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DESIGN AND CFD ANALYSIS OF PICO HYDRO TURGO TURBINE

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Abstract

This paper consists of the study, design and analysis of Turgo turbine. The main aim of this study is to design a Turgo turbine with the available head and flow as a constraint and analyze its performance by varying rpm and discharge. The design of the different components like bucket, hub, shaft, spear, and casing has been carried out with the aid of the Turgo manual that has been available. The 3-D modeling has been carried out using the different software like Creo Parametric and SolidWorks. The further analysis of the performance of Turgo is carried out in the ANSYS 13 by varying flow and RPM.

The torque, mechanical power and pressure at inlet of nozzle and outlet of casing and the efficiency has been calculated from the simulation for different nozzle openings. Constant head characteristics and Hill chart are developed based on the results obtained from the simulation. Based on the Hill chart diagram, it has been seen that the best efficiency point is at discharge factor of 0.2 (0.044 m^3/s discharge) speed factor 38 (453 rpm) at head of 10 m.

Keywords: Turgo Turbine, Modeling, Performance, Hill chart diagram

1. Introduction

Pico-hydro covers hydroelectric power generation under 5kW. In Nepal such system could be used in generating electricity in those places without electric grid system at small capital investment. Moreover, Pico hydro equipment is small and compact and can be easily transported into remote and inaccessible areas. Furthermore, they have a lower cost per kilowatt than solar or wind power. [1]

The Turgo turbine is an impulse water turbine designed for medium head applications. It can handle faster water jet effectively due to its unique bucket design. Buckets in the Pelton turbine don't remove water quickly therefore, water in the bucket interferes with the incoming jet and also reduces the efficiency of the turbine. On the other hand buckets in Turgo turbine remove water from runner quickly. The angel of water jet also plays an important role in this regard. Usually, water jet hits the runner at the angle of 20 degrees. Water jet at this angle provides the maximum impulse to the runner and let the water exit from the other side of the bucket without interfering with incoming water. [2]

Turgo turbine is usually installed in the head where Pelton turbine and Francis turbine overlap. Since Turgo runner is the half slice of Pelton turbine, therefore, Turgo turbine produces the same power as that of Pelton turbine if it has twice the diameter as that Pelton runner. Large diameter leads to higher rotational speed. In some cases, Turgo turbine can even provide better efficiency than Pelton turbine due to its ability to handle the faster flow of water. Turgo turbine can be installed at any site where the Pelton turbine can be used but Pelton turbine can't be used in all applicable sites of Turgo turbines. All these applications of Turgo turbine make it highly desirable for generating electricity. [2]

In Nepal many hydro powers have been operated. Almost all of them are of simple run of river type. So the volume of water in the river doesn't remain the same. Moreover there is more sediment in the water during monsoon season. In Nepal Francis, Crossflow and Pelton turbines have been widely used as they produce more power during high flows but as the volume of water in the river decreases the efficiency of the Turgo starts to exceed the efficiency of the Francis – the result of course being the Turgo starts to generate more power and, more importantly, more energy.

2. Calculations and design

2.1 Calculation of Parameters

The design of a Turgo runner starts with calculating the main dimensions. These are based on hydraulic parameters like head, and discharge, which are determined by the topography and hydrology of the power plant site. The standard hydraulic parameter for the given design is head and discharge of 10m and 45 lit/sec respectively.

Table 1 Different parameters at standard height and discharge

Parameter	Value	Type
Net Head (m)	10	Chosen
Flow rate(m^3/s)	0.045	Chosen
Acceleration due to gravity	9.81	Standard value
Practical Power(KW)	4.41	Calculated
Jet velocity(m/s)	13.587	Calculated
Diameter of the nozzle(m)	0.032	Calculated
Nozzle flow(m^3/s)	0.01125	Chosen
Specific speed(RPM)	53.083	Calculated
Turbine speed(RPM)	450	Chosen
Pitch Circle diameter(m)	0.265	Calculated
Speed number	0.1081	Calculated
Jet angle(degree)	20	Chosen
Speed ratio	0.46	chosen
Circumferential speed (m/s)	6.24	calculated
Inlet blade angle(degree)	35.49	calculated
Outlet blade angle(degree)	38.66	calculated

2.2 Design of components

The CAD model of the Turgo turbine has been developed using SolidWorks. The modeling of the nozzle, runner, and casing is done separately in the design software. The spear is designed for the nominal and the maximum opening of the nozzle to control its flow. The design of the runner has been developed according to the calculation made from the hydrodynamic parameters.

