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EXPERIMENTAL STUDY OF HYDRO-AGGREGATES

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Abstract The present study is based on testing the two hydro-aggregates of "Krichim" Hydropower Station (Bulgaria). The goal of the study is to determine the variation of the turbine-inlet pressure at various operating conditions that are typical of the turbines.

The results of measuring the inlet pressure of both turbines provide opportunities for estimating the level of its increase during the hydro-aggregatesstart and stoppage. The study also offers venue for determining the resistance characteristic of the penstock.

1. Introduction

This study has been completed at "Krichim" Hydropower Station (Bulgaria) where two hydro-aggregates (HA) with Francis water turbines are installed. Both operate at head H=155m and each has power P=40 MW.

The increase of the pipeline pressure at various transitional operating conditions calls for a specific attention, particularly with regard to the safe exploitation of the hydro-aggregates and of the penstock itself. An objective appraisal in accordance with this criterion could be accomplished by determining the increase of the inlet pressure of the water turbines at the aforementioned operating conditions.

The results of the present study provide opportunity for determining the resistance characteristic of the penstock that is essential for preparing the so-called operating table of HPS- a basic document, according to which the hydro-aggregates are being exploited [1].

2. Goal and Setting of the Measurements

The goal of the measurements is to determine the variation of the turbine-inlet pressure at transitional operating conditions that are typical of the station's hydro-aggregate exploitation:

- Starting of the hydro-aggregates and their synchronization with the power system;
- Loading up to maximum power (40 MW) of each hydro-aggregate;
- Normal stoppage.

The measurements are carried out with each hydro-aggregate at the station operating individually and in parallel, respectively. The markings of the various operating conditions are presented in Table 1. In addition to testing the three operating conditions

(A, B, C) as planned in the preliminary program, the draft tube inlet pressure of HA1 has also been measured, since a number of hits had been discovered in the stream part of the turbine at an active power of the generator of 20 MW (operating condition D).

