85 YEARS OF CONTINUOUS OPERATION OF A HPP. PART 2 – UNSTEADY OPERATION REGIMES

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This paper presents the experimental analysis of Dobrești HPP operation during transient regimes. The study was carried out in order to verify the safe functioning of the power plant equipment. The transient analysis consisted in monitoring the surge tank level and the turbine inlet pressure with pressures transducers, during sudden load rejection. The flow rate was measured using a portable ultrasound flowmeter connected together with the pressure transducers to a data acquisition module. The entire data acquisition process was controlled using LabVIEW software. The experimental investigation showed that during the transient operation regimes there were no dangerous loads in the hydraulic system, therefore the Dobrești HPP has a safe operation even after 85 years of continuous functioning.

Keywords: hydropower, transient, measurement, safety.

1. Introduction

Dobrești Hydro-Power Plant (HPP) has a semi-automatic controlled unit command and national grid connection. In the 30's it was among the first modern power plants in the world, having Voith-Brown-Boveri automation. Built between 1928 and 1930 for the electrical energy supply of Bucharest, Dobrești HPP had until 1960 the biggest power output (4×4 MW) in Romania. Excepting the normal maintenance periods and small failures, the Dobrești HPP has been in operation with very good efficiency for the last 85 years. In a hydroelectric site situated downstream, it was an incident when after a sudden load rejection, the penstock was blown-up due to over pressure caused by the water hammer phenomenon. As the energy market is changing with the introduction of renewable power resources, the role of hydropower in electrical grids stabilization is becoming more important. The need to regulate the grid requires more flexibility of the hydropower plants and pumping stations operation, which induces transient flow regimes in the sites pipelines. Transient flow regimes are usually caused by

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variations of the hydraulic machines operation like starts, stops, load variations and load rejections. This abnormal units operation can induce in sites pipelines water hammer and mass oscillation phenomena [1]. The water mass oscillation phenomenon consists in transforming the kinetic energy of the fluid in potential energy and sometimes overflow can occur, while water hammer implies changing their kinetic energy into pressure energy, so the pressure in the vane section will be increased [2-4]. Thus, it is necessary to analyze the influence of these transient operation regimes over the flow in the hydroelectric site pipelines to determine undesired pressure pulsations, in order to assure a safe operation of the hydraulic power systems. The transient regimes analysis is a continuous concern of the specialists [5-7].

The aim of this paper is to investigate the operation of the Dobrești Hydro-Power Plant (HPP), during transient regimes, for two different water levels in the upstream reservoir. The analysis is focused on the flow regimes in the hydroelectric site pipeline (headrace and penstock).

2. The power station and the experimental setup

2.1. Site description

Dobrești hydropower plant collects the water from two different sources, the main one, Scropoasa reservoir and an auxiliary water intake, Brătei (figure 1). These two join at the surge tank level and then the water is delivered to the turbines through a metal penstock. Scropoasa lake is a small water reservoir. The surface level is situated at 1197.5 m and the depth of the reservoir is of 18.5 m.

The water intake Scropoasa is built on the right bank of the lake, upstream the Scropoasa dam. The intake is elliptical shaped, with 7.46×5.60 m section and provided with a metal grill with vertical bars curved towards the lake. Their destination is to retain the larger floating impurities. The main intake consists in 928.21 m long concrete sector, with three access windows and a 1094.86 m long metal sector. The cross section is a circular with a diameter of 2 m.

The secondary intake, Brătei is made of metal pipe with a diameter of 1.20 m and 2979.75 m long, placed immediately downstream the water catchment. The second sector is a gallery carved in the Lespezi massif, lined with steel concrete and gunite. This sector has a 1.7 m diameter.

The surge tank is cylindrical, built from steel concrete with 7 m diameter and a height of 34 m. The two intakes deliver the water in the surge tank on diametrically opposed sides which decreases considerably the kinetic energy when the power plant is suddenly stopped.

The vane chamber is situated 58 m downstream the surge tank and houses the butterfly vane with a diameter of 1.7 m. The valve closure is an automatic process controlled by a safety system which commands the electromagnetic gear that closes the vane. There is also a manual control of the butterfly vane by pulling a grip a counter-weight is dropped and the vane suddenly closes.

The penstock is 683.5 m long and is made of metal sectors of 6 m long each with diameter varying from 1.7 m near the vanes chamber to 1.4 m near the turbine inlet. At the downstream end the penstock has a distributor that delivers water to each of the four turbines. The turbines are identical horizontal Pelton. The main characteristics of the turbines are 4 MW power output, 285 m rated head and a maximum discharge of 1.75 m^3/s.

