terms and are not known at the level imposed by the complexity of the equipment, requiring further in-depth study of the phenomena and an accumulation of a large number of data and experimental checks to establish effective technical diagnostic criteria of hydropower equipments.

In table 1, there is a summary of the correlation of vibration frequency and possible causes.

Table 1. Vibration frequency and possible causes

Nr. crt.	Frequency	Possible cause	Vibration amplitude	Direction	Observations
0	1	2	3	4	5
1.	n	a) Poor balancing	Inversely proportional to the square of the residual force	Radial	Most frequent
		b) Defective line of shafts (shafts or bearings)	Proportional with the deviation	Axial, Radial	Accompanied by 2 and 3 order harmonics
		c) Uneven air gap	Usually less important for deviations less than 10%		Disappears at disconnection of excitation
		d) Electrical fault	Up to very high values, according to the nature of the fault		Disappears at disconnection of excitation
		e) Unsymmetrical displacements and deformations of elements of the structure of rotor caused by dilatation	Usually do not have high values and are reversible, but can also be very high and remanent	Radial-axial	Value varies according to thermic regime
		f) Eccentricity of the shafts' pins	Relatively low, but may increase in time		
		g) Mechanical games			
2.	2n	a) Mechanical games			Usually associated with the defective line of shafts or balancing
		b) Defective line of shafts (shafts or bearings)	Relatively high	Axial	Often
		c) Electrical fault			Directly proportional with power; disappears at disconnection of excitation

Table 1. Vibration frequency and possible causes (sequel)

0	1	2	3	4	5
3.	3n	a). Defective line of shafts (shafts or bearings) b) Electrical fault	Relatively high	Axial, Radial	Often
4.	4n	Defective line of shafts			
5.	n/2	a). Shaft friction in the bearing (oil film, instability of the movement of the pin in the bearing) b). Defective line of shafts c). Defects in bearings d). Mechanical games		Radial Axial, Radial Radial, Axial	In groups with higher speeds, in the turbulent regime of the oil film
6.	n/3	Defects in bearings		Radial, Axial	
7.	2n/3	Defects in bearings		Radial, Axial	
8.	kn	a). Uneven air gap b). The shock generated by impact between the water and turbine blade		Radial	k = nr. of turbine blades (generally become dangerous if they produce resonance with other parts)
9.	100 Hz	Stator bar vibration			
10.		Vibrations of cavitation	Difficult to assess		For great cavitations – 10 Hz

3. THE RESULT OBTAINED BY TECHNICAL DIAGNOSIS OF SOME HYDROPOWER UNITS VIBRATIONS

The causes of vibrations, the stages of diagnosis by monitoring vibrations and the structure of the diagnosis systems based on vibrations are largely reflected in the specialized literature. The opportunity of these diagnosis systems is actually recognized, these being in full expansion. Within S.C. Hidrocentrale S.A. Cluj-Napoca they use a portable Brüel & Kjaer 2513 device for monitoring vibrations at hydro power units. At the above mentioned hydro electric plants, the measurements were periodically conducted since 1998. The measurements points were:

- superior bearing of the generator (axial ≡ 1; radial ≡ 2);
- inferior bearing of the generator (axial ≡ 3; radial ≡ 4);
- bearing of the turbine (axial ≡ 5; radial ≡ 6);

