Torque loss occurring on a Submerged impulse hydro turbine

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Abstract. Small hydropower development is one of the best way for enhancement of energy security and good solution of global environmental issues. A new submerged impulse turbine has been developing for generation by replacing a pressure reducing valve in drinking water pipe lines. This study has been especially focused on torque loss on the turbine, but it is not fully understood the reason why the loss is occurred. The torque loss is serious problem for a submerged turbine performance. Thus the torque loss on the runner and a disk was measured. This study, therefore, focuses on the loss mechanisms and aims to reveal key parameters for the loss reduction. We measured and compared to the torque loss between a simple disk and the submerged impulse runner experimentally. In addition, we aimed to reduce the agitation loss with the runner blade.

1. Introduction
Small hydro has much attracted because of its less environmental damages and much unused potential than large hydropower in many developed countries. It is, however, hard to develop small hydropower that is less than 100kW due to low benefit-cost ratio for selling commercial electricity. This is because of that the total construction cost including civil works, electric equipment per unit generating power becomes high. From this point of view, small hydropower generation in drinking water pipelines has high possibility because of no debris management and less civil works. As we well know typical impulse type turbines, Pelton turbine and Turgo impulse turbine, are suitable for very low specific speed sites. When these impulse turbines are operated in the water for generation in drinking water pipelines, their efficiency drops down due to water agitation loss with runner buckets and due to disk friction loss.

That is why it is significant that development of new impulse turbine which can be operated in the water with high efficiency and low cost. To reduce the losses of disk friction and agitation must be investigated. According to the previous studies, it is revealed that the disk friction loss is proportional to fifth power of the disk radius and to square of the disk rotating speed \([1][2]\). But there is no knowledge about the losses acting on the submerged impulse turbine. In this study, therefore, the authors showed friction loss on a rotating disk and agitation loss on a rotating runner based on the experimental results, and then visualize flow patterns in the vicinity of the runner surface. In addition
the authors investigated loss suppression method with a pair of doughnut shaped disks which was placed at the both side of the runner with small gaps.

2. Experimental apparatus and procedure

Figure 1 shows experimental apparatus for torque loss measurement on the shaft of a testing runner/disk. The runner was set in a water tank to keep enough distance from the tank walls as shown in the figure and rotated under water by a variable speed motor set over the tank with pulleys and a timing belt. The runner speed was adjusted by changing an inverter frequency for the motor. The torque and rotation speed of the runner shaft were measured simultaneously with a torque meter (Ono Sokki, SS-050), and an electromagnetic rotation meter (Ono Sokki, MP-981), respectively. No casing and nozzle were used to elucidate the agitation loss under simple condition. A pair of doughnut shaped disks was set as they sandwiched the runner/disk with a gap from \( \delta = 1 \) to 3mm. The gap was set as same value at the both side of the runner. In this experiment, slide bearing was used for supporting the shaft in the water, so mechanical loss is not negligible for agitation loss measurement. That is why before the torque loss measurement, torque on the shaft without the runner was measured, and then the measurement torque with only the shaft was subtracted from the measured torque with the runner.

Figure 2 illustrates the testing runner and detail shape of the blade. The runner has been newly developed for a submerged impulse turbine by the authors [3]. It is well recognized that the runner blade is quite smaller related to the runner diameter than the bucket of traditional impulse turbines. It is hoped that agitation loss becomes smaller than that of the traditional turbines. Cross section of the blade does not change from the hub to the tip to reduce manufacturing cost. Outer diameter and width of the runner and the disk was 195mm and 30mm, respectively.

![Figure 1. Experimental apparatus for agitation loss measurement of a submerged impulse runner.](image1)

![Figure 2. Configuration of testing runner.](image2)
3. Results and discussion

3.1. Measurement of agitation loss on the runner/the disk

Figure 3 shows measurement results of torque loss on the runner and the disk with changing the rotation speed. Plots in the graph are the experimental results and solid lines are parabolic curves approximated by least-squares method. The torque grows up rapidly with the rotation speed especially for the runner. The loss on the runner is much higher than that on the disk because of agitation loss with blades. Two parabolic curves are good agreement with all plots. Thus, torque loss on the submerged impulse runner is proportional to square of the runner rotation speed as well as that for the disk\(^{[1][2]}\).

