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Pelton Turbine Efficiency Improvement Using Optimum Number of Buckets

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ABSTRACT: There are several important parameters to consider when designing the Pelton turbine. There are three parameters which are majorly contributing to the efficiency parameters. Those parameters are the number of buckets, bucket radial position, and bucket angular position. The number of buckets will affect the water flow characteristics in buckets as well as the performance of the turbine. For optimal performance of turbines, it is essential that there are the right number of buckets. A reduced bucket number will result in loss of water since the jet may not hit the buckets and leave without leaving any impact. By increasing the bucket count, the excess weight, manufacturing cost, and jet interference will increase. In this study, the optimal number of buckets of a Pelton turbine is determined using a CFD analysis. In the present case, a simple Pelton turbine has been analyzed using ANSYS CFX software. Also, various literature reviews have been observed. This CFD analysis shows that the number of buckets is inversely proportional to the efficiency of the turbine. So, a reduction in the number of buckets will lead to an increase in the efficiency.

KEYWORDS: Pelton Turbine, Efficiency Improvement, CFD Analysis, Number of buckets.

I. INTRODUCTION

Lester Pelton invented the Pelton turbine[1] in 1880. Thereafter it has been in development for more than a century[2]. The Pelton turbine is a low specific speed turbine. It has buckets fitted to the outer edge of a circular disc mounted on a rotating shaft; these buckets are used on the high head and low discharge sites. The nozzle emits a jet of water that exerts a torque on the runner, causing it to rotate. The jet of water converts all available energy of water into kinetic energy. However, few studies have been published regarding optimum bucket numbers. Most studies deal with distributors [3], injectors [4], bucket geometry [5], or turbine casing analysis or design optimizations.

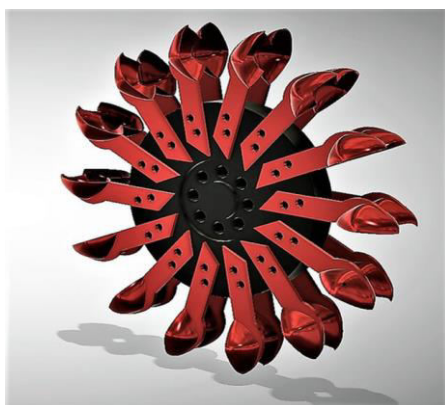


Figure 1 Pelton Turbine In Isometric View

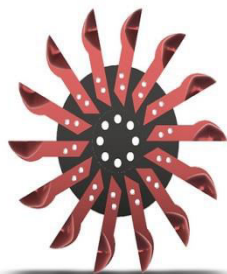


Figure 2 Pelton Turbine In Front View



Figure 3 Pelton Turbine Bucket In Isometric View

A water jet is generally designed to move efficiently from one bucket to another by fitting as many buckets on the runner as possible. There is still some energy lost as the bucket's outer surface strikes the jet's surface as the jet enters the bucket and provides some counter-torque (Fig. 1.). In order to avoid losing water particles from one bucket to another, a minimum number of buckets should be identified [6].

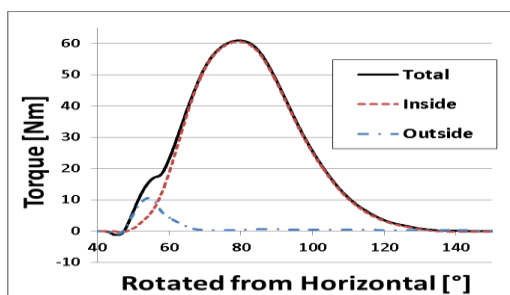


Figure 4 General Torque Curve of Pelton Turbine

The purpose of this paper is to develop a Pelton turbine by identifying the optimum bucket number to get maximum efficiency. To investigate the effect of the number of buckets [For our study 18, 20 & 22 number of buckets analyzed] on local flow parameters like velocities, distribution of water in a bucket, a numerical simulation is performed in this paper using the existing Pelton turbine model. Also, their dependency on turbine efficiency has been discussed.

II. RELATED WORK

Paper Title	Author Name	Methodology	Result
Experimental studies of the jet of a Pelton turbine[7]	Zh Zhang et. al.	The fluid dynamic properties of the jet and its free surface have been identified through the use of laser Doppler anemometry experiments.	Weak secondary flow is generated by the bends which causes small flow disturbances.

