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Tests Performed on Hydraulic Turbines at Commissioning or after Capital Repairs. Part II. Tests Performed on a 6.5 MW Kaplan Turbine

The paper presents the tests performed on a hydraulic turbine on commissioning, the devices, test methods and the results obtained from the respective tests, as well as the conclusions and recommendations resulted from these tests. This kind of tests can be performed for the verification of guarantees.

Keywords*: tests at hydro units commissioning, index tests, Kaplan turbine, power ejects*

1. Introduction

The hydro unit on which the tests were executed and presented in this paper is Hydro Unit no.1 belonging to one of the few hydro units built in Romania in the past 10 years. It belongs to the AHE of River Strei on the sector Subcetate-Simeria and it is a hydro power plant without its own storage accumulation of a plant type on derivation channel.

The construction of the hydro power plant started in 1989 and was finished in 2010. At present, 2 of the 7 hydro power pants are put into exploitation.

The technical characteristics of the hydro unit (figure 1) subjected to tests are:

- Number of hydro unit: 2 pcs
- Turbine type KVB 6.5 – 14.3
- Maximum net head: 15 m
- Nominal net head: 14 m
- Maximum flow at nominal head: 52 m^3/sec
- Idle operation flow: 22 m^3/sec
- Maximum power: 6500 kW
- Maximum admissible intake load: -0.4 m;

- Normal rotating speed : 3000 mm;
- Nominal speed: 166.7 rpm;
- Number o of rotor blades: 4 pcs;
- Number of wicket gate blades: 24 pcs;
- Racing speed :
    - o With the maintenance of the combinatory link: 290 rpm
    - o Without the maintenance of the combinatory link 420 rpm

Figure 1. Tested hydro unit

We must mention also that the tests were performed in parallel on both hydro units composing the plant, but the paper presents only the results obtained during the tests on hydro unit no. 1.

2. Tests performed

The beneficiary and the constructor, together with the tests performer establishes toe execute the following tests, according to [1]:

- Hydro unit behavior at power ejects;
- Determination of maximum operation power of the hydro unit;
- Index tests;
- Operation of turbine in transient regimes;
- Operation of turbine in stabilized regimes.

Dimensions measured and sensors used for the acquisition of their values are presented in table 1.

Table 1. Measured parameters and the measuring instruments

Measured parameter	Measuring instrument
Active power, currents and voltages at the generator's terminals and data acquisition data	VPA323 analyser of electrical parameters and process parameters
Upstream level	Rittmeyer level transducer MPB, 0 -10 m
Downstream level	MJK 7065 level transducer 0-10 m
Wicket gate servomotor travel	Temposonics shift transducer GP 0 – 100 mm
Pressure in wicket gate servomotor	Siemens SITRANS P 7MF4433-1DA02-1AA1-Z pressure gap transducer, 0 – 300 mBar
Pressure on one side of the piston of the wicket gate servomotor	GS4003 pressure transducer, 0 – 40 bar
Number of revolutions	Banner QS30LDQ laser revolution sensor, 0-120000 rpm
Vibrations	Accelerometer Hansford Sensors, 533,3 mV/g

For the study of the hydro unit behavior at power ejects one performed the following regimes:

- power eject of HU 1 from 50% Pn with HU 2 in operation at 100% Pn;
- power eject a HU 1 de la 75%Pn with HU 2 in operation at 100%Pn;
- power eject a HU 1 de la 100%Pn with HU 2 in operation at 100%Pn.

At the index test from the measured dimensions, presented in table 1, one calculated:

- Net head Hn [m]:

$$H_n = z_i - z_e + \frac{Q^2}{2g}\left(\frac{1}{S_i^2} - \frac{1}{S_e^2}\right) + \frac{p_i}{\gamma} - \frac{p_e}{\gamma} \tag{1}$$

where: z_i is the upstream level in entry section ; z_e, downstream level in entry section ; S_i, entry section to the turbine; S_e, exit section from the turbine, Q discharge measured by the Winer-Kennedy method; g, acceleration due to gravity; p_i, pressure at the inlet section; p_e, pressure at the outlet section.

- Index discharge Q [m^3/s]:

$$Q_i = k_{WK} \cdot \Delta WK^n \tag{2}$$

were k_{wk} is the Winter-Kennedy coefficient; ΔWK pressure difference measured on Winter-Kennedy pressure taps; n, usually equal with 0.5 [2].

