Numerical prediction of the performance of a micro class pelton turbine

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Abstract. Pelton turbine is the most efficient impulse turbine and its performance keeps improving since its invention. The design of the Pelton turbine mostly based on extensive experiment which is expensive and very time consuming. Hence, commercial turbine know-how is secured due to high competitive market. A reference model of the turbine is vital for researchers who are studying the Pelton turbine. In this study, design and numerical analysis of 5kW Pelton turbine is presented. The turbine geometry is designed according to existing literature and Ansys CFX was selected for numerical tool. The numerical simulation was performed under the several rotational speed in order to specify the speed coefficient specification of the turbine.

1. Design of the 5 kW Pelton turbine
Dimensioning of bucket is the most important aspect of designing of the Pelton turbine. In the hydro energy sector, there is no specific bucket designing methods until now, therefore, wheel size of the Pelton turbine designed based on general thumb rules which are described in the [1], [5]. Other specific geometry of the bucket such as splitter tip angle, notch shape and back side shape are defined based on the designers. Following criteria is basic indications to for the design procedure.

The peripheral speed coefficient. This parameter indicates ratio of jet speed and tangential velocity of rotating wheel.

\[ K_m = \frac{U}{V_{jet}} \]  \hspace{1cm} (1)

Here, \( K_m \) is speed coefficient, \( U \) is tangential velocity of the wheel, \( V_{jet} \) is jet velocity.

The bucket width is approximately three times of the jet at normal operating condition and defined by:

\[ B = 3 \ast d_{jet} \] \hspace{1cm} (2)

Here, \( B \) is bucket width, \( d_{jet} \) is jet diameter.

Bucket width and wheel diameter ratio is should also be three times or more

\[ D > 3 \ast B \] \hspace{1cm} (3)

Here, \( D \) is diameter of the turbine also known as pitch circle diameter.

The specific speed should be \( n_q < 0.13 \) according to [5] and it is defined as follows:

\[ n_q = n \frac{Q}{\sqrt{V_{jet} \ast H^{3/4}}} \] \hspace{1cm} (4)
Here, \( n \) is rotational speed of turbine, \( \dot{Q} \) is flow rate which is normalized by 1 m\(^3\)/s and \( \dot{H} \) is pressure head which is normalized by 1 m. Thus, \( n_q \) and \( n \) used with same unit 1/s or 1/min. Here specific speed is used unit of 1/s.

After combining all these criteria size of the wheel can be defined, table 1 shows design parameters of the turbine which is calculated according to above criteria and Figure 1 and figure 2 shows basic dimensions of the Pelton wheel, 3D view of the bucket respectively.

**Table 1.** Design parameters of the Pelton turbine

| Parameters       | Values  |
|------------------|---------|
| Gross head       | 34 m    |
| Flow             | 17.96 l/s |
| Hydraulic Power  | 5.77 kW |
| Speed Ratio      | 0.5     |
| Number of Jet    | 1       |
| Runner Speed     | 750 rpm |
| Runner diameter  | 300 mm  |
| Bucket width     | 90 mm   |
| Number of buckets| 19      |

**Figure 1.** Dimensions of the bucket
2. Numerical analysis of the turbine

Numerical analysis of any problem consist of following fundamental steps: CAD modeling, Meshing, Physical setup, Solver, data obtaining, result and discussions.

2.1. Model and meshing

Modeling of the computational domain is performed with NX 8.5 CAD software. Computational domain consists of two domains rotor and stator. Figure 3 is showing sketch of the computational domains. While the stationary domain containing jet the rotating domain containing 3 buckets. Basically, the idea behind this method is that the middle bucket is subject to one complete water-jet cycle. Data obtained from this bucket can be used to model the total runner torque [4]. The Pelton turbine geometry is symmetric, therefore only half of the geometry used for analysis due to reduce computational cost.

Mesh generation was done by ICEM CFD meshing tool. Both domain consist of unstructured tetrahedral elements and only on the bucket surface prism layers are created. Figure 4 shows typical mesh generation of the fluid domains. Mesh independency analysis is performed with six different size
of meshes table 2 shows mesh sizes and graph 1 shows mesh results of the mesh independence analysis. At M5 elements the solutions can be considered mesh independent.

### Table 2. Mesh independency

| Number of nodes, million | Normalized torque |
|--------------------------|-------------------|
| M1                       | 1.21              | 0.960 |
| M2                       | 1.41              | 0.976 |
| M3                       | 1.9               | 0.983 |
| M4                       | 3.7               | 0.997 |
| M5                       | 4.3               | 0.999 |
| M6                       | 5.2               | 1.00  |

Graph 1. Number of mesh with normalized torque.

![Graph 1](image)

**Figure 4.** Typical mesh of the Pelton turbine
2.2. Physical setup.
Ansys CFX13 commercial software used for performance analysis of the turbine. In the figure 5 showing the initial position of the rotating domain and from then rotating domain sliding down along the stationary domain. Pelton turbine can be specified by velocity coefficient and bucket volumetric load. In this analysis specification of the velocity coefficient is presented. In order to analyze velocity coefficient specification five different rotational speed cases carried out. Therefore, rotating domain speed was defined differently for each cases. Simulation type is transient total time is set to until middle bucket torque complete and time step is set to 0.5 degrees of rotation of the turbine. The fluid model is free surface two phase homogeneous and turbulence model is k-omega SST.

![Figure 5. Computational domain](image)

2.3. Results and discussion
Result of the middle bucket torque measurement cannot provide data which can be directly used for the Performance analysis of the turbine, therefore, duplication of this torque used for total torque on the runner. In order to do that bucket frequency calculated by (5) and then we can duplicate n times by using equation (6). Graph 2 shows duplication of single bucket torque and oscillation of the total torque. Time averaged torque on the runner then can be calculated after assuming total torque oscillation.

Bucket frequency:

\[ F_b = \frac{\omega \times Z}{2\pi} \]  

(5)

Number n bucket from first measured bucket:

\[ t = n \times \frac{1}{F_z} \]  

(6)
Graph 2. Total torque of runner (black) with analysis time step. Calculated torque from single bucket (red). Case is 750 rpm.

Table 3 shows results of the efficiency calculation for each cases and graph 3 shows relation of the rotational speed and efficiency.

**Table 3.** Results of the CFD analysis

| Case  | PRM | Torque, Nm | Speed coefficient | Efficiency, % |
|-------|-----|------------|-------------------|---------------|
| Case1 | 550 | 77.9       | 0.34              | 77.78         |
| Case2 | 650 | 69.98      | 0.40              | 82.55         |
| Case3 | 750 | 62.74      | 0.46              | 85.39         |
| Case4 | 850 | 54.68      | 0.53              | 84.35         |
| Case5 | 950 | 44.62      | 0.59              | 76.93         |
3. Conclusion

Design of Pelton turbine is performed according to general designing rules available in the bibliography. All dimension ratios were well matched with design criterion. Efficiency developed from the turbine is satisfied mentioned in [1] which is around 75-85 for micro Pelton turbines. Speed coefficient analysis performed for five different case of rotational speed. Peripheral speed coefficient is one of the most important parameters in design of Pelton turbines. In practice, Pelton turbine efficiency maximum in range of speed coefficient 0.45-0.48. CFD analysis results showing speed coefficient of 0.46 shows maximum efficiency and well matched with the theoretical.

Reference

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