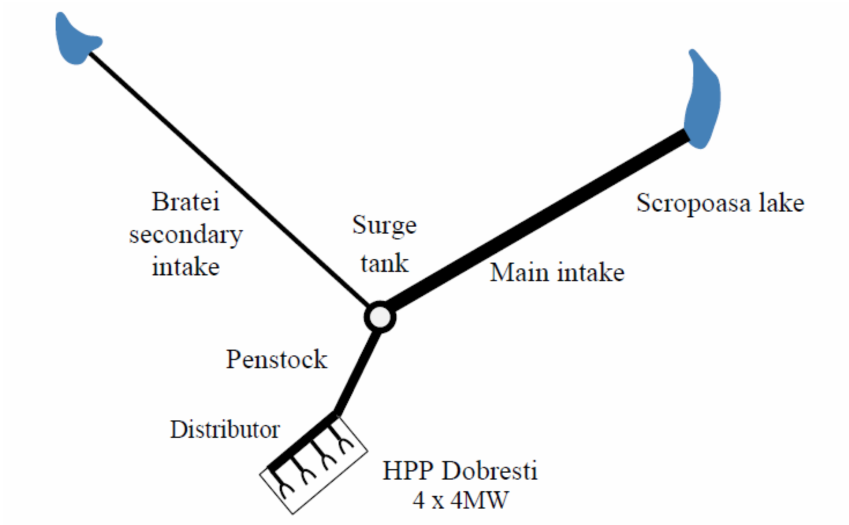

Fig 1. Dobrești HPP site scheme.

2.2. Measuring program

In order to investigate the power plant operation during transient regimes, the pressure at the inlet of the turbines, p_1 and the water level in the surge tank, H_{ST} were measured during sudden load rejection, a critical situation in the normal functioning of the turbines [8].

The pressure variation in the turbine inlet pipe was determined with a pressure transducer installed at the turbine admission. The water level in the surge tank, H_{ST} was determined by measuring the pressure head in the closest possible section, the vanes chamber, downstream the butterfly vane.

The sensors positions are justified by the attempt to monitor the two phenomena, water hammer and mass oscillations that take place in site pipelines during transient operation of hydraulic turbines. The setting of pressure sensors was done with zero discharge in the HPP. The static head was verified with reference to site leveling.

2.3. Measured hydraulic parameters

The pressure head at the surge tank, H_{ST}, was determined by measuring the pressure at the valves chamber, upstream the butterfly valve considering the elevation of the measuring position. Given the short distance between surge and valve chamber (58 m), it was considered that the pressure head measured at the valves chamber reflects also the water level in the surge tank. The pressure measurements were done using a relative pressure transducer with a precision of ± 0.6%, operating range of 0 – 10 bar and output type current 4 – 20 mA.

The pressure in the turbine inlet pipe was measured the pressure between the butterfly valve and the nozzle distributor (figure 2), using a relative pressure transducer with ± 0.6 % precision, operating range 0 – 50 bar and output type 4 – 20 mA.

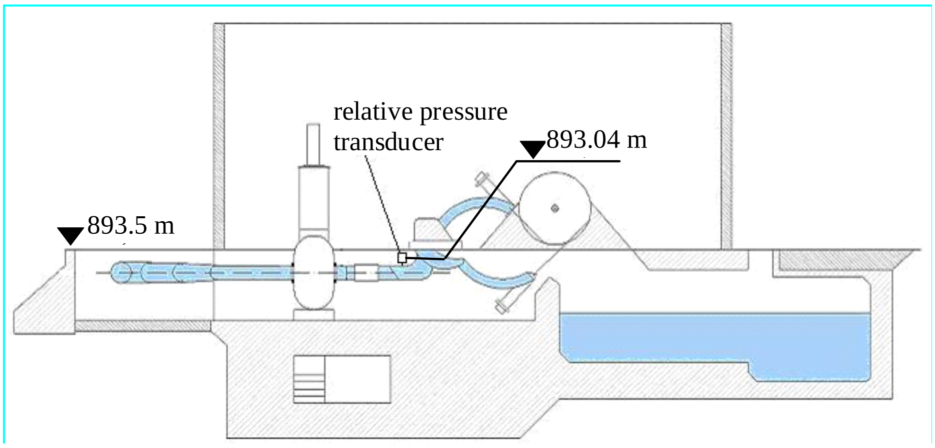

Fig 2. The location of the pressure transducer on turbine inlet pipe.