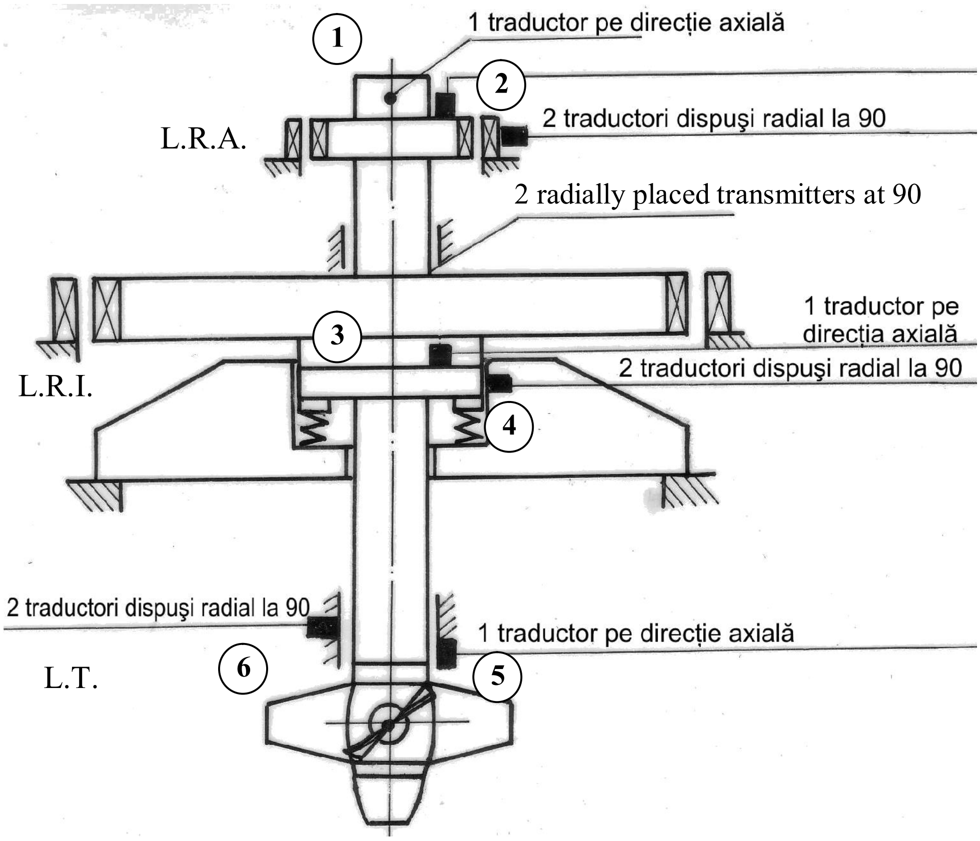

Fig. 1. Points where measurements were made

Measurements were made in the following operating modes:

- empty non-excited (RG1);
- empty excited (RG2);
- operating at 25 % of nominal load (RG3);
- operating at 50 % of nominal load (RG4);
- operating at 75 % of nominal load (RG5);
- operating at nominal load (RG6);

Moments in which measurements were made were as follows: at fixed intervals (periodically) before and after RT or RC.

The measured parameters of the vibrations are:

- double amplitude of vibration [μm];
- vibration speed (vibro-speed) [mm/s];
- acceleration [mm/s^2];

For instance, in fig. 2. is presented the spectrum of the vibrations recorded at hydro aggregate nr. 1 of Hydro Electric Plant Tileagd, and in fig. 3. there is presented the time mediated variation of variable “2 A” (double amplitude of vibration) for the respective hydro aggregate.