Figure 4 shows the ratio of the torque loss on the runner and that on the disk. The torque loss ratio is increased with increase the runner rotation speed. High growth rate is observed for the low rotation speed of \(N < 300\) rpm, the growth rate becomes gentle with increase the rotation speed. The maximum torque loss ratio is approximately 4 around \(N=1000\) rpm.

![Figure 3. Torque loss measurement result of a runner and a disk.](image)

![Figure 4. Torque loss ratio of the runner and the disk.](image)

3.2. Visualization of flow patterns

Figure 5 illustrates visualization result of the runner surface with oil film method after rotation. Fig.5(a) is a whole image at the one side of the runner. This image is superimposed hand writing black lines which trace the oil flowing trajectory for easy observation. The composition weight ratio of the
oil is titanium dioxide of 10 wt.%, liquid paraffin of 5 wt.% and oleic acid of 2 wt.%. From the previous studies, it is well known that spiral pattern from the inside toward the outside is formed on the disk surface. The line patterns shown in Fig.5(a) are distorted comparing the previous patterns on a disk. The distorted trajectories might be influenced by the turbulence flow around blades. This result indicates that flow pattern of the runner is different from that of the disk, that is why loss generating mechanism should be different from the case of the disk.

Figure 5(b) is a magnification image around the runner blades. It is noticed that shade irregularity in the blade height direction is easily recognized on the blade suction side. Light color portion remains oil film, on the contrast the film was peeled at dark portion shown as A. The peeled portions can be observed on all blades. This pattern indicates impingement of surrounding water toward the dark potion by submerged rotation. In this case, high differential pressure occurs between the suction and pressure side of the blade. This is the one of the major reason for increasing the agitation loss on the submerged runner.

(a) After rotation at 800rpm for10 min
(b) Magnification image

Figure 5. Visualized oil film patterns on the runner surface.

3.3. Reduction of torque loss on the runner

Figure 6 shows measurement results of torque loss on the runner with or without a pair of doughnut shaped disks for the gap of $\delta=1.0$, 2.0 and 3.0mm. Plots in the graph are the experimental results and solid line is parabolic curves approximated by least-squares method. All experimental data are on each parabolic curve. All results show rapidly growth of torque loss with increase the rotation speed. The torque loss without disks is apparently higher than that with disks for $\delta=1.0$ and 2.0mm. The disks have no effect with $\delta \geq 3.0$mm. It is thought that smaller disk clearance disturbs the water flowing through the runner blade. The blade shape is not symmetry as shown in Fig. 2. In this case, rotating runner in the water works as a pump. The pumping loss can be reduced by sandwiching the runner with a pair of disks.

Figure 7 shows variation of the ratio of torque loss with a pair of disks to the loss without the disks. The torque loss ratio are decreased with increase the runner rotation speed. It is well recognized that the torque loss for $\delta=1.0$mm is approximately 60% of the loss without the disks. On the other hand, a disadvantage with disks is that the torque loss increases drastically for the lower turbine speed condition, $N \leq 200$rpm.
4. Conclusions

This study was focused on investigation of the torque loss on the runner for submerged impulse turbine. As a result, it is revealed that agitation loss of water is major reason for deterioration of the turbine performance. Furthermore, the authors also clarified that the loss can be decreased by sandwiching the runner blade with a pair of disks.

(1) The torque loss on the submerged impulse runner is proportional to the square of the runner rotation speed as well as that on a simple disk.

(2) The torque loss on the runner becomes approximately four times larger than that on a simple disk. This is due to the water impingement toward the suction side of blade rows and the pumping effect by the asymmetry blades.
(3) The torque loss can be reduced up to 40% by covering the inlet and outlet of blades by a pair of disks with small gap in axial direction. Future works are needed to apply the loss reduction method into actual submerged turbine. The authors are trying to reveal the detail flow field around the runner by CFD simulation, and will introduce new results at the conference.

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