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MODERNIZATION OF A PELTON WATER TURBINE

This study presents the results from the implementation of a design for creation of new runner of the Pelton turbine installed at Levski HPP (Bulgaria).
The new runner design has been worked out on the grounds of analysis of the main external parameters of the turbine and its structure. With view to the specific conditions one has adopted a plan for calculation of the runner based on the consecutive application of the task related to the synthesis of the buckets and analysis of the streamlining by the water jets. The analysis of the results from the tests shows that the exchange of the old runner with a new one has lead to significant increase of the power and the efficiency.

Introduction

The low headwater sources are an important energy reserve especially in countries, which do not possess large amounts of fossil fuel sources. In Bulgaria, there are more than 300 hydroelectric plants and most of them have low installed power. Some of the hydroelectric plants are already 50 years old and upgrade of this equipment is urgently needed.

This paper presents the results of the project for construction of a new runner for the Pelton turbine of the Levski HPP. This plant has three installed aggregates using Pelton turbines. The study was aimed at turbine No. 3 produced in 1934 by Escher Wyss. The turbine has two nozzles and horizontal shaft. The calculated parameters for the turbine are listed in Table 1.

Table1. Turbine parameters

Parameter	Value
Head (calculated), *m*	300.0
Flow (calculated), *l/s*	888.0
Frequency of rotation, min^{-1}	750.0
Power, *HP*	3000.0
Main diameter, *m*	0.9

I. RUNNER

1. Calculation procedure

Having in mind the real conditions, following procedure was used for the calculation of the main runner:

a) A basic model of blade is chosen (selected from the nomenclature of the Technical University - Sofia);

b) The coefficient for the geometric affinity law is determined and the geometry parameters of the new blades are calculated;

c) The face geometry of the blade is optimized by means of the software system PelTAD [1];

d) Several variants are developed by variation of the blade number and variation of the orientation of the blade inlet edge;

e) The kinematical interaction between the flow and the designed turbine blades is studied (for this purpose the Bound Jet software [2] is used) and through the optimization procedure the optimal values of the control parameters are determined;

In the phase of variant development it is very important to follow the requirement for adjustment of the runner size to the construction of the turbine - body, nozzles, deflectors etc. From this point of view four variants were developed (L19/559, L20/519, L19/544, L20/544) which differ in the number of the blades and the orientation of the inlet edge.

2. Results of the calculations

The calculations are performed with the software [2], which is part of the software system [1]. So, lots of parameters are possible to be calculated: the number of the blades, the orientation of the inlet edge, the radius of the tip, the active curvature, the angle of the full injection, the trajectory of the water particles on the rear side of the blade, etc. The aim of the calculation is to eliminate all possible volume loss from streamlining of the blades. This is achieved by a precise calculation of the blade number and by proper determination of the rear side blade profile by means of the relative jet trajectory on the whole active curvature. The software generates a text file where the results of the calculation are stored together with several graphic files showing the interaction between the jet and the blades within the limits of the active curvature. The trajectories for a given number of points in the jet for its limitation size are also calculated.

3. Runner design

After determination of the form and the orientation of the blades according to the axis of the runner, it is possible to begin with the design of the runner itself. Following the requirements of the technical assignment, the new runner should be a composite one and should have mechanical fixation of the blades. A strength check was performed for the new blades, the carrying disc and the fixation elements. By means of the PelTad software the distribution of the pressure on the face surface of the blade was determined. The determination of the fixation point of the blades to the disk is performed with forces and the torque analysis. This is done for the three extreme modes of performance: during start mode, during maximum power and during runaway speed mode.

Construction documentation for the new runner is prepared.

II. EXPERIMENTAL STUDY

The experimental study of the turbine with the new runner was performed after 500 working hours of the aggregate. A thermodynamic method has been used, according to Standard 41 of IEC [3] for the measurement of the efficiency. The basic results of the test at different modes are shown in Table 2.