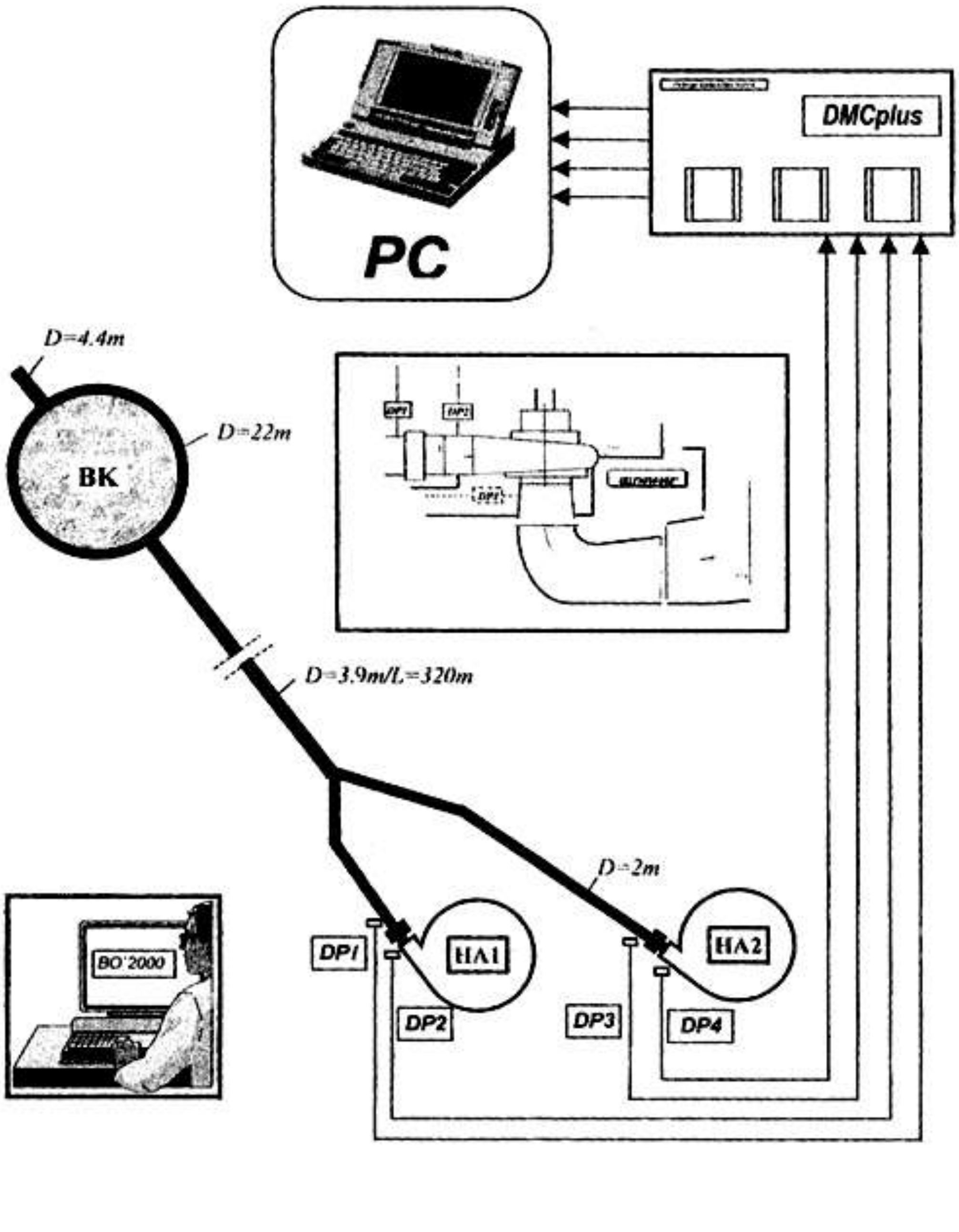

Fig. 1

Fig. 1 shows the principal diagram of the position of the penstock from the water tower (WT) to the hydro-aggregates as well as the position and the connection scheme of the elements of the measuring apparatus.

Table 1

№	Operating condition	Operating Hydro-aggregate
1.	A	HA1
2.	B	HA2
3.	C	HA1+HA2
4.	D	HA1

The pressure transducers are installed at the inlet section of the turbine's spiral cases (DP2 and DP4 - Fig. 1) and immediately before disc valves (Butterfly type) - DP1 and DP3. The transducers are installed at the same height and all measure absolute pressure.

The pressure transducers DP1 and DP3 are type P31AP/100B1 (accuracy class 0.05), whereas the transducers DP2 and DP4 are type P8AP/100B (accuracy class 0.3). All four sensors are manufactured by Hottinger Baldwin Messtechnik (HBM) with a range of 0 ÷ 100 bar.

All transducers are calibrated before the start of the actual measurements and immediately after their end.

The data input from the pressure transducers is fed into the DMC plus measuring device, which is produced by HBM. The variables are transformed into a digital code, then tracked and recorded in real time by a COMPAQ notebook computer. The notebook then processes the experimental data through specialized software CATMAN, developed by HBM for use under Windows OS. The data are recorded in the course of 850-2200 seconds (depending on the operating condition) with an interval of one second in files that are later processed by a computer programming system. The registering system is installed in the machine shop.

The atmosphere pressure has been properly measured, so that the relative pressure at the measurement points could be determined. The upper water-level mark during the measurements was 410.47m.

