

INFLUENCE OF DEBRIS COLLECTED ON A TRASHRACK ON THE ECONOMICS OF A HYDROPOWER PLANT

Aleš Hribernik
University of Maribor, Faculty of Mechanical Engineering
Smetanova 17, Maribor
Slovenia

ABSTRACT

The losses caused by the debris collected on the trashrack of a 20 MW hydropower plant aggregate were analyzed. Pressure sensors in front of, and behind, the trashrack were applied to measure the instantaneous head loss of a trashrack in 15-minute time intervals. Simultaneously, the flow rate and water temperature were measured. Data for one year of operations was collected and processed. It was assumed that the trashrack was perfectly clean after the general refit of the aggregate, which takes place once a year in the winter, when the flow rate is low and almost no debris is found in the water. Thus, the head losses measured immediately after the refit may be attributed to the trashrack design only and can be used to model the losses of a clean trashrack. A simple temperature-compensated polynomial model was used to predict clean trashrack losses as a function of the flow rate. Using this model, it was possible to clearly distinguish between the losses caused by the trashrack itself and by the debris collected on the trashrack. This made it possible to examine the seasonal effect of the debris on the head losses and to predict the optimal frequency of trashrack cleaning as well as annual losses during electricity production and power plant economics in general.

Keywords: hydropower plant, trashrack losses, power plant economics

1. INTRODUCTION

A substantial amount of debris, ice and trash drifting in the river can damage vital parts of a hydropower plant. Trashracks are, therefore, used to restrict the entrance of significantly sized material present in the water. Trashracks produce unwanted energy-losses, which can be partly attributed to debris, as well as the large-scale flow structures or eddies/vortices generated by the trashrack bars [1]. The latter cannot be omitted. However, the losses caused by the debris collected on the trashrack can be reduced significantly when the trashrack is regularly cleaned. Trashrack losses for one of the three 20 MW hydropower plant aggregates were analyzed. Head losses caused by the trashrack, flow rate and water temperature were measured simultaneously in 15 minute-time intervals. Data for one year of operation was collected and processed. It was possible to separate the head losses caused by the trashrack structure itself and those caused by the debris collected on it. This made it possible to isolate the seasonal effect of the debris on the head losses and to predict the optimal frequency of trashrack cleaning as well as annual losses during electricity production and power plant economics in general.

2. MEASUREMENTS

The trashrack is situated at the entrance of the inflow channel of the hydropower plant aggregate. Energy losses caused by the trashrack are commonly categorized as a head loss. Using submersible level transmitters in front of, and behind, the trashrack it is possible to measure the instantaneous head loss caused by the trashrack. Two temperature compensated *Hydrobar I* sensors with long term stability less than 0.1% produced by Klay-Instruments [2], were applied in our case. Simultaneously, water temperature and flow rate were acquired via computer every 15 minutes and saved to the computer's hard disk. Fig. 1 shows the characteristic head loss and flow rate signals acquired during a

48 hour period. There are two long operation periods and two short periods when the aggregate stand still and flow rate was 0. Significantly high variations in the flow rate were observed during the aggregate's operation and therefore the variations of head loss, which changes with the second power of velocity, are even higher. Their frequency and amplitude agree well with the flow rate variations and prove that the sensors were correctly chosen and that the measurements were adequately performed.