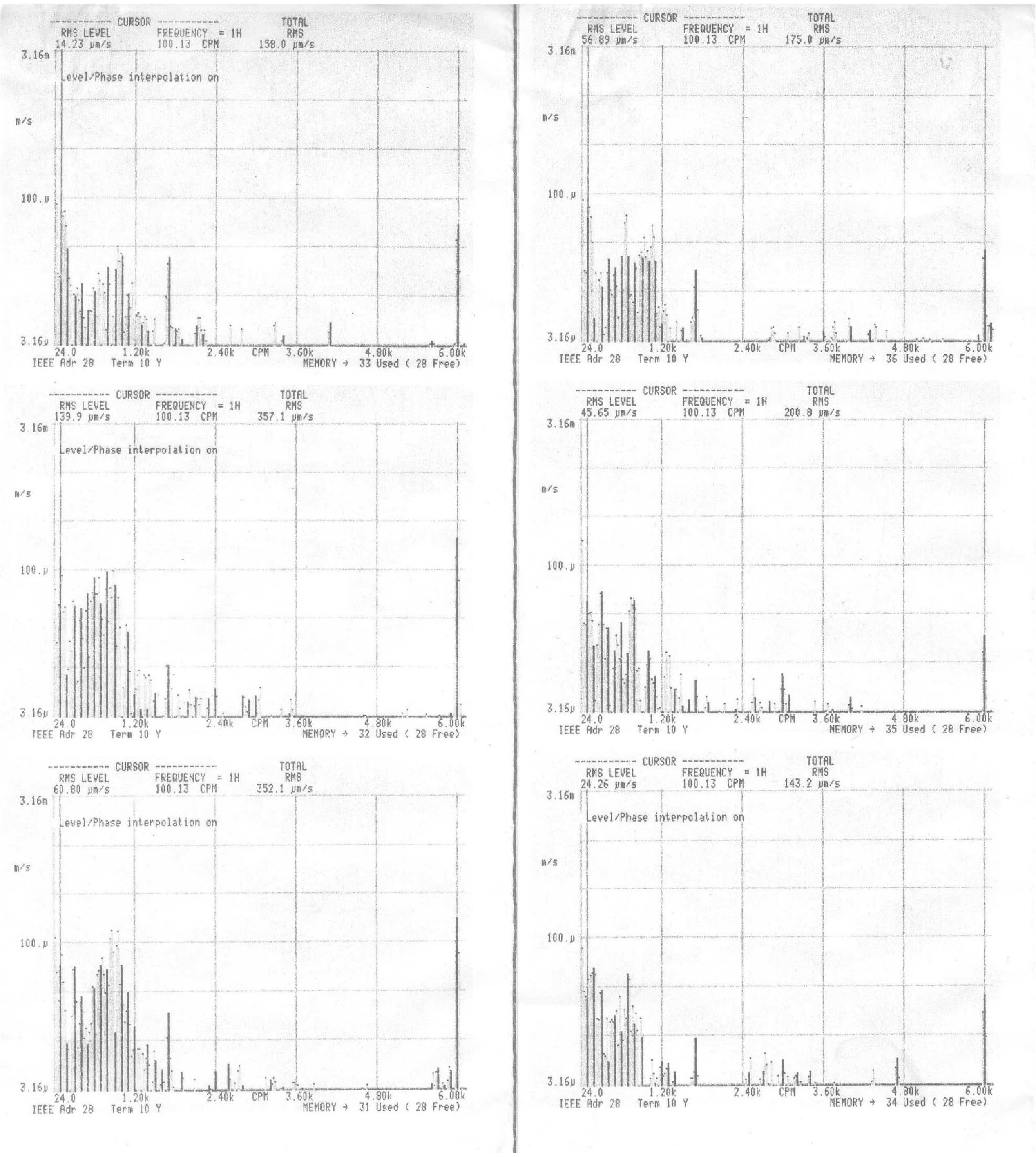

Fig. 2. The Spectrum of vibrations of hydro-generator nr. 1 at H.E.P. Tileagd