3. Results

3.1 Variation of the turbine-inlet pressure

Determining the pressure increase at the turbine inlets during starting and stopping schedules as well as during pressure changes. The following annotations are introduced:

$$\Delta p_p = p_{m1} - p_0,$$

$$\Delta p_s = p_{m2} - p_0,$$

$$\Delta p_{pb} = \Delta p_p / p_0,$$

$$\Delta p_{sb} = \Delta p_s / p_0,$$

3.1.2 PRESSURE INCREASE WHEN STOPPING THE TURBINES

The pressure variation in the penstock when stopping the turbines depends mostly on the law of closing the guiding vessel. Similarly to sub-section 3.1.1, Fig. 5 compares the values of the absolute Δp_p, while Fig. 6 shows the values of the relative Δp_{pb} maximum pressure increase in the process of stopping the turbines during their individual and parallel operation (A, B and C).

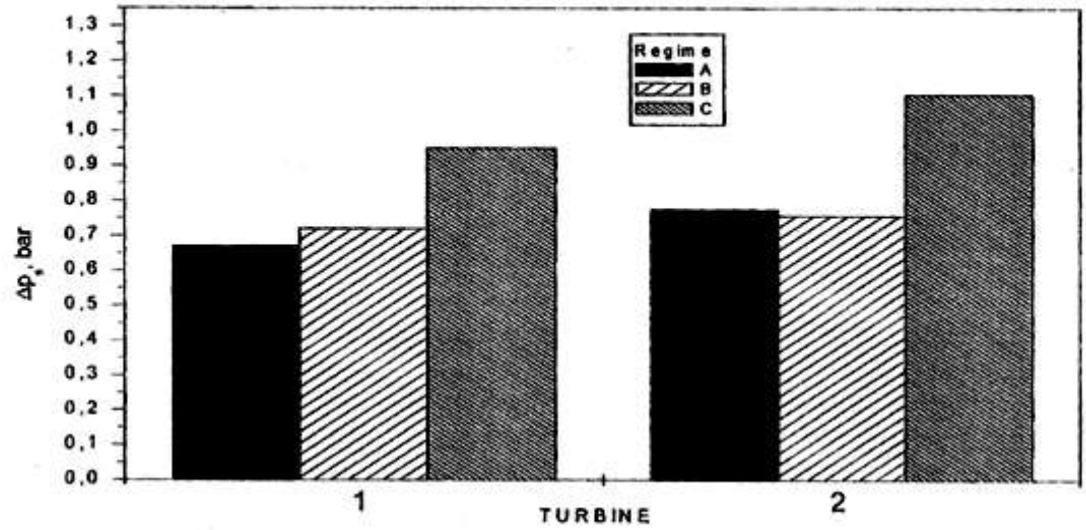

Fig. 5

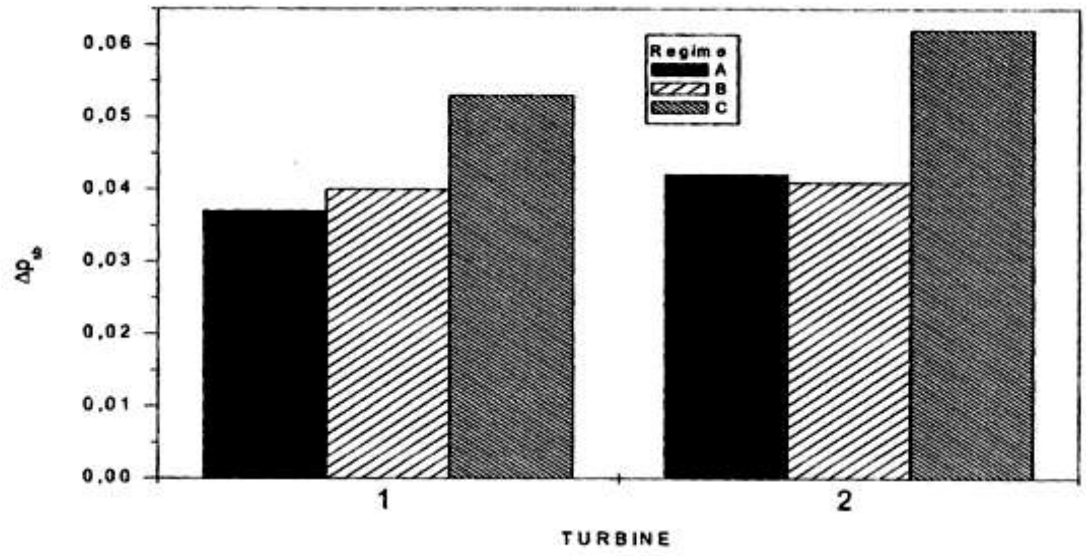

Fig. 6

The data analysis shows that the greatest pressure increase is registered at the inlet of turbine No.2 when both hydro-aggregates operate. The absolute pressure increase is 1.105 bar, whereas the relative increase is 6.2 %. The reason for this is the fact that, during parallel operations, XA2 is started, synchronized, loaded and stopped last.