Table 2. Test results

№	P_g	P_{ef}	Q	H	η	n_{11}	Q_{11}	n_s	a_0
	MW		m^3/s	m	-	min^{-1}	m^3/s	min^{-1}	%
1.	0,19	0,21	0,0804	339,3	0,8108	36,6	0,0027	7,46	7,0
2.	0,65	0,69	0,244	338,6	0,8631	36,7	0,0082	13,36	15,0
3.	1,21	1,27	0,4367	337,3	0,8935	36,8	0,0147	18,49	26,0
4.	1,69	1,76	0,5996	335,8	0,9016	36,8	0,0202	21,89	38,5
5.	2,09	2,17	0,7457	332,9	0,9018	37,0	0,0252	24,57	54,5
6.	2,4	2,49	0,8713	329,3	0,8957	37,2	0,0296	26,68	72,5
7.	2,61	2,70	0,9678	325,7	0,8869	37,4	0,0331	28,17	98,0

In Table 2 $n_{11} = \frac{nD_1}{\sqrt{H}}$, $Q_{11} = \frac{Q}{D_1^2\sqrt{H}}$, $n_s = \frac{n\sqrt{P}}{H^{5/4}}$ denote the reduced frequency of rotation, the reduced flow rate and the specific speed; a_0 denotes the relative opening of the needles (relation between the actual and the maximal opening). P_g, P_{ef}, Q, H ***and*** η denote generation power, effective power (of the turbine shaft), flow rate, head and efficiency of the turbine, respectively.

The obtained results lead to following more important conclusions:

1. The measured efficiency of the turbine corresponds in principal with the expected performance of turbines of this type at these external parameters (flow, head and specific speed) for generation of power in the range $P=190 \div 2610\ kW$. The maximum value of the turbine efficiency at head H=$332.9m$ is $\eta_{max}=90.18\%$. The value of the specific speed in the optimal mode of performance is 24.57 min^{-1} (table 2). This means that related to one jet this value is 17.37 min^{-1}, which is less than the optimal speed recommended for this head [4].

On Fig.1 the curve $\eta = f(P_{ef})$ of the examined turbine is shown. It is seen that the energy loss in the turbine remains constant in a relatively wide range, which is common for this type of turbines [4].

It is important to notice that the optimal working conditions of the turbine follow accurately the calculated values.

