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Rotor-Stator Air Gap Unevenness Influence on Vibrations in Operation of High Power Hydro-generators

This paper refers to the determination of the influence of rotor-stator unevenness on operating performances in terms of vibration. All generators are generally characterized by certain unevenness which must be taken into account for stator centering. The paper presents the experimental verification method of unevenness influence on hydrogenerator's vibrations.

Keywords: *hydrogenerator, air gap, stator-rotor, vibration.*

1. Introduction

Theoretical studies have shown that the rotor-stator unevenness shape leading to uneven air gap are likely to cause additional vibrations in hydroaggregate. When an optimal centering is achieved, the vibrations are within reasonable limits and do not lead to significant changes in the operating performances. If the centering is not properly done, there is a risk of significant vibrations that can adversely affect the operation of hydro. The increase of vibrations is determined by the appearance of additional unbalance forces that is, the appearance of additional forces in the hydro camps. The experimental tests performed on a hydro-power plant Ostrovul Mare, revealed a proper functioning in terms of the hydro-aggregate's vibrations which shows a right hydro centering from the magnetic point of view.

2. Theoretical considerations

The determination of interaction forces between the stator and rotor rely on two methods based on:

- the use of Maxwell power tensor;
- the principle of virtual forces.

The calculation of forces and couples applies to the finite element method or analytical methods based on Maxwell power tensor.

Electromagnetic force f_e will be given by the surface integral of the Maxwell tensor:

$$\overline{f}_e = \int_S \overline{\sigma} dS \qquad (1)$$

Considering the tensor expression σ, we get:

$$\overline{f_e} = \oint_S \left[\frac{1}{\mu_0} \left(\overline{B} \cdot \overline{n} \right) \overline{B} - \frac{1}{2\mu_0} B^2 \overline{n} \right] \cdot dS \qquad (2)$$

Where:

- $\overline{n}$ is the normal unit vector at the surface;
- μ_0 is magnetic permeability of that respective environment in the air gap ;

The finite element method can also be applied based on the principle of virtual forces to calculate the interaction forces:

$$\overline{f}_e = -\nabla W = \left[\frac{\delta W_c}{\partial x} \cdot \frac{\delta W_c}{\delta y} \right]^T \qquad (3)$$

Where:

- $\overline{f}_e$ is the vector of the interaction forces;
- W_c is the corresponding energy of the considered environment.

The effect depends on the degree of asymmetry of the air gap. In the case of the electrical machines with symmetrical air gap, the resultant of centrifugal forces will be zero.

In practice, all generators, especially high power ones, are characterized by a certain degree of unbalance of the air gap.

An example of the unbalance of the air gap is when the stator magnetic core center does not coincide with the center of the rotor magnetic core.

In this case, eccentricity (in relative units) is defined by the value:

$$\varepsilon = \frac{e}{\Delta R} \qquad (4)$$

Where:

- e is moving on the radius between the center of the rotor and stator center;
- ΔR is the average air gap value, given by the difference between inner radius of stator laminations package and outer radius of rotor laminations package.

Rotor eccentricity is shown in Figure 1.

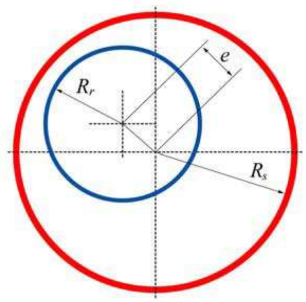

Figure 1. Rotor eccentricity

3. Results of measurements

The influence determination of the rotor-stator unevenness on operating performances involves measuring the vibrations in three distinct operating modes:

3.1. Verification of the vibrations in the starting process in unexcited idling

During the start, there were recorded:
- the rotor speed
- the vibrations in the axial radial bearing and in the lower radial bearing.

Table 1

Nr.	Speed	Vibrations		
	n	$v_{LRAG\_X\_rad}$	$v_{LRAG\_Y\_rad}$	$v_{LRG\_X\_rad}$
	[rpm]	[mm/s]	[mm/s]	[mm/s]
1	214.5	0.613	0.681	0.42

Where:
$v_1 = v_{LRAG\_X\_rad}$ = radial - axial upper bearing vibration x radial axis generator;
$v_2 = v_{LRAG\_Y\_rad}$ = vibration upper bearing radial - axial y radial generator;
$v_3 = v_{LRG\_X\_rad}$ = lower radial bearing vibration generator x-axis radial.