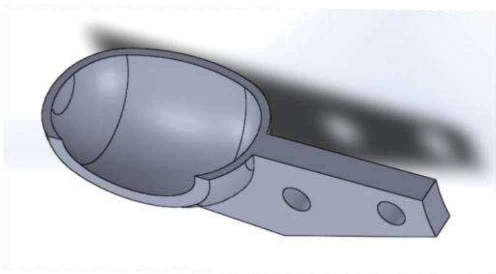

Figure 1. The basic bucket stem design for clamped or bolted fixing

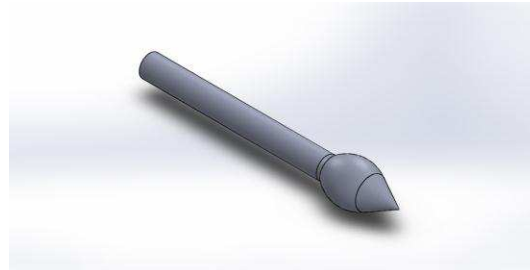

Figure 2. Spear valve design

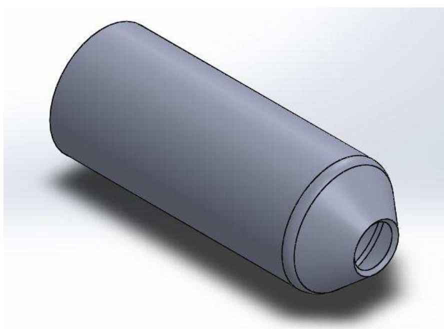

Figure 3. Nozzle Design

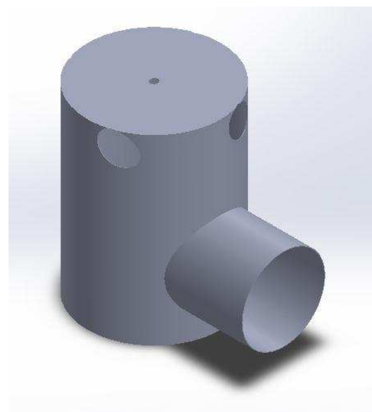

Figure 4. Casing design

2.3 Numerical model

Tetrahedral meshing was done after the definition of the domain to each nozzle i.e. 4 nozzles, runner and casing in the workbench meshing platform. The relevance Centre was taken as medium and the inflation layer with layer quantity 5 of grown rate 1.2 was defined.

The analysis was carried out at steady state. The working fluid was chosen as water and air at 25^0 C. The reference pressure was kept to 1 atm for both domains. The buoyancy model and the homogenous option were turned on multiphase option. The turbulence model was set to SST model and the turbulence condition was set to medium (Intensity = 5%). Domain motion was set to stationary for the nozzle and casing while rotating for runner with appropriate speed. The motion of the rotating domain was set in clockwise direction along positive Y-axis direction. The Surface Tension Coefficient between air and water was set to 0.072 N/m.

The Dirichlet boundary condition i.e., the specified values of the velocity was applied on the inlet boundary. For optimum flow i.e 70% opening of the spear the optimum value of 1.25 m/s^2 was assigned. On the exit boundary, the reference pressure was set to zero. No Slip condition was used because of influence of wall on the flow of fluid layers next to it and smooth wall was used for the wall roughness.