On the other hand, it is clear that—as in the previous case—during individual operation of the hydro-aggregates (A and B operating conditions), the pressure increase at the inlet of the turbine that is not operating will be greater. Fig. 1 shows that the two turbines share one pipeline and that the distribution of the hit wave impacts substantially their inlet pressure.

It is also pertinent to note that the peak values of the pressure are registered for a short interval of time (1÷3s).

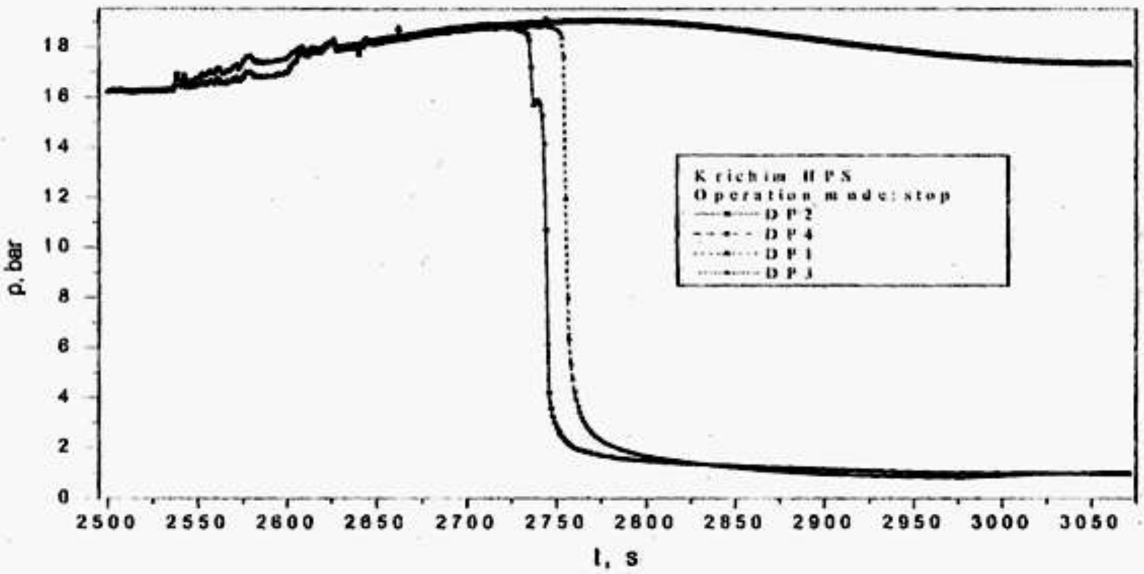

Fig. 7

Fig. 7 demonstrates a recording of the pressure variation at the measurement points when the two hydro-aggregates, operating in parallel, are being stopped (operating condition C).

3.2 Pressure variation at the draft tube

The measurement is conducted at the draft tube inlet (Fig. 1) of turbine No.1. Its goal is to determine the pressure change in this zone, because a number of hits have been detected at lighter loading. Fig. 8 shows the change of the absolute pressure at the measurement point in the following operating scheme: start, loading up to 20MW, loading up to 40MW, unloading and stopping.