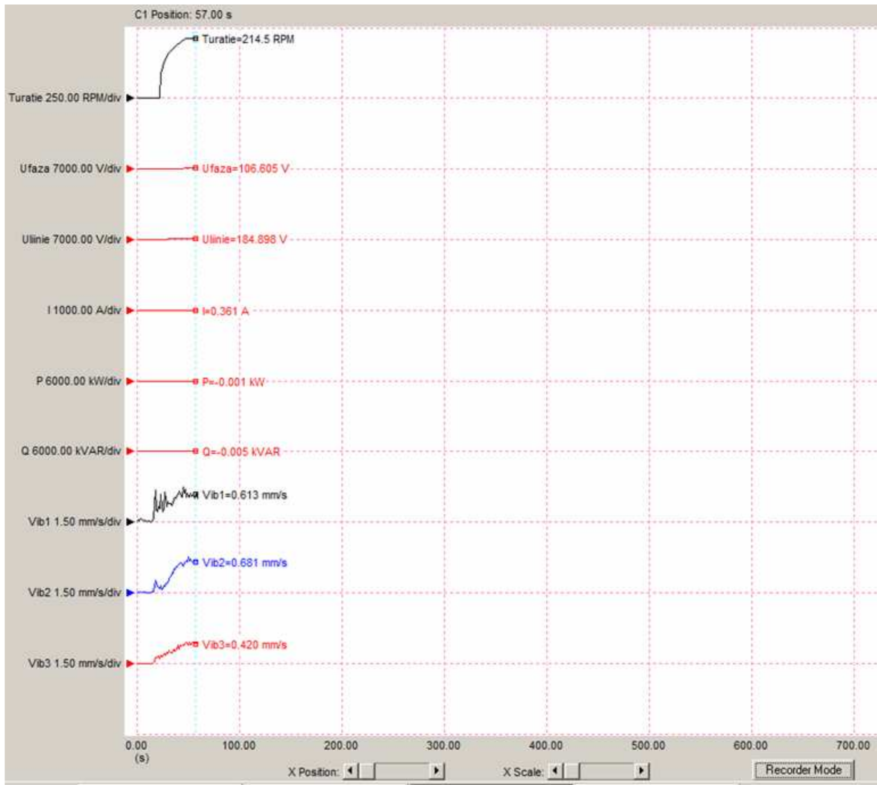

Figure 2. Vibrations at idling unexcited regime at rated speed, n = 214,5 rpm

It is noted that the vibrations are within acceptable limits, which shows a mechanically correct centering.

3.2. Verification of the vibration in the starting process in excited idling

During startup, there were recorded:

- Rotor speed;
- Vibration bearings;
- Line voltage generator;
- Excitation voltage generator;
- Voltage and current excitation exciter.

Table 2.

Nr.	Electrical parameters				Bearing vibration			Speed
	$U_{med\ line}$	I_e	U_e	U_{eG}	$v_{LRAG\_X\_rad}$	$v_{LRAG\_Y\_rad}$	$v_{LRG\_X\_rad}$	n
	[V]	[A]	[V]	[V]	[mm/s]	[mm/s]	[mm/s]	[rpm]
1.	6021.12	7.93	18.61	66.04	0.62	0.63	0.30	214.3

Where:
$v_1 = v_{LRAG\_X\_rad}$ = upper bearing radial vibration - axial x radial axis generator;
$v_2 = v_{LRAG\_Y\_rad}$ = vibration upper bearing radial - axial y radial generator;
$v_3 = v_{LRG\_X\_rad}$ = lower radial bearing vibration generator x-axis radial.

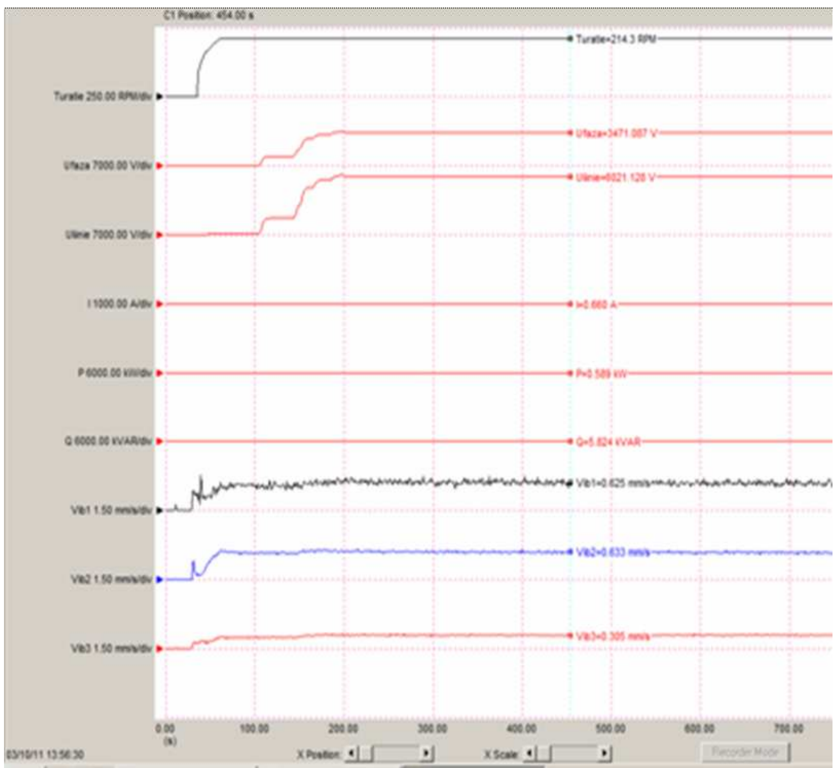

Figure 3. Vibrations in idling excited regime

It is noted that the vibration does not change in the moment of the excitation connection, which shows that the generator is properly centered.