Parametric optimisation of two Pelton turbine runner designs using CFD[8]	Audrius Židonis et. al.	A simple bucket geometry was taken and optimized using a fast Lagrangian solver (FLS). It is then further optimized with a more accurate method using ANSYS Fluent.	Pelton turbine bucket design was optimized.
Effect of the Bucket and Nozzle Dimension on the Performance of a Pelton Water Turbine [9]	M. M. Alnakhlani et. al.	The experiment was conducted at the Energy Conversion Laboratory of Sebelas Maret University. This experiment has been completed at 90° needle seat ring and 45° needle seat tip, and +15% bucket size and 92° angle of attack.	The comparative study among the different parameters shows that the value of maximum efficiency was 21.65%.
Numerical and experimental study of the effects of physical and the geometrical parameters on efficiency of a Micro-Pelton Turbine[10]	Shahram Derakhshan et. al.	The flow was simulated using the commercial software Ansys CFX 13 and the simulation results of the performance point were compared and evaluated with experimental results.	The effect of physical parameters: flow rate and head and geometric parameters: the distance from nozzle to the axis of buckets, the number of buckets in constant pitch circle diameter and constant bucket size, the number of buckets in constant pitch circle diameter and variable bucket size and the number of buckets in variable pitch circle diameter and constant bucket size on the performance of a micro-turbine was investigated.

Based on the relative paths of the water particles, there are mathematical relations or formulas for calculating the number of buckets needed. A number of buckets, (N_b), was suggested by Nechleba[11] in 1957 based on a ratio: jet diameter (d_0) over runner diameter (D) shown in Table 1. This suggestion leads to quite a large number of buckets based on the ratio. Therefore it is not very accurate and reliable.

Table 1[11]

$\frac{d_0}{D}$	N_b
0.1667	17 - 21
0.125	18 - 22
0.1	19 - 24
0.0667	22 - 27
0.05	24 - 30
0.04	26 - 33

By relating the pitch circle diameter to the optimum jet diameter, Eq. (1) enables Eisenring[12] to calculate the optimal number of buckets.

$$N_b = \frac{\pi D_p}{2 d_0} \text{-----}[1]$$

where N_b is the number of buckets, D_p is the pitch circle diameter and d_0 is the optimum jet diameter. However, under certain conditions this statement doesn't agree with Nechleba. According to Atthanayake[13], the number of buckets can be selected empirically based on the relationship given in Eq.(2).

$$N_b = \frac{D_p + 15 d_0}{d_0} \text{-----}[2]$$

A paper published by Nasir[14] also discusses the number of buckets, and using Eq.(3) to determine the number of buckets would be the optimal solution. In our work, we have taken the parameters mentioned in the below table.

$$N_b = \frac{D_p}{2 d_0} + 15 \text{-----}[3]$$

Table 2

Parameters	Value
Pitch circle diameters	0.1755 m
Jet diameters	0.0324 m
Nozzle diameters	0.047 m

We have also calculated the resultant number of buckets from different sources suggested by different researchers.

Table 3

Name of researchers	Value of buckets
Nechleba[11]	17 - 21
Eisenring[12]	17
Atthanayake[13]	26
Nasir[14]	18

Since their suggestions are not supported by experimental or numerical research data, we have done a CFD analysis to calculate the numbers of buckets to get optimum efficiency. Since most of the researchers find that maximum efficiency can be obtained in the range of 17 to 23 number of buckets, so we take 18, 20 and 22 number of buckets for our CFD simulation.

III. METHODOLOGY

In this study, CFD is used to evaluate the performance of the runner at different combinations of the three parameters of interest, and to find its efficiency at the best efficiency point. The literature cites ANSYS CFX as the most effective CFD software for numerical modelling of Pelton turbines and accurate prediction of efficiency. We use CFX to model Pelton turbines with $k-\omega$ SST turbulence model because it has the ability to capture the flow with sharp curvature. In order to simplify Pelton turbine performance modelling that requires a substantial amount of computational resources, we introduce a number of simplifications: Taking gravity does not into account or assuming surface tension is negligible, or modelling only few buckets of the runner and calculating torque for the entire runner. Detailed information about the CFD method has been provided in the introduction.

Among other things, the jet diameter is 32.4 mm and the pitch circle diameter is 175.5 mm. The runner and the buckets of Pelton are axis-symmetric in nature.