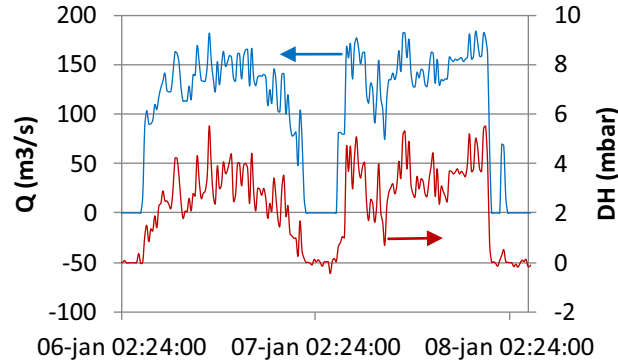


Figure 1. Measured flow rate and trashrack loss

3. CLEAN TRASHRACK HEAD LOSS MODEL

Trashrack losses are generated by trashrack bars and by the debris that is collected on the trashrack. When clean, the trashrack losses are the smallest and they increase with the amount of trash collected on the trashrack. In order to determine the energy-losses caused by the collected trash, the energy losses of a clean trashrack need to be known. One can apply empirical equations [1] or use measured results to predict the energy-losses of a clean trashrack. In our case, the latter was used. It was assumed that the trashrack was perfectly clean after the general refit of the aggregate, which takes place once a year in wintertime. During the refit, which lasts between two and three weeks, the water is pumped out of the inflow channel and the trashrack is dismantled for any necessary repairs and cleaning. Thus, it is perfectly clean when the aggregate is assembled and put into operation again. The flow rate is low in the wintertime and almost no debris is present in the water. Therefore, the trashrack operates in a clean state for a period long enough to acquire data on its operation and build a simple model for energy loss prediction. One week of data on the flow rate and head losses measured immediately after the refit were used in our case. A simple second order polynomial was applied to fit the measured data. Fig 2 shows the resulted polynomial. It fits the measured data very well ($R^2 > 0,99$), however, it does not consider seasonal water temperature variations, which may influence water viscosity significantly. In February, when the general refit took place, the average water temperature was $2\text{ }^{\circ}\text{C}$, while in summer the water temperature rises to $20\text{ }^{\circ}\text{C}$. The kinematic viscosity of water is $\nu = 1.79\text{ mm}^2/\text{s}$ at $0\text{ }^{\circ}\text{C}$ and $\nu = 1.01\text{ mm}^2/\text{s}$ at $20\text{ }^{\circ}\text{C}$, thus a clean trashrack's head losses are lower in the summer, which means the head loss model has to be expanded in order to take water temperature into account. Trashracks are comprised of an array of vertical bars that are generally held together by horizontal beams. When water moving at uniform velocity u meets a fixed solid surface of rackbar a boundary layer is formed starting at zero thickness and increasing in the thickness as the water moves along the surface. This growing boundary layer is laminar until the local Reynolds number reaches:

$$\text{Re}_x = \frac{u \cdot x}{\nu} \approx 5 \cdot 10^5 \quad \dots (1)$$

when the transition into the turbulent boundary layer takes place. The rectangle rackbar profile $15 \times 130\text{ mm}$ was used in our case, thus $x_{\text{max}} = l = 130\text{ mm}$ and at $u_{\text{max}} = 1.4\text{ m/s}$ the Re_x was well below $5 \cdot 10^5$, thus an assumption of prevailing laminar boundary layer may be used. The mathematical solution of the laminar boundary layer equations provide an expression for the local friction factor at distance x from the leading edge [3]:

$$f_{0,x} = \frac{\tau_{0,x}}{\rho \cdot \frac{u^2}{2}} = \frac{0.664}{\sqrt{\text{Re}_x}} \quad \dots (2)$$

By integrating equation (2) from the leading to the trailing edge of the rackbar profile, i.e. from 0 to l , the average value of the friction factor can be obtained [3]:

$$\overline{f_{0l}} = \frac{\overline{\tau_{0l}}}{\rho \cdot \frac{u^2}{2}} = \frac{1.328}{\sqrt{\text{Re}_l}} \quad \dots (3)$$

which may be used to predict the friction losses between the leading and trailing edge. At the reference water temperature, the reference average friction factor is:

$$\overline{f_{0l,ref}} = 1.328 \sqrt{\frac{v_{Tref}}{u \cdot l}} \quad \dots (4)$$

while kinematic viscosity v_T can be used to calculate the average friction factor at other water temperatures. It follows that a simple polynomial model for a clean trashrack's head loss obtained at the reference water temperature needs to be corrected as:

$$\Delta h = \Delta h_{ref} \sqrt{\frac{v_{Tref}}{v_T}} \quad \dots (5)$$

in order to consider actual water temperature. Fig. 2 shows a comparison of clean trashrack head losses at the reference temperature and at 20 °C. We can see that the difference for clean trashrack head losses is up to 25% between winter and summer time, and thus should not be neglected.

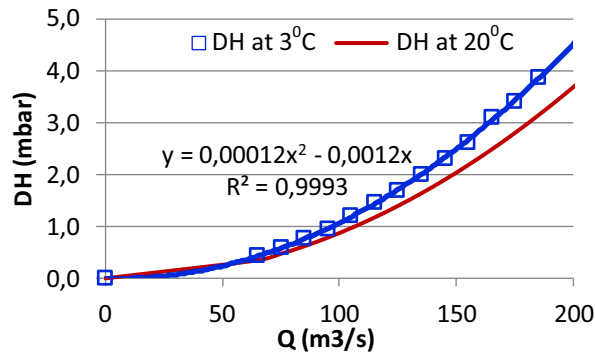


Figure 2. Clean trashrack head losses at $T_{ref} = 3 \text{ }^{\circ}\text{C}$ and at $T = 20 \text{ }^{\circ}\text{C}$

4. RESULTS

The presented model has made it possible to clearly distinguish between the losses caused by the trashrack itself and by the debris collected on the trashrack. Fig. 3 shows the cumulative one year energy losses and the variation of the flow rate. The losses are flow rate dependent, thus the increase in cumulative losses is the highest in the autumn high water season and, at the same time, due to the high concentration of drifting trash the influence of the collected debris on cumulative losses is the highest too. During one year of operations, debris causes up to 140 MWh of electricity losses, which is 50% of all losses, and 45% of all these losses take place in the relatively short three-month-long autumn high water period.