The pressure transducers were connected to a laptop through an acquisition data system. The recording of the pressure variations was made through an acquisition program created in LabVIEW. Acquisitions were performed with a sampling frequency of 1000 Hz, at various intervals of time [9].

The analysed transient situations are presented in table 1, for two levels in the upstream reservoir situated 4.6 m and 1.3 m below normal retention level (Z_{NRL}). As the amplitude of the transient regimes is influenced by the steady flow rate, in table 1 is included the penstock flow rate in steady state regime as a ratio to the maximum flow rate of the hydropower plant (Q_{HPP}). Because one unit was out of operation, the manoeuvres were executed for only three of the four units. The main objectives are to determine if during mass oscillation phenomena the water flows over the surge tank or if the water elevation decreases below the bottom of the surge tank, which will allow air entrapment.

Table 1

Analysed load rejection situations of the hydro units (HU)

Nr.	Z_{lake} [m]	Units in operation	Penstock normalized flow rate Q/Q_{HPP} [m^3/s]	Sudden load rejection
1	Z_{NRL}-4.6	Single unit	0.23	Single unit
2		Three units	0.70	Three units
3	Z_{NRL}-1.3	Single unit	0.24	Single unit
4		Three units	0.71	Three units

3. Results

The results are presented as variations after the load rejections manoeuvres of pressure head in the surge tank as a ratio to tank maximum height, H/H_{ST} and pressure in the turbine inlet pipe as a ratio to turbines rated pressure, p/p_r.

In figure 3, the normalized pressure head variations in the surge tank, H/H_{ST}, for single and three units load rejections, for both reservoir levels are presented. It can be seen that the shape of the curves are similar, the oscillation period being identical and only the maximum normalized amplitudes being increased for three units load rejection compared to single unit, from 0.086 to 0.164. The difference between the two curves corresponding to single unit (figure 3a) and three units load rejections (figure 3b) is due to the different values of the reservoir levels, this being of 3.3 m, which means a normalized difference of 0.1. A fast damping of the oscillations was noticed when three turbines were investigated due to the higher flow rate inside the pipe, thus higher hydraulic losses. It can be seen that the water, in both situations, fills half of the surge tank volume.

Figure 4 presents the variation of the normalized pressure in the turbine inlet pipe. It can be seen that the pressure increases abruptly right after the sudden load rejection. In case of single unit load rejections (figure 4a) the overpressure reached 2% from the normal operating pressure of the turbines, while for three units load rejections (figure 4b) the overpressure was of 6%. These values are not considered dangerous for the penstock exploitation. As in the pressure head variation in the surge tank, the difference noticed between the two curves from each figure is due to the different values of the reservoir levels. After the appearance of the maximum overpressure, it can be seen that the pressure presents oscillations, influenced by the surge tank level oscillation.

As the water hammer phenomenon is very fast, in order to highlight it, a frequency analysis was employed to determine the pressure wave period. Fig. 5 presents the results obtained using a Fast Fourier Transform on the pressure measured after a single unit sudden load rejection. The frequency of f = 0.395 Hz was determined both at turbine inlet and surge tank measurement sections, and it was found in all pressure signals. As the pressure is higher closer to the nozzle (flow obturator), the amplitude of the frequency component corresponding to the water hammer pressure wave in the turbine inlet is higher than at the surge tank.

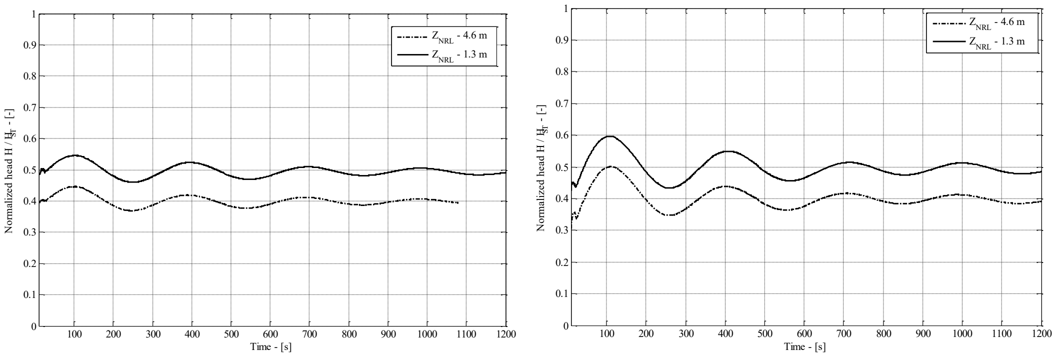

Fig 3. Normalized pressure head variation in the surge tank due to sudden load rejection of
a) Single unit b) Three units