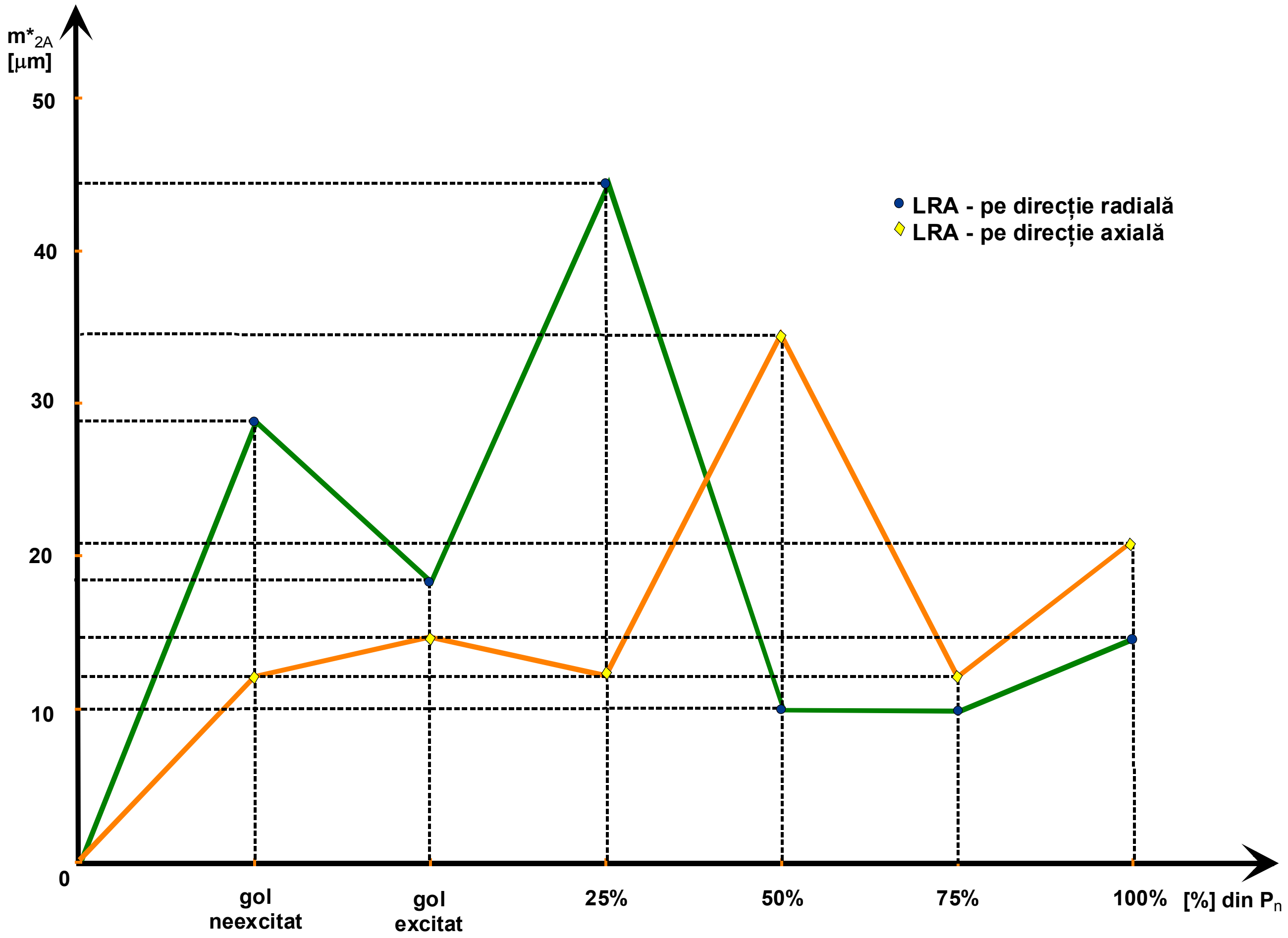

Fig. 3.a Time mediated variation of variable "2A" for HA nr. 1 at H.E.P Tileagd, in radial axial bearing (R.A.B)