With a physical time-step of 0.015 sec, convergence criteria of RMS and $1 * 10^{-5}$ residual were considered for maximum of 200 iterations to achieve the convergence of the solution to an acceptable level. All simulations were performed using ANSYS CFX in parallel network workstation.

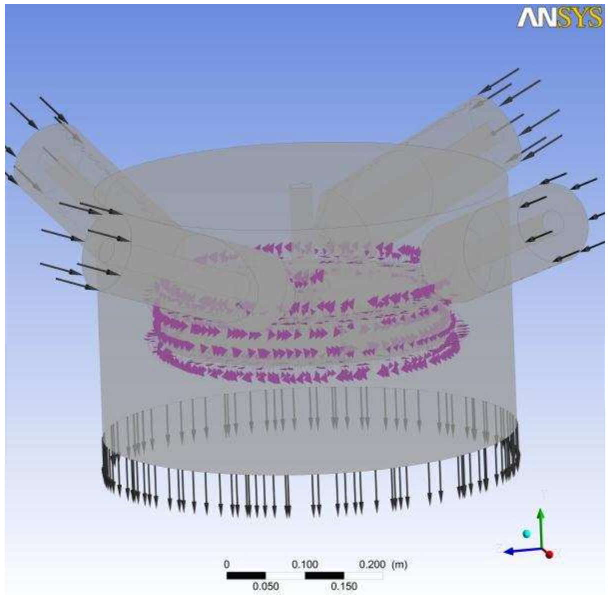

Figure 5 Boundary condition of whole setting

3. Result

3.1 Pressure and velocity distribution

Bernoulli's principle defines a relationship between the fluid pressure and the speed (velocity) of that fluid. It is an inverse relationship, which means that as one thing increases the other decreases. For fluids it works like this: As the velocity of a moving fluid increases, the pressure that it exerts decreases.

In figures below it can be observed that the Pressure has been decreasing gradually as we move from Inlet to opening of nozzle while the velocity has been increasing until it strikes the bucket and then decreases. It can be figured out that jet emerges out of opening of nozzle at maximum velocity, strikes the bucket and then decrease to almost negligible values.

Moreover, the flow of water in the nozzle is streamline flow and its velocity has been gradually increasing towards its tip from 0.2 m/s to 15 m/s.

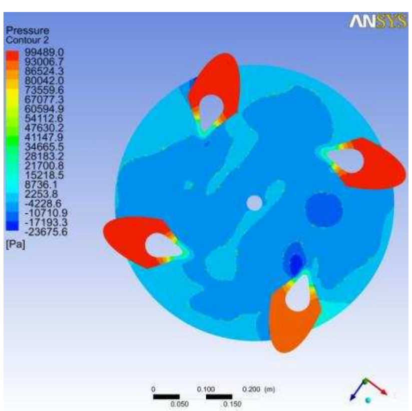

Figure 6. Pressure distribution in a plane at Y-axis

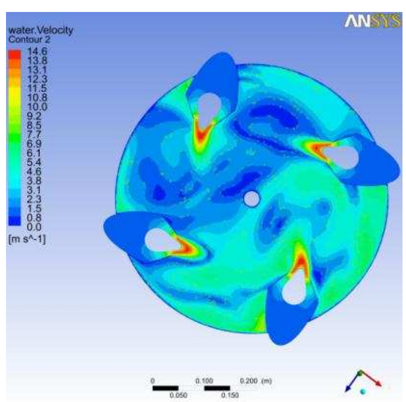

Figure 7. Velocity distribution in a plane at Y-axis

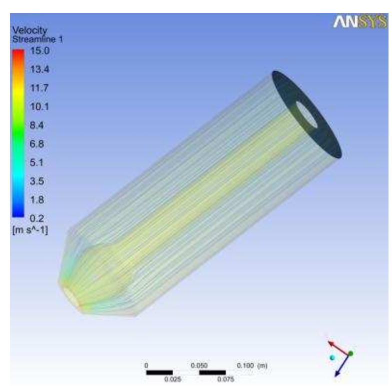

Figure 8. Streamline flow in a nozzle

From the given figures below it is observed that there is maximum pressure at the spot where the jet strikes the bucket, and then decreases towards the edges of the bucket. At the places where the jet strikes the value of pressure is 99920 Pa and it decreases to the value of 38250 Pa.