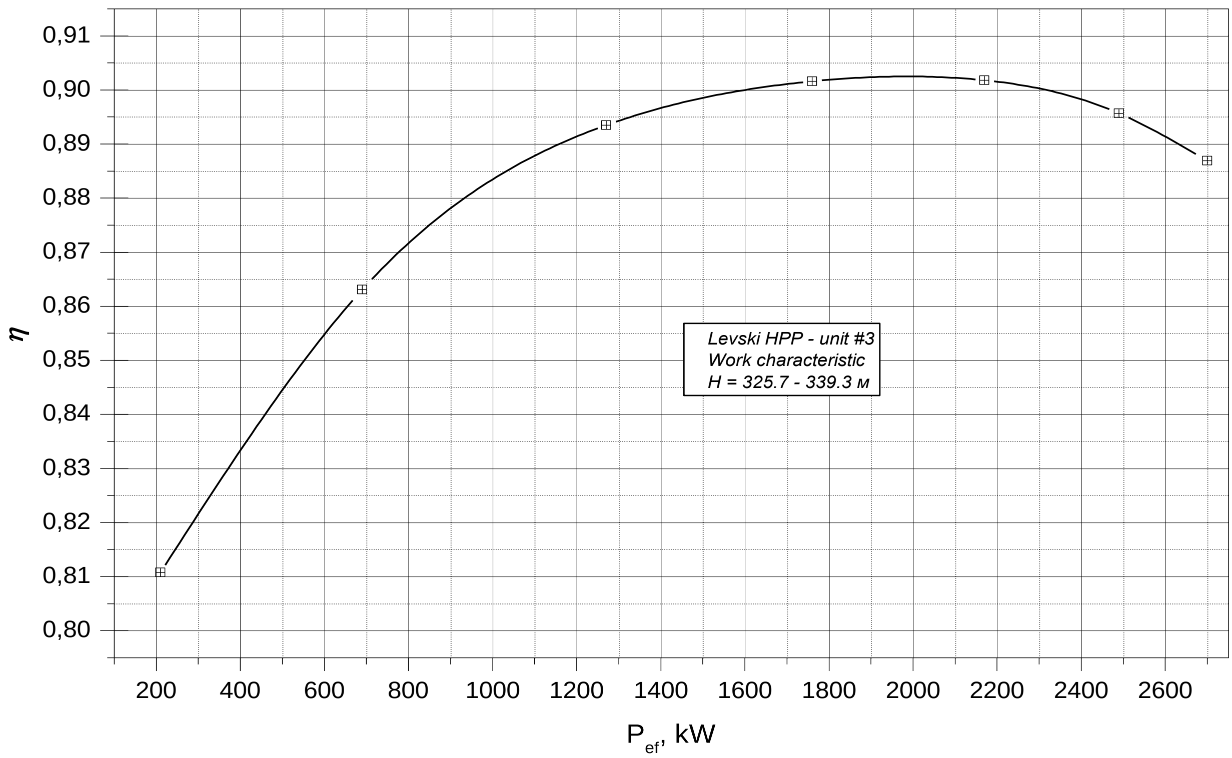

Fig.1. Work characteristic

2. One of the most important issues in the upgraded turbines is the improvement of their energy and cavitations performance, and the improvement of their reliability. From this point of view, it is interesting to compare the turbine performance of the old and the new main. The measurements on the turbine with old runner have been performed just before starting the project, only for the values of the active power of the generator at different gate opening. During these measurements, the turbine power was restricted up to 2100 kW, due to risk of main blade destruction. So, the measurements are made up to 63% of relative opening. The results of both measurements are compared on fig. 2.

It is seen that within the entire range, the turbine power increases significantly. Near the optimal performance, the difference between the power for both cases is most significant. Note that this fact is only a consequence of the energy characteristics of the new main blade, because in the Pelton turbines designed for a given head the flow rate depends solely on the needle opening. It is not realistic to expect large increase of the efficiency because the original turbine has been designed by one of the leading water turbine producers of that time - Escher Wyss - and has been maintained in a good condition.

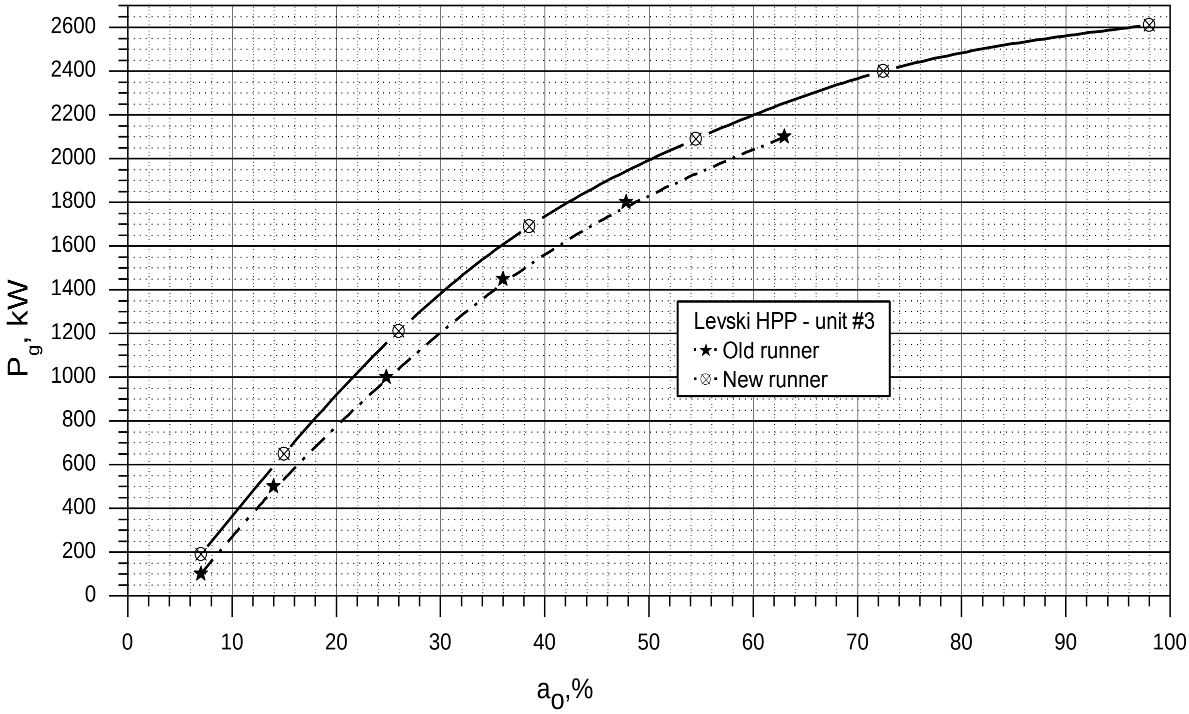

Fig.2. Comparison of the turbine performances

3. The results from the measurements allow to draw the curve of the generator active power and flow vs. needle opening. This curve can be used for evaluation of the performance upgrades of the turbine and the generator in future. The curve is shown on fig.3.