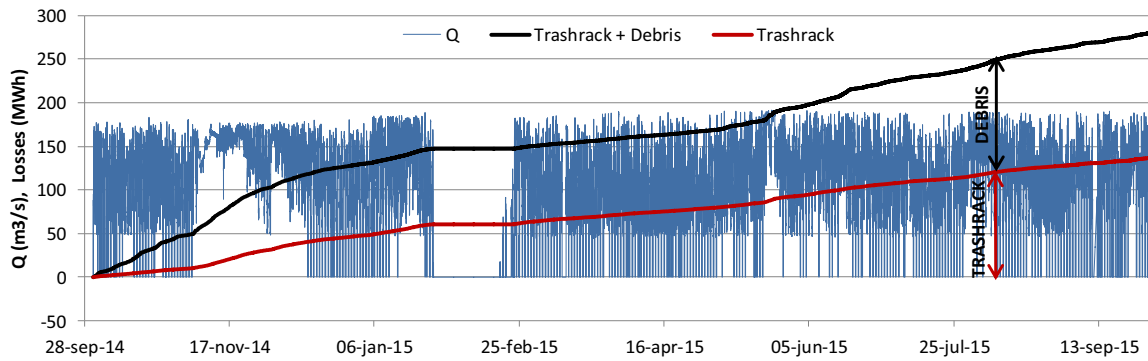


Figure 3. Energy losses caused by a clean trashrack and by collected debris

Fig. 4 shows the week-to-week variation of energy losses. The general refit took place in February. Therefore, no losses were generated between the 5th and 7th week. In the 45th and 46th week, the losses were the highest. On the other hand, very low losses can be observed between the 8th and 17th week, i.e. in the winter period of low water when the influence of debris on energy losses is almost zero. The first spike in debris-caused energy losses takes place between the 20th and 24th week, which is mid-spring, when frequent rain and thunderstorms spill debris collected in surrounding forests during the winter into the river. Even higher is the influence of debris on energy losses in October and November (the period between the 40th and 48th week). The water level is high during this period, with a lot of drifting debris originating from over-flooded river banks and whole curtains of dead algae, which were blooming in the upstream reservoirs during the summer season, also appearing.

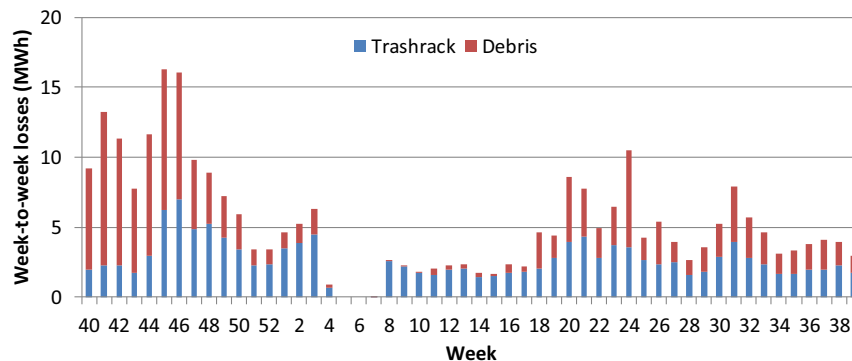


Fig. 4. Week-to-week variation of energy losses caused by a clean trashrack and by collected debris

5. CONCLUSION

This study examined the influence of the debris collected on a trashrack on energy losses for a 20 MW hydropower plant aggregate. Although the trashrack was regularly cleaned, the cleaning was performed once a week, the collected debris increased the annual energy losses by 100%. This translates to an income deficit of 7,000 EUR per year. By applying an optimal cleaning strategy, this deficit can be significantly reduced. However, an optimal strategy is difficult to predict, because of the stochastic nature of the amount of debris drifting daily in the river. It is much easier to perform cleaning as circumstances require by determining an upper limit of head loss above which the trashrack should be cleaned. Using trial and error, it was found that when the upper limit of the head loss is set to 100 mmH₂O the number of trashrack cleaning per year remains unchanged. However, the extra energy losses due to debris are reduced by 50%.

6. REFERENCES

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