3.3. Verification of vibrations in the starting process with the network connection of the hydro

During startup, there were recorded:

- Rotor speed;
- Vibration bearings;
- Line voltage generator;
- Excitation voltage generator;
- Voltage and current excitation exciter.
- Stator current.
- Active power

Table 3.

Nr.	Electrical parameters						Vibrations			Speed
	U	I	P	I_e	U_e	U_{eG}	v_{LRAG_X}	v_{LRAG_Y}	v_{LRG_X}	n
	[V]	[A]	[MW]	[A]	[V]	[V]	[mm/s]	[mm/s]	[mm/s]	[rpm]
1	6189.61	238.19	1920.59	10.66	25.33	91.33	0.49	0.56	0.50	214.3
2	6183.95	318.89	2995.51	10.70	25.49	91.85	0.48	0.57	0.51	214.2
3	6212.01	766.28	8009.4	13.35	31.58	111.63	0.55	0.58	0.53	214.2

Where:

$v_1 = v_{LRAG\_X\_rad}$ = upper bearing radial vibration - axial x radial axis generator;

$v_2 = v_{LRAG\_Y\_rad}$ = vibration upper bearing radial - axial y radial generator;

$v_3 = v_{LRG\_X\_rad}$ = lower radial bearing vibration generator x-axis radial.

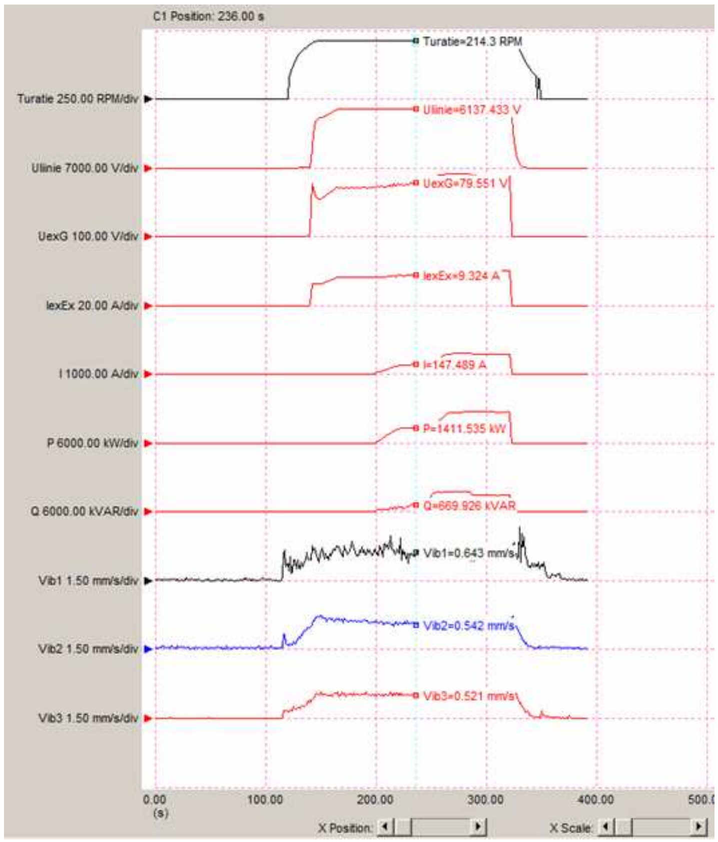

Figure 4. Vibration start load, Hydro-power generator 1

Vibration values do not significantly change during the idling excitation process of the generator, or during network connection. Likewise the load does not involve a significant increase in the level of vibration.

This indicates a correct centering of the generator.

4. Conclusions

Measurements were made in three distinct modes:

- Under load unexcited regime when only the mechanical unbalance forces act on the rotor;
- In idle excited regime when over the mechanical unbalance forces overlap the magnetic unbalance forces;

- In load regime, when unbalance magnetic forces are influenced by the reaction field caused by stator currents.

When the geometric centring is not accompanied by a magnetic centering the connection of the excitation current leads to appearance of important unbalance magnetic forces causing significant increase of vibrations under excited idling regime.

From the experimental tests, it results a correct centering from the magnetic point of view of the tried generator, the vibrations under excited idling regime keeping the same level of vibrations as the vibrations under unexcited idling regime.

The fact that under load regime, the level of vibrations does not change as compared to the level of vibration from the unexcited idling regime indicates a dynamic stability corresponding to the movement of the rotor under the reaction magnetic field which is variable depending on the task.

Thus, through the three types of tests easily to be achieved, some conclusions can be drawn regarding the technical performances in all operating modes.

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