- Turbine hydraulic power, P_T [MW]:

$$P_T = \rho \cdot g \cdot H_n \cdot Q \cdot \eta_h = \frac{P_A}{\eta_G} \tag{3}$$

where P_A – active power measured at the generator terminals; η_G – generator efficiency by calorimetric method. The mechanical losses of the turbine were neglected.

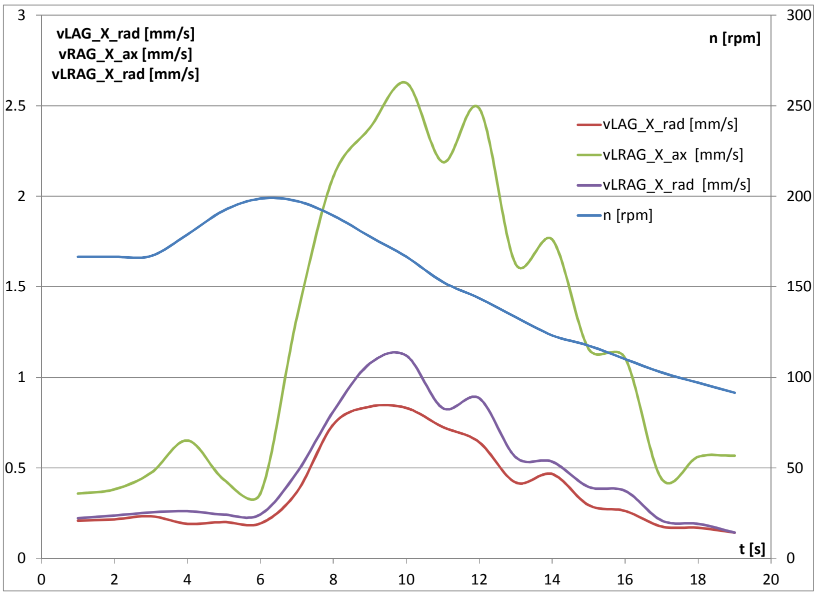
- Turbine efficiency, η_T [%]

$$\eta_T = \eta_h = \frac{P_T}{\rho \cdot g \cdot H_n Q} \tag{5}$$

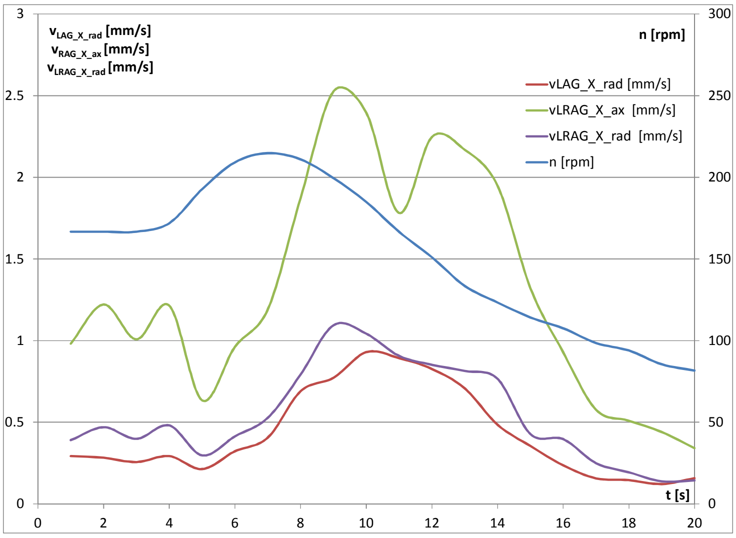
The procedure of index tests performance was executed in accordance with [3] and is presented in detail in [4].

