Design and Development of Rotating Disk Apparatus to Test Sediment Erosion in Cross Flow turbine Runner Blades

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Abstract

Sediment erosion is the main challenge in the Nepalese hydro power Project. Water carries sand containing highly abrasive particle that is produced due to continuous uplift of the mountain ranges, cracks in rock and heavy rainfall. The water with erodent erodes the several components of the hydraulic turbine during operation time which decreases the life and efficiency of the plant. Sedimentation affect from high head Pelton and Francis turbine to low head Cross flow turbine (CFT) regardless to capacity of the plant. Several research works had been performed to identify the parameters that control the erosion rate and to develop mathematical model to estimate the effect on different components of hydraulic turbine. New design was introduced to reduce the effect of erosion on high head Francis turbine. Although there are plenty number research had been done and going on as well in Nepal, no traces is found which addresses the sediment effect in locally made Cross flow turbine. Therefore, there is a need of innovative turbine design which resists the erosion from sand particle. In order to investigate the wear pattern of the CFT blades, the whirling arm rig or Rotating disc apparatus (RDA) is selected for the erosion test with controlled parameters. The erosion tester is designed and installed at Turbine Testing Lab (TTL).

Keywords: Sediment erosion, cross flow turbine blades, rotating disk apparatus, experiment

1. Introduction

1.1. Background

The Federal Democratic Republic of Nepal is the second richest country in inland renewable water resources beside Brazil. The perennial attributes of rivers originated from steep decline mountain ranges of Nepal provide the conservative hydroelectric potential of approximately 83,000 MW. With huge opportunity of producing hydro based electricity through water flowing in river, large amount of sediment is carried as well. The main reason behind the high sediment yield is that the mountains have been uplifted rapidly and the rocks have fractured and weathered more than most geologic zones in other mountains with high rainfall [1]. Sedimentation is one of the major challenges faced by the hydro power project developed in Nepal. It not only affect the turbines with high head Pelton turbine or Francis turbine but also harms micro class Cross flow turbine with low head. Such turbine are installed in micro hydropower system
Water flow along with the sediment through penstock pipe strikes the turbine results erosion on surface of various components of turbine. Continuous wear on the turbine declines efficiency and decrease the operation life of the plant [2]. There are numerous examples of failure of CFT runner due to sediment erosion. One of them is Daram Khola MHP. In this project, two turbines are mechanically synchronized to single generator with gross head of 13 meter, flow rate 550 l/s.

![Figure 1. Damaged CFT runner blades of Daram Khola MHP due to sediment erosion](image)

Fig. 1 shows both runners completely damaged due to sediment erosion. Erosion on blades can be clearly seen in both turbines as indicated inside rectangular boxes which finally leads in breakdown of blades. Previous study [3] has shown the erosion patterns in CFT using ANSYS CFD as a numerical investigation tool. In the report, it is concluded that erosion pattern depends upon several factors including guide vane openings, sediment size, shape factor and sediment concentration. There has been numerous research work in the field of sediment erosion in hydraulic turbines. The studies are focused to identify the parameters which influence the erosion rate and to develop mathematical model to estimate the effect on different components of hydraulic turbine [2] [4] [5] [6]. Furthermore, hydraulic design of high head Francis turbine was performed to minimize the sediment erosion effect [6]. Despite the fact with such a successful research and development in Pelton and Francis turbine, lacks research and development in the field of effect of sediments on CFT. In the absence of such study, there is no significant contribution in this field to tackle the local problem of sediment erosion. The effect due to sand particles are not considered in design of micro hydro turbines. As a result, the power output of turbines gets affected when operated with higher concentration of sand particles. The purpose of this paper is to visualize the wear pattern on CFT blades with simplified erosion tester.

1.2. Types of Sediment erosion tester

There are numerous erosion test setups which are used by the researchers around the world. They can be basically categorized into mainly four types: (i) Sand or gas-blast rig (ii) recirculating liquid slurry loop (iii) centrifugal accelerator (iv) Whirling arm rig [7]. In the gas-blast rig, particles are introduced into a fluid (gas or water) flowing in a high velocity before striking the test piece. The erodent is only used once. In case of recirculating liquid slurry, the erodent and fluid are recirculated throughout the test rig. The centrifugal accelerator and whirling arm types of erosion testing apparatus are different from the first two in context of the motion of the erodent that hit the test surface. Both of these provide circular motion where as two previous rigs possess linear motion. In the centrifugal accelerator, test samples are fixed at the edge of the rotor and the sediment particle are introduce through the center of the rotor. As the apparatus runs at
high velocity due to centrifugal action particles tends to rotate toward the end of rotor eroding the test specimen.