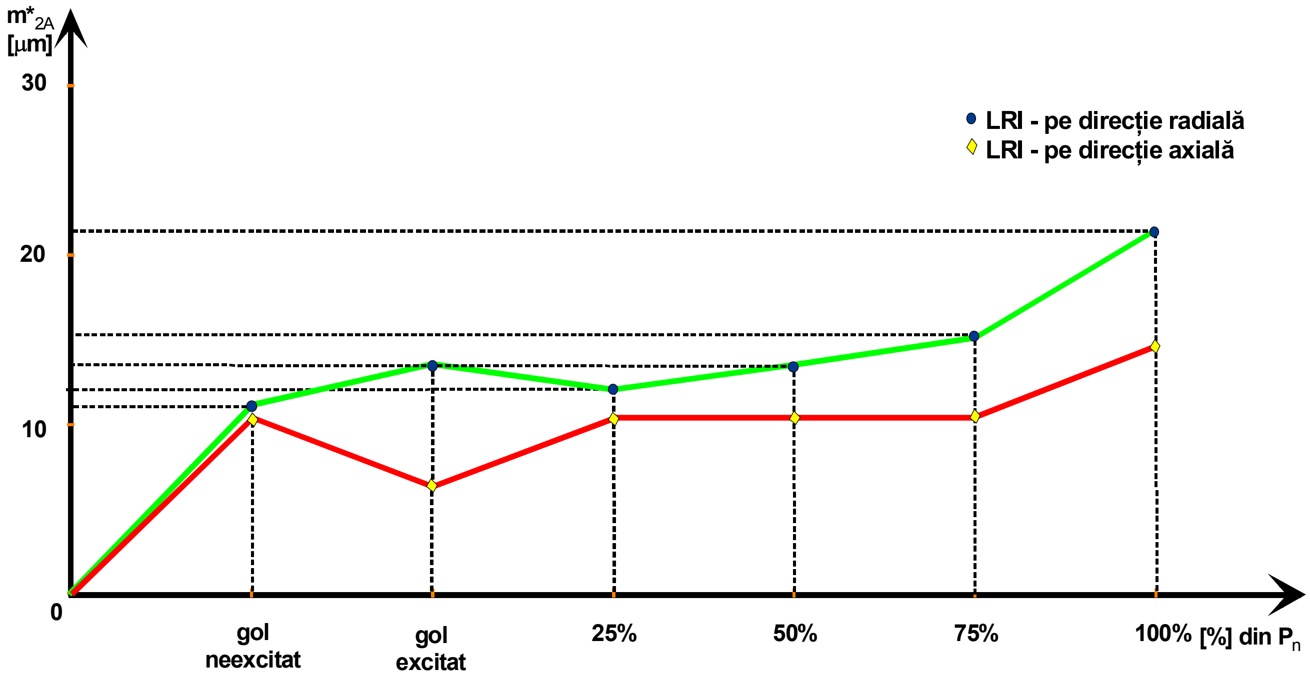

Fig. 3.b Time mediated variation of variable "2A" for HA nr. 1 at H.E.P Tileagd, in radial inferior bearing (R.I.B)