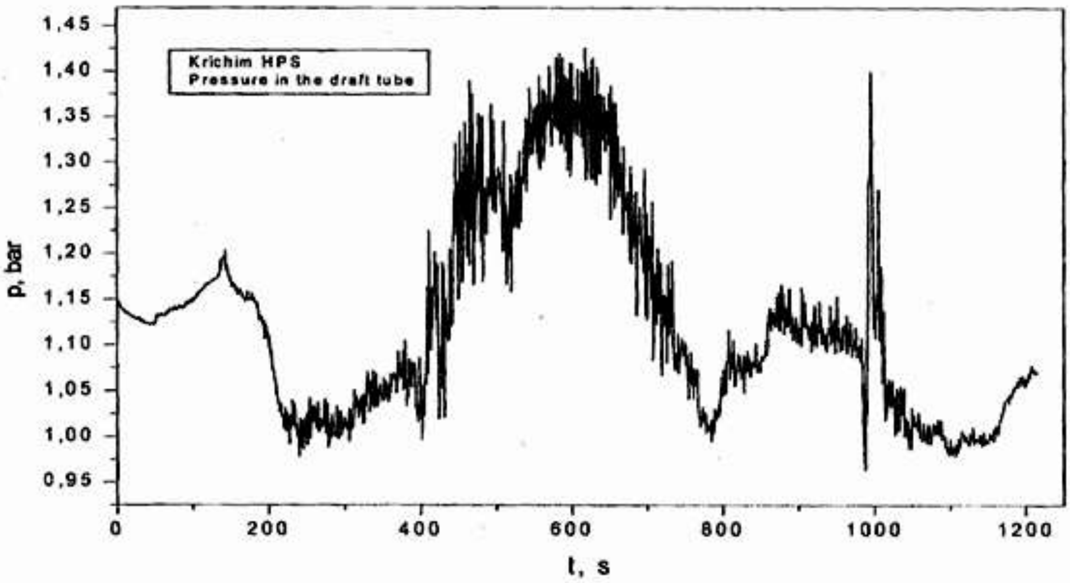

Fig. 8

The data analysis shows that the pressure does not decrease to critical values that would make possible the development of cavitation processes. However, the movement of the vortex core in this zone must be heeded, especially under operating conditions other than the optimal one as this phenomenon is mainly connected with the changes in the flow circulation [2]. A more detailed study of this phenomenon is thus required. It is also seen that the pressure increases at operation with maximum power- the reason for this event is the special system, which lets off air after the action wheel.

3.3 Hydraulic losses in the penstock

One of goals of the conducted tests is determining the hydraulic losses in the penstock at various operating conditions.

Table 2

№	Regime	Q, m^3/s	P, MW	h_v, m
1.	A	14,70	20	1,20
2.	A	21,70	30	2,75
3.	A	28,07	40	5,15
4.	C	43,40	60	12,98
5.	C	49,90	70	15,96
6.	C	56,14	80	21,62

The so-called 'loss pressure,' respectively 'loss height' h_v (hydraulic losses), is the difference between the measured pressure values of non-operating machines and the averaged pressure values at various hydro-aggregate loads, accounting for the dynamic pressure in the measured section as well. The values of these losses as well as the values of the active power of generator P and of the debit of pipeline Q are shown in Table 2.

