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ECONOMICAL OPTIMIZATION OF A TRASHRACK DESIGN FOR A HYDROPOWER PLANT

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ABSTRACT

This paper presents an investigation into the different trashrack designs and their impact on fluid flow losses. Three different rackbar profiles were examined which cause different flow losses. A simple low-cost rectangle profile was used as a base-case and compared with two alternative aerodynamically-shaped profiles, which made the trashrack much more expensive. The river's flow from 200 m upstream of the hydropower plant to the turbine inlet was simulated by 3D CFD simulations using an ANSYS CFX 12 solver. The aim of the simulations was to predict the exact velocity field ahead of the trashrack. The local head-losses caused by the trashrack were then calculated using an empirical formula at each point of the velocity field, and finally integrated to obtain the gross head-loss caused by the specific trashrack design. Annual losses during electricity production were then predicted using experimentally-obtained river flow-rate data and the net profit then calculated, which served for the final study of the alternative trashrack design's economics. The study showed that a profit from the alternative trashrack design could be expected after a period of 10 years, which may be of the interest when replacing an old or damaged trashrack with a new one.
Keywords: hydropower plant, trashrack, flow losses, economic analysis

1. INTRODUCTION

The purpose of trashrack structures regarding hydropower plant is restricting the entrance of materials of considerable dimensions present in water, which could cause damage to generating machine, particularly to the pre-distributor, distributor, and the spiral-casing and runner of the turbine [1]. Trashracks are comprised of arrays of vertical bars that are generally held together by horizontal beams. Trashracks, particularly when not cleaned, produce unwanted energy-losses that directly reduce energy production. These energy-losses can be partly attributed to debris, ice, or finer trash, as well as the large-scale flow structures or eddies/vortices generated by the bars. It is well-recognized that the formation of vortices by arrays of bars, their evolution and interaction, strongly depend on bar spacing and bar profiling [2]. Thus it is possible to minimize the energy-losses within the turbine entry section using carefully selected trashrack design. A study was, therefore, performed on the trashrack design optimization of a hydropower plant on the river Drava. The installed capacity of the plant is 60 MW. It has three equal generators each driven by a Kaplan type turbine with a nominal flow rate 180 m^3/s and a nominal net-head of 14 m. The original trashrack used bars with a low-cost rectangular profile. Its live-span had expired and it needed to be replaced by a new optimized one. In order to perform optimization, the energy-losses of the original trashrack design was analyzed and compared with two alternative trashrack designs employing aerodynamically-shaped profiles. A combined simple 1D empirical and comprehensive 3D numerical approach was used to obtain the gross head-loss caused by the specific trashrack design. Annual losses during the electricity production were then predicted using experimentally obtained river flow-rate data and the possible net profit was predicted, which served for the final study of the alternative trashrack design's economics.

2. TRASHRACK LOSSES

Nowadays commonly-used formulas for determining the energy-losses caused by the trashracks origin from the early 20th century, e.g. Kirschmer [3] published in 1926. Derived under laboratory conditions these formulas normally lack the means of taking into account phenomena such as inhomogeneous velocity distributions, section blockage of the trashrack, turbulence or even vortices structures, which may all strongly influence the actual performance of the trashrack in practice. According to [4], this might be the reason why actually measured energy-losses tend to be remarkably higher than the theoretically-determined losses. Application of 3D CFD simulation may simply solve this problem, however, the computational mesh necessary to accurately solve it would be enormous, since the trashrack bar length to width ratio exceeds 10^3. A combination of 3D numerical and 1D empirical approaches, respectively, was, therefore, applied during our study. The 3D CFD simulation of the large scale-flow ahead of the river's dam and within the turbine intake channels was used to predict the velocity field ahead of the trashrack, while the local head-losses caused by the trashrack which appeared on a small scale were obtained empirically. The WAV empirical formula [4] was used to calculate the local head-losses at each computational mesh-point ahead of the trashrack, and these local head losses were finally integrated in order to obtain the gross head-loss of the trashrack.

2.1. Global flow simulation

The river flow from 200 m upstream of the hydropower plant dam to the turbine inlet was simulated by 3D CFD simulations using an ANSYS CFX 12 solver. The aim of the simulations was to predict the exact velocity field ahead of the trashrack.