3. The results

Power ejects were performed as follows: the hydro unit was dropped to 50% of the nominal power (3.2 MW), one executed the power eject and one recorded the parameters. The same for the other power steps, i.e. 75% of Pn (4,7 MW) and 100% of Pn (6.2 MW). Figure 2 a, b, c presents the evaluation of the number of revolutions n, of vibrations vLAG_x_rad – vibrations of the lower radial bearing of the generator, vLRAG_x_ax – vibrations of the radial upper bearing– axial generator, vLRAG_x_rad = vibrations of the radial-axial upper generator.



a)



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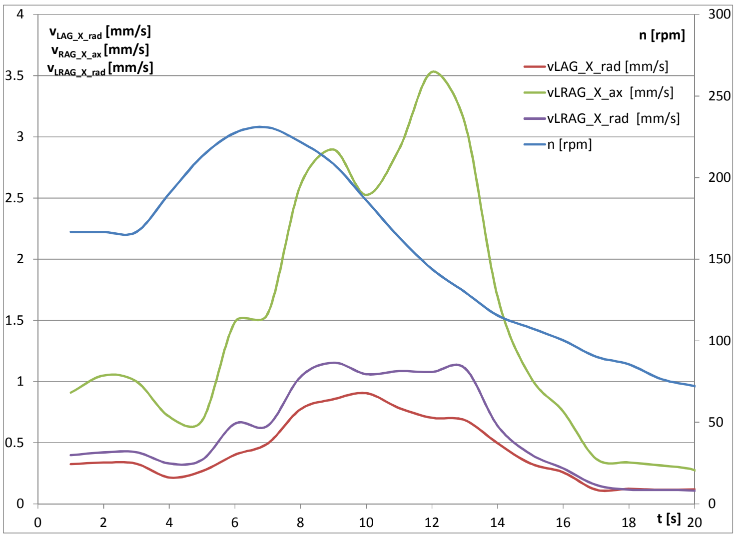

c)

Figure 2. Vibrations and rotational speed recorded at power eject

From the analysis of the records performed during this power eject it results the following:

- power eject from 50% Pn determines a racing of the rotor on HU1 by 19,267% and a substantial increase of vibrations on HU1 bearings, their maximum value being: $v_{LAG\_x\_rad}$ = 0,838 mm/s, $v_{LAG\_x\_ax}$ = 2,626 mm/s; $v_{LRAG\_x\_rad}$ = 1,120 mm/s.
- power eject from 75% Pn determined a racing of the rotor on HU1 by 28,931% and of vibrations on bearings, their maximum value being: $v_{LAG\_x\_rad}$ = 0,929 mm/s, $v_{LAG\_x\_ax}$ = 2,526 mm/s; $v_{LRAG\_x\_rad}$ = 1,094 mm/s.
- power eject from 100% Pn determines a rotor racing on HU1 by 38,535% and of vibrations on bearing, their maximum value being: $v_{LAG\_x\_rad}$ = 0,904 mm/s, $v_{LAG\_x\_ax}$ = 3,531 mm/s; $v_{LRAG\_x\_rad}$ = 1,154 mm/s.

In order to determine the maximum operation power at NNR (normal retention level in the storage accumulation), the hydro unit was charged to the maximum power that can be reached, more precisely 6.711 MW. The hydro unit was left to stabilize and records were made of the stabilized regime for 250 seconds. Figure 3 shows the evolution of the wicket gate servomotor stroke SAD, of the pressure in the wicket gate servomotor PSAD and of Winter-Kennedy pressure gap a DWK for this regime.

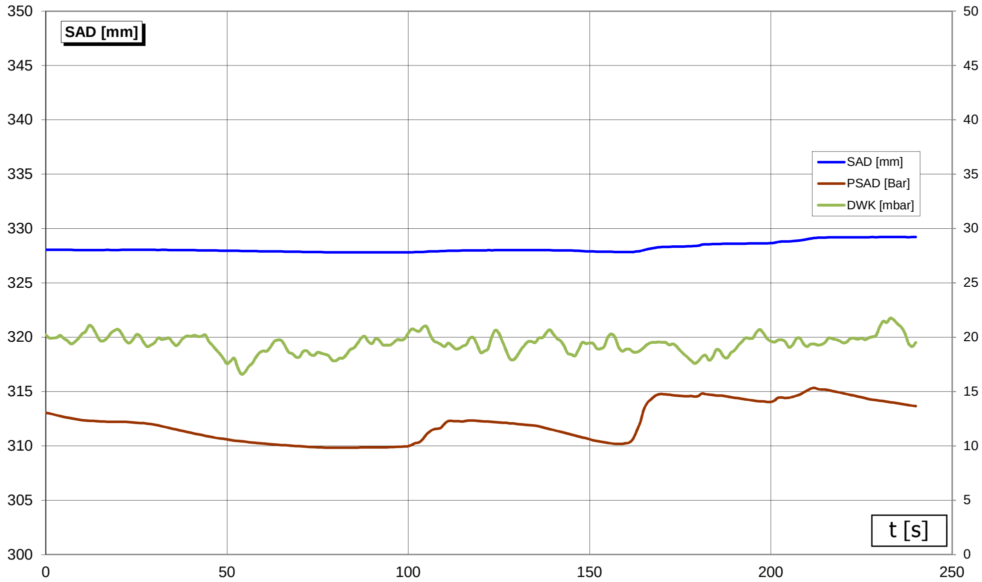

Figure 3. Wicket gate servomotor stroke, pressure in the wicket gate servomotor and Winter-Kennedy pressure gap