The resistance characteristic of the penstock (shown on Fig. 9), i.e. the dependence $h_v = f(Q)$, is determined on the basis of the above data. The debit values are determined according to the characteristics $Q = f(P, H)$, derived from the conducted tests [3]. The coefficients of the dependence (a squared equation) for approximating the experimental data are also determined. The dependence is as follows:

$$h_v = -0.01816 - 0.02069Q + 0.00713Q^2$$

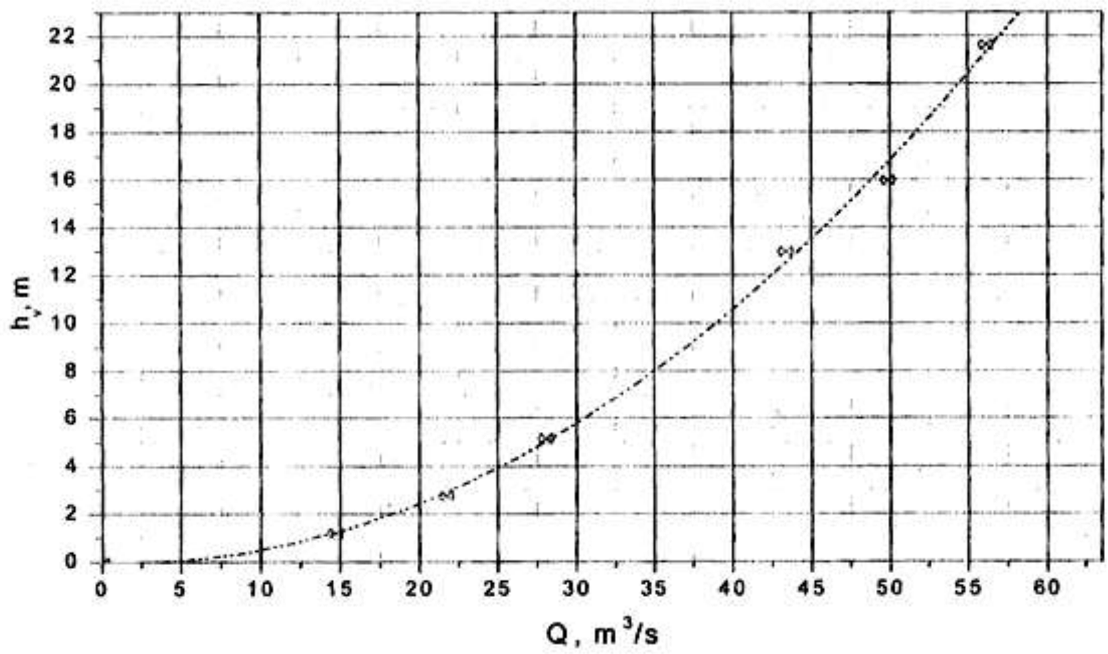

Fig. 9

This dependence could be used for determining the hydraulic losses at various pipeline debits. It is formal, since it is usually a squared parabola in the case of turbulent flows: $h_v = kQ^2$. The availability of significant experimental data for the pressure at the tested operating conditions, however, shows that the dependence of Fig. 9 has one and the same character. After determining the resistance characteristic of the penstock and after the operating characteristics of the water turbines and the hydro-aggregates become known, it is possible to determine some of the basic parameters of the so-called 'regime table' [1].

4. Conclusion

The main results from conducting the experimental tests on the hydro-aggregates of "Krichim" hydropower station are:

1. The results from measuring the inlet pressure of both water turbines provide opportunity for evaluating the degree of pressure increase at the hydro-aggregates' start and normal stoppage. The maximum value of the relative increase of pressure is determined to be 12.1%. The pressure increase is greater before a non-operating machine when the turbines are operating individually. When the turbines are operating in parallel, the pressure increase is greater before turbine No.2.

2. The resistance characteristic of the penstock is determined. An approximating dependence is defined on the basis of the experimentally obtained data, which can be used for determining the hydraulic losses at various pipeline debits.

References

[1] Obretenov V. Regime Tables for Hydropower Stations. Proceedings of Energy Forum'02, Varna, 2002.
[2] Obretenov V. Water Turbines and Hydropower Equipment. TU, Sofia, 1996.
[3] Analysis of the Hydro-aggregate Characteristics of Hydropower Stations. Report on project №9/09.02.1999, HPS – groups "Rodopi", Plovdiv.

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