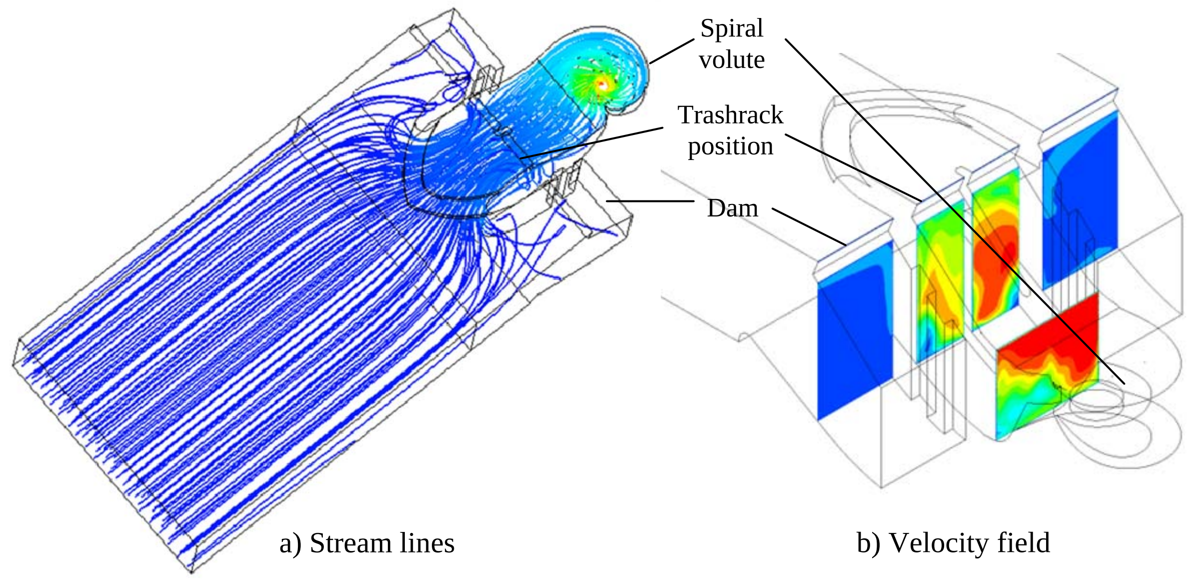

Figure 1. Global simulation

The computational domain, together with some of the stream lines, is presented in Fig. 1a. Only one turbine was considered in order to reduce the computational domain, which was possible by the application of periodical boundary conditions at both sides of the computational domain. An unstructured mesh was used with 2.2 million elements. As can be seen from Fig. 1, the water inflow is split into two symmetric channels with trashracks mounted in front of them. Both channels joined together ahead of the turbine, however, due to the characteristic position of the spiral volute the velocity field was far from symmetrical (Fig. 1b) which is reflected in a non-symmetrical velocity field ahead of the trashracks. The mean velocities of the left and right hand-sides differed by more than 20 %, which is the reason why global-flow simulations were necessary in order to correctly predict the trashrack losses that increased by the second power of velocity. Several flow-rates were simulated according to the actual turbine operational data and the velocity fields ahead of the trashrack were obtained every 5 m^3/s for the flow-rates between 90 m^3/s and 180 m^3/s.

2.2. Local trashrack losses

The local head-losses of the trashrack were calculated by applying the empirical formula proposed by the WAV Institute [4]:

$$\Delta h = K_f(1 + 0{,}65\delta)p^{1{,}33}\left(\frac{b}{l}\right)^{-0{,}43}\sin\theta\,\frac{v^2}{2g} \tag{1}$$

where: K_f – form factor,
δ – horizontal angle of inflow,
p – blockage ratio,
b – clear spacing between the bars,
l – length of the bars,
θ – vertical angle between the main direction of the local current and the trashrack,
v – local flow velocity ahead of the trashrack.

Equation (1) was applied for every single point of the predicted velocity field ahead of the trashrack, using local flow-velocity v and local flow-angles (vertical angle θ and horizontal angle δ) resulting from global simulation.

2.3. Gross head losses of trashrack

The gross head-loss of the trashrack was obtained by the numerical integration of the predicted local head-losses over the whole trashrack domain. Fig. 2 shows the gross head-losses of a trashrack as a function of flow-rate for three different profiles of trashrack bars. Although profiles 2 and 3 did not have optimal aerodynamic shapes their application reduced the gross head-losses significantly. The head-losses reduction for profile 2 was 30 % and more than 60 % when profile 3 was applied instead of the original low cost rectangular profile 1.

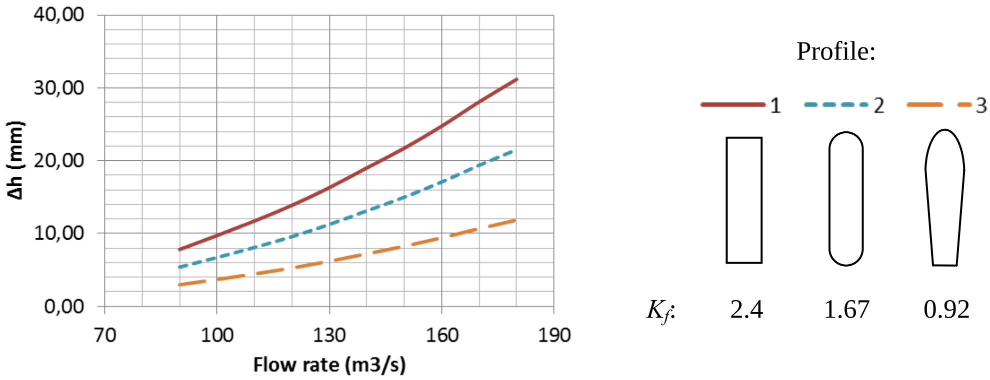

Figure 2. Gross head losses of trashrack for three different trashrack bar profiles