At the maximum power reached, the hydro unit operated stably from the point of view of the adjustment system, the pulses and / or oscillations of wicket gate servomotor travel and the spiral chamber following within the normal range.

The index tests were performed in view of determining the turbine efficiency. index The power range where the tests were made for HU1 is 3 – 6,5 MW at the falls NNR +25cm, NNR and NNR–1m.

Figure 4 represents the efficiency of hydro unit η_A, of turbine ηT, the hydro unit power P_A, the hydro unit power P_T, the wicket gate servomotor travel SAD and the rotor servomotor travel SR against the flow at NNR, figure 5 at NNR-1 m and figure 6 at NNR +25 cm respectively .

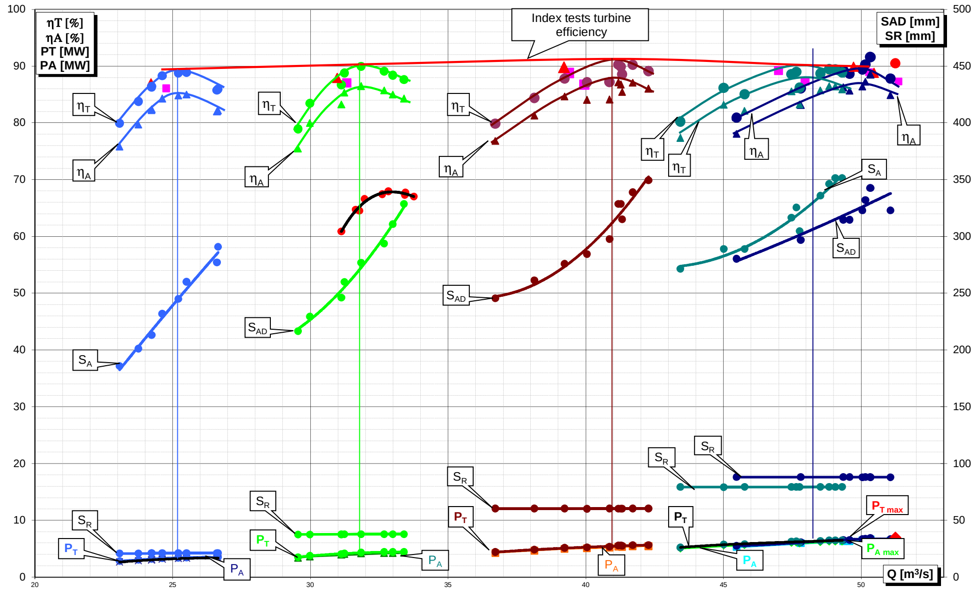

Figure 4. Index tests at NNR

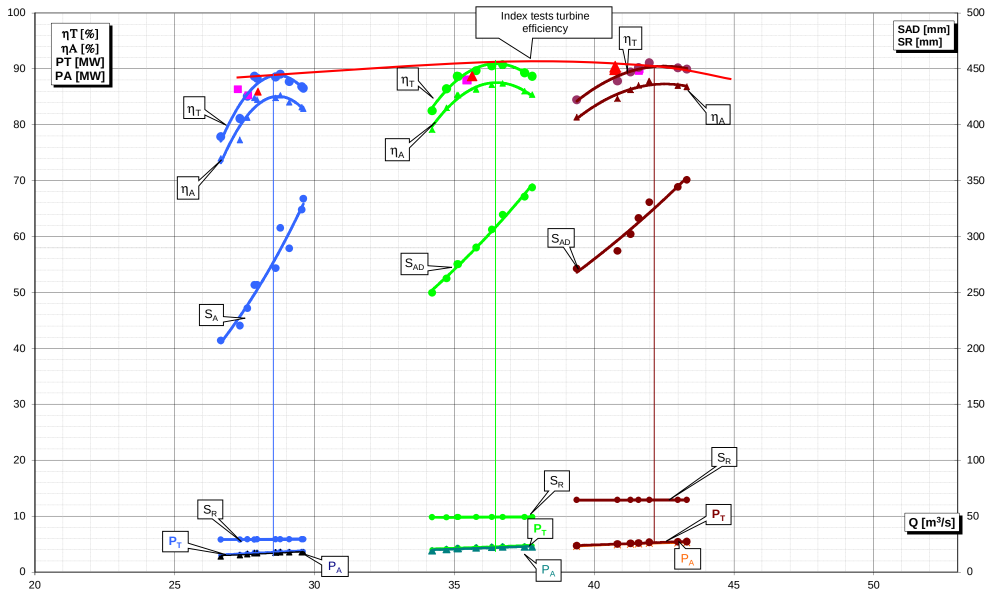

Figure 5. Index tests at NNR -1 m

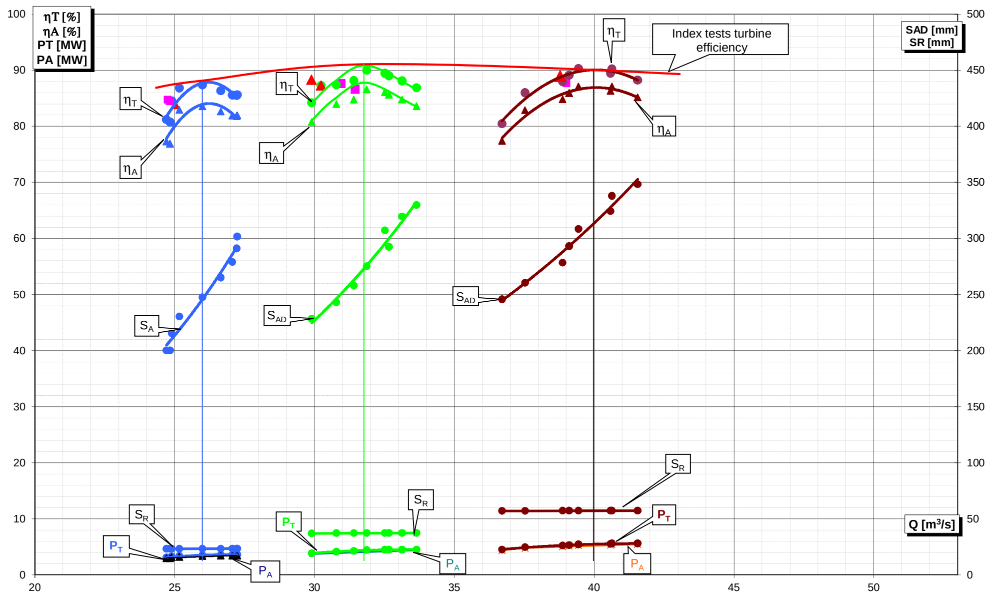

Figure 6. Index tests at NNR +25 cm

Following the index test one found that the turbine efficiencies have values ranging between 88 and 91%. The optimum turbine efficiency is reached at a power representing 60-65% of the maximum power. Under these circumstances, the maximum power is supplied by the turbine at an efficiency 3 – 4 % lower than the optimum one.

4. Conclusion

Following the tests performed, the records analysis and processing, one found that the efficiency obtained from tests is the right one, and the maximum power at which the hydro unit can operate at NNR is 6.711 MW.

From the power eject tests one found that the hydro unit behaves normally, the vibrations recorded in these regimes fall within the normal limits.

The optimum efficiency is reached at a power representing 60-65% of the maximum power. Under these circumstances, the maximum power is supplied by the turbine at an efficiency 3-4% lower than the optimum one. Due to the hydro power plant construction, one recommended the performance of studies of cascade operation of the hydro power plant along the channel, in order to determine the optimum ranges of powers for the hydro units operation, in view of yielding a power output of maximum efficiency, with a minimum water consumption.

The paper may be useful for the beneficiaries as well as for the hydro unit constructors as model for the acceptance tests on commissioning, after refurbishment or capital repairs, and the results presented may be used for comparison with other hydro units similar from the hydraulic point of view or with data resulted from numerical simulations, but also as model for other laboratories.

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