The whirling arm rig has an arm or rotor or disc to which the test specimen is placed at the end of it. The rotor is submerged with mixture of calculated sand and water. Same set up is selected to test the erosion pattern on CFT blades. This new set up is the modified version of RDA designed earlier by Chaudhary [8] and Rajkarnikar [9].

2. Experimental setup

2.1. Rotating disc apparatus

First of all, the design of CFT-15 has been completed with provided head and flow rate as shown in Table 1. The outcome of calculated parameters are used to design erosion tester.

<table>
<thead>
<tr>
<th>SN</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Net head</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>2</td>
<td>Designed flow rate</td>
<td>82</td>
<td>l/s</td>
</tr>
<tr>
<td>3</td>
<td>Runner diameter</td>
<td>200</td>
<td>mm</td>
</tr>
<tr>
<td>4</td>
<td>Width of runner</td>
<td>175</td>
<td>mm</td>
</tr>
<tr>
<td>5</td>
<td>Specific speed</td>
<td>38</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>Designed RPM</td>
<td>584</td>
<td>rpm</td>
</tr>
</tbody>
</table>

Rotating Disc Apparatus (RDA) has been designed and installed at Turbine Testing Lab (TTL) for Korea Institute of Energy Technology Evaluation & Planning (KETEP) project under title “Development of sand erosion proof 20 kW micro-hydro cross-flow turbine & its site demonstration in Nepal”.

There are numerous components in the apparatus which have been designed taking parameters of previously calculated CFT. The major factor is relative velocity of water at the inlet of runner blades which is 7.77 m/s. The best suit distance to place the leading edge of the blades is found to be of 320 mm diameter in case of the tester. The relative velocity is 12 m/s with 720 rpm to accelerate the erosion rate comparatively. The calculation of motor power is accomplished considering drag force on the disc and four number of blades due to water and sand sample. Total power of 2 kW is finalized after considering hydraulic, mechanical and electrical efficiency. The disc achieved speed of 720 rpm through type ‘B’ V belt with motor shaft pulley to disc shaft pulley ratio of 1:2. The required diameter of shaft is calculated to be 25 mm with safety factor of 4. The shaft material selected is SS-304 (1.4301). Other parameter of the apparatus are as indicated in Table 2.
Table 2. Design parameter of Rotating disc apparatus

<table>
<thead>
<tr>
<th>SN</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Speed of rotation of motor</td>
<td>1440</td>
<td>rpm</td>
</tr>
<tr>
<td>2</td>
<td>Speed of rotation of disc</td>
<td>720</td>
<td>rpm</td>
</tr>
<tr>
<td>3</td>
<td>V-belt drive (motor to shaft)</td>
<td>2:1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Direction of rotation of disc</td>
<td>Clockwise</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Diameter of disc</td>
<td>350</td>
<td>mm</td>
</tr>
<tr>
<td>6</td>
<td>Outer diameter of mounting of specimen</td>
<td>300</td>
<td>mm</td>
</tr>
<tr>
<td>7</td>
<td>Test specimen</td>
<td>CFT blades</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Material of blades</td>
<td>IS-2062</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Number of blades</td>
<td>4</td>
<td>Nos</td>
</tr>
<tr>
<td>10</td>
<td>Volume of water in casing</td>
<td>9.17</td>
<td>liters</td>
</tr>
</tbody>
</table>

The overall 3D modeling of the apparatus has been completed using CATIA V5 which is shown in Fig. 2(a) and 2(b). Fig. 3(a) and 3(b) show the fabricated test setup installed at TTL. It also shows some of the supplementary components: cooling water pipe line; power supply control panel with temperature sensor and tachometer. Temperature probe is inserted through the pipe to measure the temperature of water during the test. Thermal cutoff switch is introduced to stop the machine when it exceeds 70ºc of water temperature inside the apparatus.

(a) 3D cad modeling of RDA

(b) Front view of RDA

Figure 2. 3D Modeling of Rotating disc apparatus
2.2. CFT blades

Blades of previously designed turbine are used as test specimens in order to test the erosion on blades due to erodent: sand. The 3D modeling of the blades are produced using AutoCAD 2015 and CATIA V5. Mild steel is used to fabricate the blade profile as indicated in Table 2. For erosion tester, four numbers of blades are clamped at the edge of the disc. The test specimens are punched with number 1, 2, 3 and 4 respectively as presented in Fig 4.