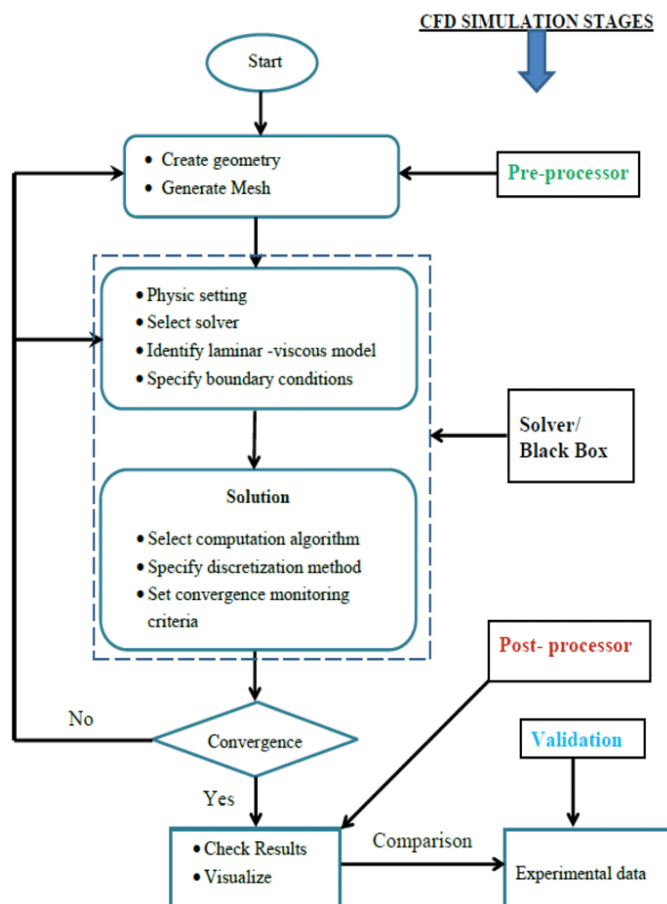


Figure 5 Flow Chart Of CFD Simulation[15]

Mesh details: 1. Physics Preference: Mechanical 2. Relevance Centre: Fine 3. Shape Checking: CFD process 4. Element Mid-size Node: Dropped

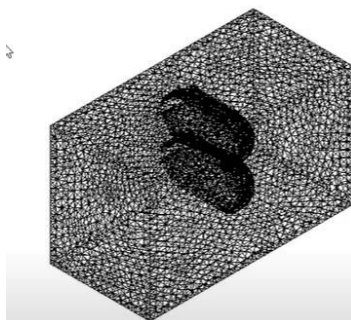


Figure 6 Meshing of Bucket

Boundary Conditions: 1. Flow Regime: Inlet boundary condition : Subsonic flow with velocity 4.17 m/s, Intensity of turbulence is 5 %. Outlet boundary condition: Subsonic flow with atmospheric pressure.

IV. EXPERIMENTAL RESULTS

Figure 6 shows the results variation in flow pattern after the CFD simulation.

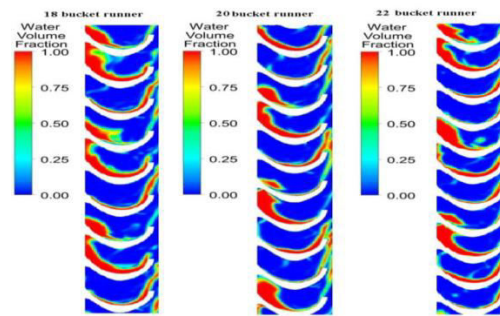


Figure 7 Variation In Flow Pattern

The water volume fraction in Fig.6 clearly indicates that less water remains on buckets as the number of buckets decreases. The buckets are not fully emptied before the next jet. The volume of water remaining on bucket decreases with increase in number of buckets.

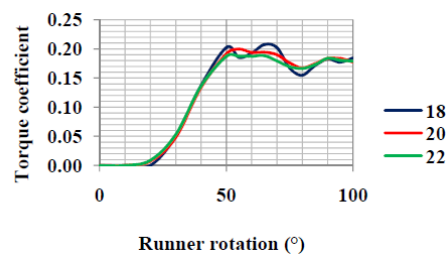


Figure 8 Runner Torque Variation

The figure 8 suggest that with 18 numbers of bucket turbine has more torque fluctuation. It may be because the time taken to reach the bucket normal to jet decreases as the number of buckets increases.

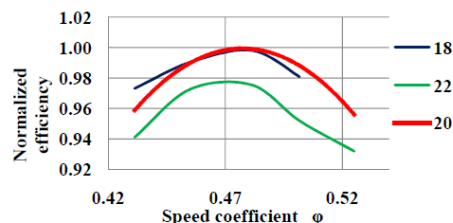


Figure 9 Variation In Normalized Efficiency

Figure 9 shows that 22 number of bucket has lowest efficiency while 20 number of bucket has highest efficiency. It also can be noted that 18 number of bucket has just very less efficiency compared to 20 number of bucket efficiency. It may be possible that less number of buckets result in less water loss, and more buckets may interfere with the flow of water between them. So we get this type of graph.

V. CONCLUSION

The following conclusions are noted-

1. For less number of buckets, the torque is more fluctuating.
2. This is due to reduction in time taken to reach the bucket normal to the jet as the number of bucket increases.
3. The highest torque is achieved with 20 buckets.
4. This is due to loss of water jet in less number of buckets.

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