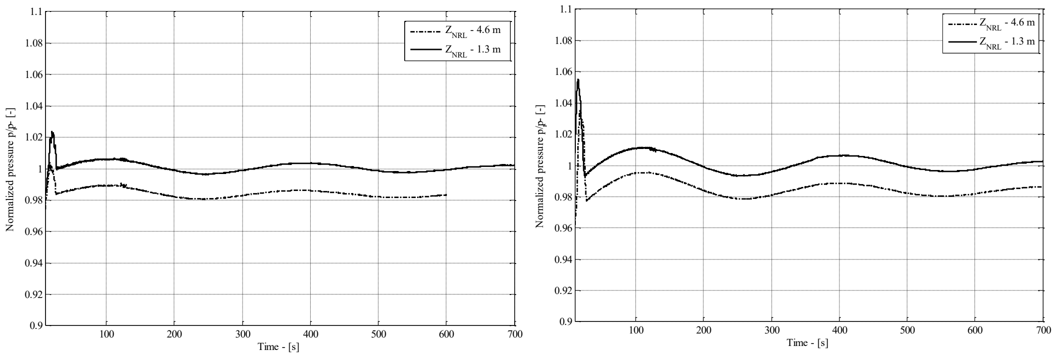

Fig. 4. Normalized pressure variation in the turbine inlet pipe due to sudden load rejection of
a) Single unit b) Three units

Using the frequency of f = 0.395 Hz, an experimental value for the pressure wave speed, c_{exp}, is computed using the equation:

$$c_{exp} = \frac{4L}{T} = 4Lf = 1079.93 \text{ m/s},$$

where T is the pressure oscillation period and L is the penstock length (L = 683.5 meters).

The theoretical value of the pressure wave speed, c_{theo}, can be determined considering the characteristics of the fluid and of the pipe:

$$c_{theo} = \frac{\sqrt{\varepsilon/\rho}}{\sqrt{1+(\varepsilon D)/(eE)}} = 1020 \text{ m/s},$$

where ε is the bulk modulus of the fluid, D – the pipe diameter, e – the pipe wall thickness and E – the Young modulus of the pipe.

Taking into account the geometric complexity of the penstock, the difference between the theoretical and experimental results for the pressure wave speed is considered acceptable.

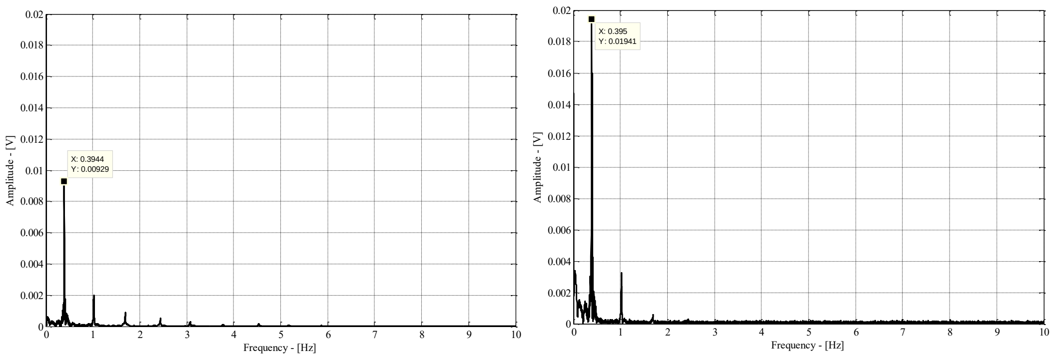

Fig. 5. Frequency spectrum for pressure head measured during single unit sudden load rejection
a) in the surge tank b) at the turbine inlet.

4. Conclusions

The paper analyses the flow in the pipelines of one of the first hydropower plants of Romania during transient regimes caused by sudden load rejection manoeuvres of one or three hydro units simultaneously.

In the case of the water level surge variations, it can be observed that the mass oscillations presents a maximum normalized pressure head amplitude between 0.086 and 0.164 for load rejection of a single unit, respectively for load rejection of three groups. In the most detrimental case, the water level in the surge tank reaches 0.6 of the maximum surge tank head.

The pressure in the turbine inlet pipe records high values in the moment of the sudden load rejection manoeuvres, which corresponds to the created pressure wave (water hammer). This over pressure has a normalized value between 2 and 6% for one group and for three groups, but for a very short period of time (approx. 15 s).

Considering both the water hammer phenomenon and mass oscillations that occurred, the hydropower development is in safe operation domain.

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