**Figure 3.** Erosion tester installed at Lab

(a) RDA installed at TTL  
(b) RDA installed at TTL

**Figure 4:** Disc showing the test specimens

(a) Disc with mounted test blades  
(b) Top view of test blade  
(c) Front view of test blade
2.3. Erodent

Turbine testing Lab has been collecting sediment from hydropower projects of Nepal in order to study the severity of sediment on several components of turbine. As per the adequate availability, sand collected from Tamor river is used. There is not any study found related to sediment erosion or concentration in the rivers of any micro hydro Cross Flow Turbine. Therefore, the sediment concentration data of Jhimruk hydropower is taken into account as this hydropower project is highly affected by sand. The study of sediment concentration in the turbine unit in the period of 1994-97 shows that the mean concentration ranges from as low as 15 to 1,700 ppm in the dry season in October. However, the concentration level during the peak monsoon ranges from about 2,000 to 6,000 ppm with upper values ranging from about 20,000 to as high as 60,000 ppm \[10\]. The test being carried out needs to produce result in very less time as compared to the actual site condition. This can be achieved by accelerating the rate of erosion in the test with the help of higher concentration of sediment. Thus, the sand concentration is selected as 82,000 ppm which requires 650 gm of sand in a single run. For the experiment, sediment size between 150 to 200 µm was chosen. The sand sample of this range was achieved using sieve.

2.4. Erosion experiment

The main aim of the experiment is to carry out the sediment erosion test in CFT T-15 blades to observe erosion pattern and rate of erosion. Different parameters are set constant throughout the experiment as listed in Table 2. The test begins with weighing and clamping the test specimen blades on disc. Then the disc is mounted on the shaft and is tightened with pair of lock nut and clamp pin. After the cover is tighten firmly, mixture of water and sand are filled in the test chamber. First and second experiment was perform for five and ten minutes respectively to check how much paint is eroded. From third experiment the tester was run for half an hour each. The cover was removed and the test samples were cleaned thoroughly and dried. Photographs of the specimen were taken after each experiment in order to analysis wear patterns.

3. Result and discussion

The observation of pattern of wear is carried out through visual inspection and photographs. Painted test specimens are run in the apparatus to observe the removal of paint from the surface for specified time as indicated to identify the location of wear. The paint removal process gives a location of the wear and its pattern. At the same time the photographs of the test pieces are recorded after every test carried out for material removal. Sand with same size and concentration is reloaded into the apparatus after every visual inspection and snap shot for series of experiment.

Series of experiments were completed at TTL and pictures of all blades are taken after each test as presented in Fig. 4. Fig. 5(a) shows the painted blade specimen before the test and from Fig. 5(a) to 5(h) exhibit the wear pattern. In Fig. 5(b) and 5(c), it can be clearly seen that paint at the edge is scratched which may be due to secondary flow vortex erosion \[11\]. It can be caused by obstacles in the flow field or secondary flow in leading edge of the blade and secondary flow is generated around the blade \[4\] \[11\]. The wear pattern observed in the numerical investigation had similar result as indicated in Fig. 5(i). The paint removal in Fig. 5(d), 5(e) and 5(g) is not due to erosion because paint at that particular area is defective. The removal of paint at the backside of the trailing edge from Fig. 5(f) and 5(h) has been significantly increased. It should be result of micro erosion as sand particles are moving at high velocity creates rotational motion to these particles causing several scratches in the direction of flow \[11\] \[4\]. In Fig. 5(d), 5(e) and 5(g), it is seen that the elimination of paint started from upper end of leading edge and continued to toward the trailing edge. After number of tests, the wear appears to be more significant which is in inverted triangular shape. This should have happened as the disc is only provided at one end only. When the tester started, water strikes the surface of the disc and it is forced to flow in circular fashion towards the otherend. In the turbine, discs are welded on the both end of the blade. The secondary flow gets generated from both end. Then wear would occur in similar fashion along the width of leading edge.
4. **Conclusion**

Based on the experimentation, observation and result, it can be concluded that the study of erosion on CFT blades is feasible with simplified design of RDA at laboratory. The design of RDA is a success as the result of wear pattern in numerical analysis is similar to that of RDA result. However, there is need of modification in the design of RDA disc to get accurate result with reference to CFT. It can be sum up that there is a significant amount of erosion in the existing blade and need to optimize design of blade to reduce the abrasion effect of sand particle on blades. Series of experiments will be conducted in RDA with modified design of the blades as future works.
Acknowledgement

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References