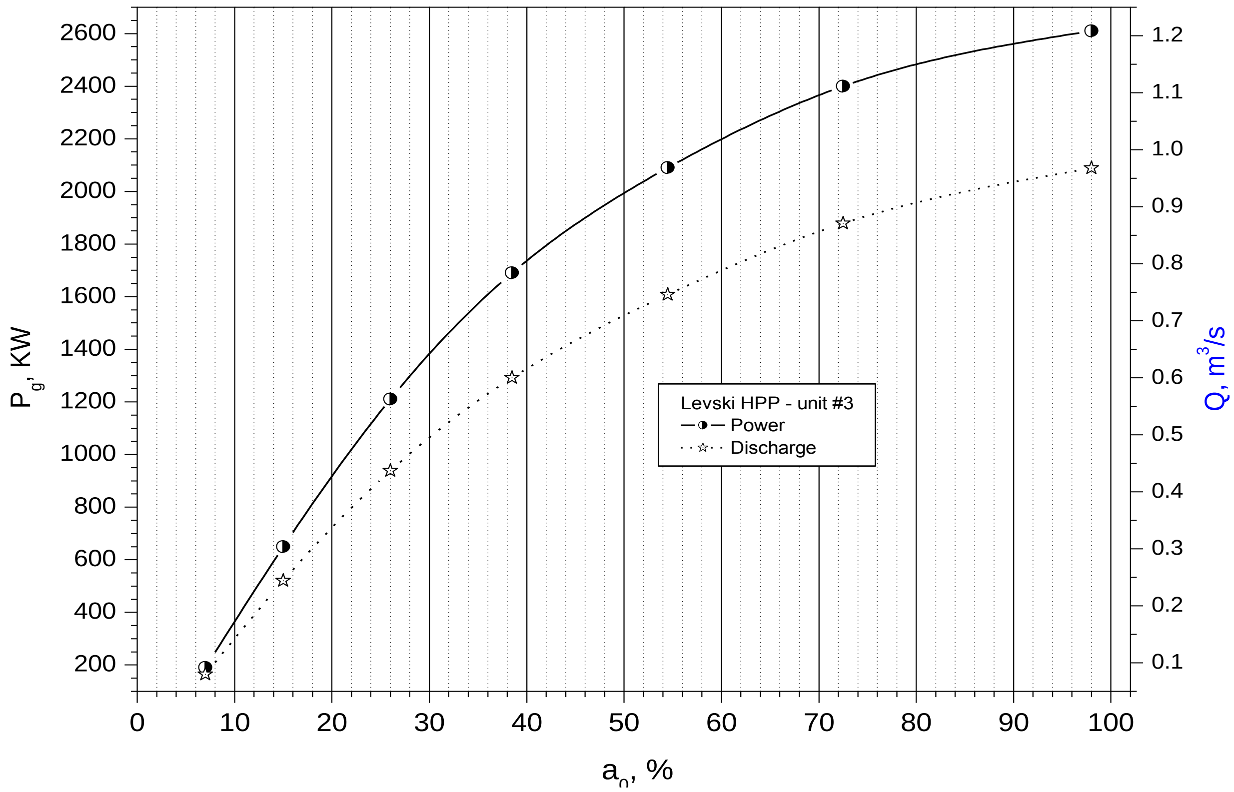

Fig.3. Dependence of the power and the flow rate from the needle opening

CONCLUSION

The basic results from the upgrade of the Pelton turbine runner No. 3 of the Levski HPP lead to the following main conclusions:

1. The abilities of the computer software system, developed in the Technical University of Sofia are checked in a practical case, with calculation of the main of a Pelton water turbine.
2. The analysis of the results from the tests shows that the exchange of the old runner with a new one has lead to significant increase of the efficiency.
3. There is a potential opportunity to further increase the efficiency of the aggregate by means of an upgrade of the turbine gate device and through an improvement of the aggregate control system.

References

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