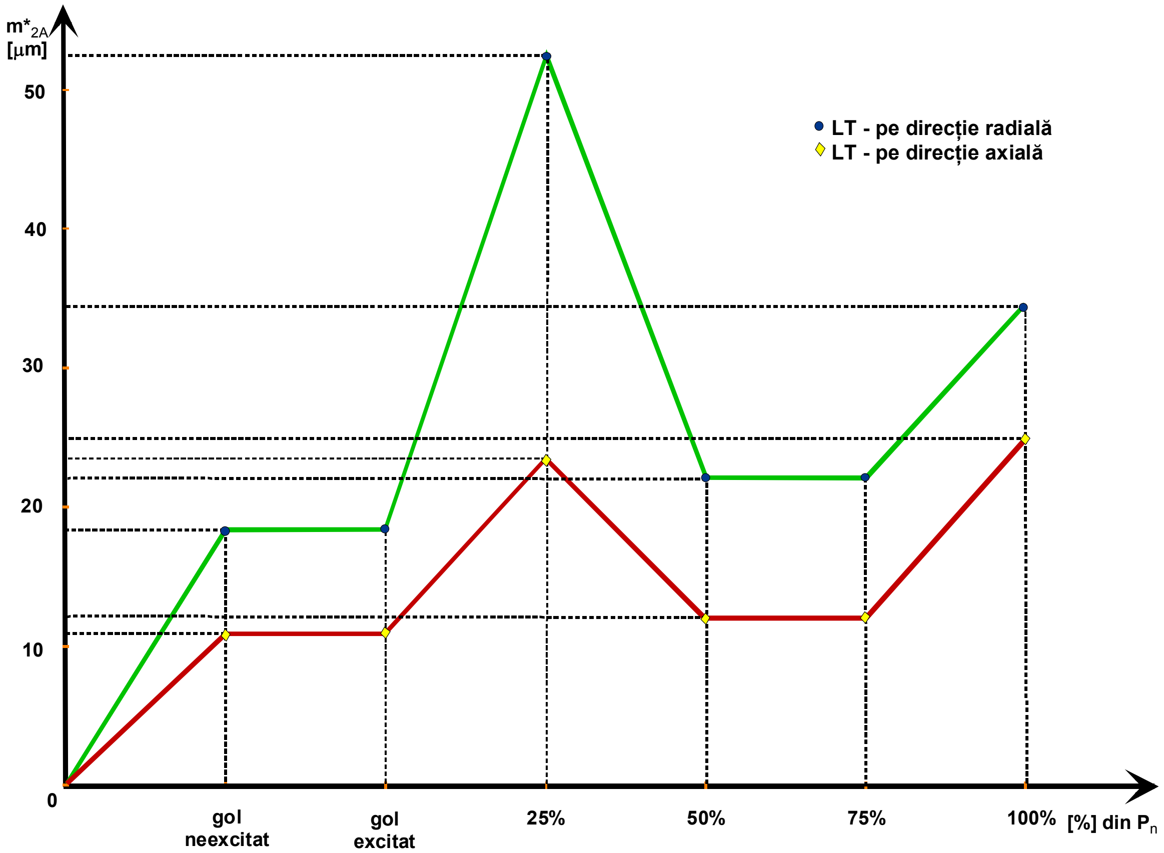

Fig. 3.c Time mediated variation of variable "2A" for HA nr. 1 at H.E.P Tileagd, in turbine bearing (L.T.)

Most extensive investigations were conducted on hydro aggregate nr.1 at H.E.P. Tileagd.

During the 4 years in which the hydro aggregates were investigated by monitoring vibrations, a database was established that includes parameters of vibrations (2A, V, a). Statistical processing of these data has led to a number of indicators, previously defined and particularly expressed as useful for the operation of H.E.P. (Table 2).

Table. 2. Summary of parameters describing the vibrations level at investigated HA

H.P.U. Indicator	H.P.U. Mărişelu	H.P.U. Tarnița	H.P.U. Munteni	H.P.U. Lugaş	H.P.U. Tileagd	H.P.U. Săcădat
$A_M[\mu m]$	320	320	320	320	320	320
$A_0[\mu m]$	0,0123	43,28	6,72	6,55	6,86	6,17
$m_A^*[\mu m]$	11,5	35,69	41,78	29,73	30,83	8,55
$\sigma_A^*[\mu m]$	4,99	21,93	47,27	2,65	2,86	5,13
$m_{VA}^*[\mu m/h]$	0,006	0,009	0,16	0,013	0,01	0,003
$\sigma^*_{V_A}\left[\mu m / h\right]$	$2{,}65 \cdot 10^{-3}$	$9{,}39 \cdot 10^{-3}$	$20{,}97 \cdot 10^{-3}$	$1{,}52 \cdot 10^{-3}$	$1{,}64 \cdot 10^{-3}$	$5{,}2 \cdot 10^{-3}$
$m^*_{t_F}\left[h\right]$	55517	118531	12347	32475	33641	126063
$\sigma^*_{t_F}\left[h\right]$	2174	167781	19940	25328	25600	88107

The period of assessment also included a current repair R.C. in the period August-September 1999.