3. ECONOMIC ANALYSES OF DIFFERENT TRASHRACK DESIGNS

The application of a specific trashrack bar profile in practice depends on two factors: its influence on the mechanical characteristics of a trashrack, and its economic efficiency. The dynamic behavior of the trashrack has to be studied carefully in order to avoid any possibility that the frequencies of flow-induced vibrations match the resonance frequency of trashrack. The corresponding vibration study showed that some necessary trashrack modifications were needed when alternative bar profiles were used in order to increase its stiffness. The number of horizontal beams was increased, therefore, thus solving the vibration problems. However, this safety measure increased the blockage ratio of the trashrack and slightly deteriorated its efficiency which had to be considered in the economic analysis. The latter was performed by calculating the annual energy-losses of the hydropower plant for each trashrack design and by predicting the possible net-savings using the alternative bar profiles 2 and 3.

Those savings were then discounted back to time zero for comparison between the difference in the sums invested in the original and alternative trashracks, respectively. The so-called net present value method was used with a 5 % discount rate.

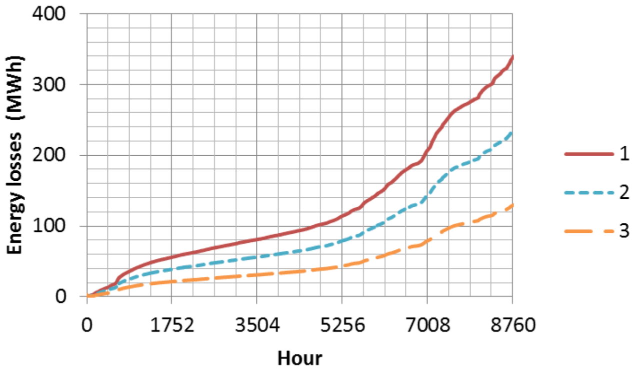

Figure 3. Cumulative annual diagram of energy losses for three different profiles

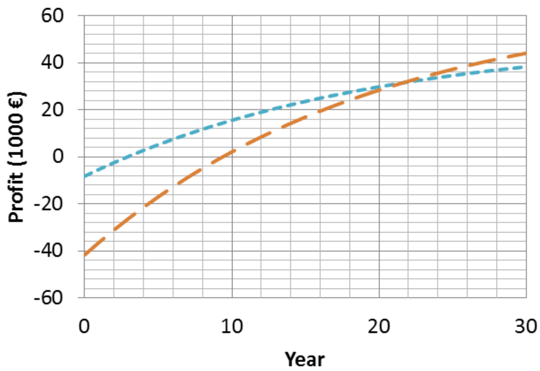

Figure 4. Cumulatively discounted cash-flow over time

Fig. 3 shows a cumulative annual diagram of energy-losses for all three profiles. Actual annual flow-rates acquired on hourly bases were used to construct this diagram, simply by assigning the gross-head losses from the diagram in Fig. 2 to the actual flow-rate and transferring them to energy-losses. Possible energy savings using alternative bar profiles were 104.4 MWh and 210.1 MWh for profiles 2 and 3, respectively. However, both profiles required higher investments. A new trashrack with bar profile 2 would cost approximately 5 % more than the one with the old bar profile design, while a new trashrack with bar profile 3, which is significantly more expensive, would cost approximately 30 % more. Fig. 4 shows the cumulative cash-flow over time for both alternative profiles. The discounted pay-back period for a new trashrack with bar profile 2 would only be 3 years, while 9.3 years would be needed to gain a profit with bar profile 3. However, the expected live span-profit would be higher if bar profile 3 were applied.

4. CONCLUSION

The study has been presented on the optimization of a trashrack design. An existing hydropower plant on the river Drava was examined. A trashrack gross head-losses diagram was constructed first. Then a 3D CFD simulation using an ANSYS CFX 12 solver was used to predict the velocity field ahead of the trashrack in order to obtain those local velocity vectors which were necessary for calculating the local head-losses using a simple empirical formula. The local losses were then integrated over the trashrack domain for determining the gross head-loss at a specific flow-rate. Using an annual flow-rate data and gross head-losses diagram it was possible to predict the annual energy-losses. Two alternative trashrack bar profiles were examined and compared with the existing rectangular profile. The economic analysis showed that any investment in even a small improvement of bar profile aerodynamic may ensure a short pay-back period, and a final profit gain.

5. REFERENCES

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