Interpretation of vibrations spectra allows us to see:

- axial vibration with the highest amplitudes are of the radial – axial bearing, are given by the fundamental harmonic (0,782 mm / s), second harmonic (0,511 mm / s) and the eighth harmonic (0, 311 mm / s) (Fig. 2 and 3.a);
- radial vibrations of radial-axial bearing are given by the fundamental harmonic (0,38 mm/s), second harmonic (0,57 mm/s) and third harmonic (2,43 mm/s);
- axial and radial vibrations of the inferior radial bearing are very small very small in magnitude and correspond to the fundamental harmonic (fig. 3.b);
- the spectrum of vibrations collected on axial direction, at the turbine bearing, is a very rich spectrum of frequencies and is characteristic for the phenomenon of cavitation, pulsations manifesting themselves around 320 Hz (Fig. 3.c)
- the spectrum collected on the radial direction at the bearing of the turbine is dominated by the harmonic given by the turbine blades, of a high density of spectral lines that characterize the operation in the cavitational regime and of shocks, with events in the field [320 ÷ 585] Hz.

When idling with HA nr.1. Tileagd loud noises were heard in the area of the rotor of the turbine. With regard to these noises, we can say that they are due to the complex hydrodynamic phenomena which take place in the hydraulic turbines, mostly in the area of the rotor of the turbine. These phenomena favor the emergence of some low pressure areas, under the value of the pressure of water vaporization, thus creating conditions for the emergence and development of cavitation phenomenon.

The lowest pressures appear, usually, on the underside of the rotor blades in both normal operation and especially in regimes different from this. The cavitation phenomenon in hydraulic turbines manifests in all its characteristic aspects: noise, vibration, erosion, declines in performance, decline of functional characteristics.

With regard to the pulsations which appear in the spectra of vibrations, we noticed that fissures that develop gradually appear only in the case of variable tensions which oscillate between two limit values. Under the action of variable efforts, a fissure is caused which gradually spreads in the blade. Since tensions vary continuously, there are situations when the edges of the fissure approach and press each other and situations when the edges distance themselves, the material wears out in time, thus resulting in the characteristic fracture surface.

The empty excited operation of HA nr.1 Tileagd, as compared to the empty non-excited operation, is characterized by the decrease of the amplitude of fundamental harmonic at radial-axial bearing on Radial direction (from 3,8 mm/s to 1,35mm/s). The same pulsations are present at the bearing of the turbine on both directions.

When operating in load, we notice that vibrations measured at the three bearings decrease a lot, that due to the increased water flow in the turbine. Cavitation is also present in this operating mode.

CONCLUSIONS

1. Implementing a system of technical diagnosis (SD) in hydropower aggregates (AHE) has an impact on the maintenance strategy, meaning that, in this way, the maintenance strategy based on reliability (RCM) is practicable.
2. The most important component of a SD at AHE is the diagnosis system based on vibrations which involves the recording of vibration parameters (amplitude, speed, frequency, acceleration) and comparison with normal values (rated).
3. Vibration parameters can be treated as random variables, by the statistical processing and interpretation of the selection characteristics of these variables, based on the parametric reliability model, resulting the level of momentary reliability of the AHE and the optimal pace of the work of "predictive and to the purpose maintenance" (a RCM type strategy).
4. The results of statistical analysis of AHE vibration parameters show a very good agreement between the growth rate of vibration amplitude and lifetime of the AHE to overhaul (RK), tab. 6.5, specified in normative as 30 years; consequently careful analysis of the evolution of AHE vibration parameters and the statistical processing of their parameters allows the elimination of the system of planned-preventive repairs referring to technical revisions (R.T.) and current repairs (R.C.) creating the premises for the transition to predictive maintenance and reliability based maintenance.
5. Hydropower aggregates in Someş and Crişul Repede hydropower plants are suitable for the investigation of the technical status by vibration monitoring.

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