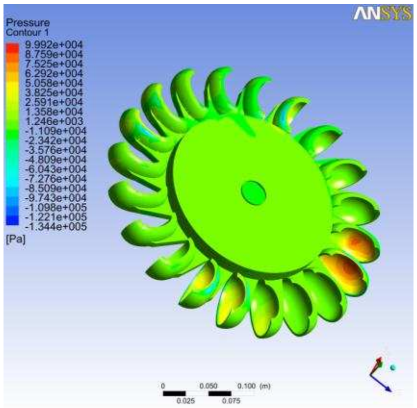

Figure 9. Pressure distribution in runner

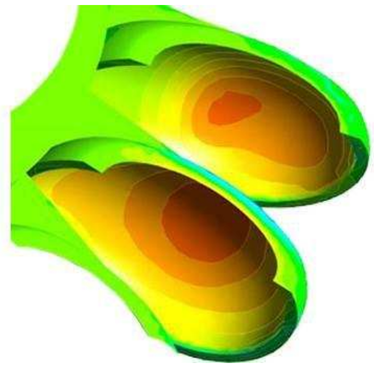

Figure 10. Pressure distribution in two consecutive buckets

3.2 Performance curve

Based on the simulation of the design of the system for different spear opening of the nozzle, the analysis of the Turgo turbine was done. For each spear opening of the nozzle with different value of the speed of the turbine N different results were obtained. After the run of simulation, the result (i.e data) was obtained and based on it the performance characteristic curve was obtained below

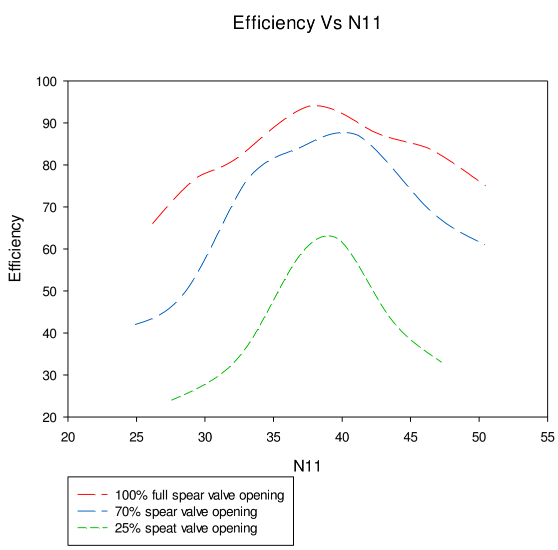

Figure 11. Speed factor vs efficiency graph

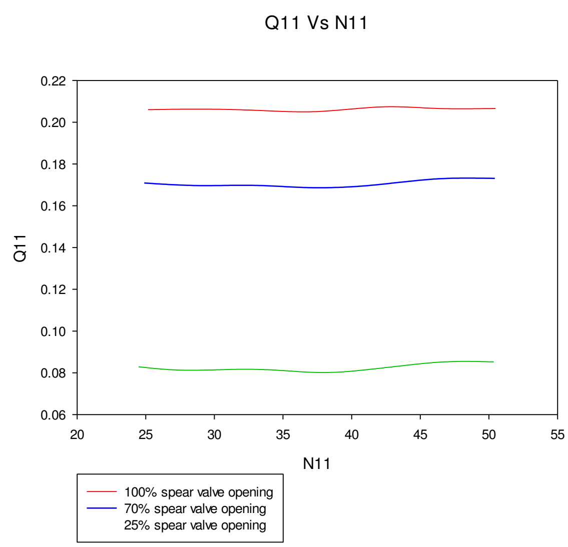

Figure 12. Speed factor vs Discharge factor

From the hill chart diagram drawn below, it is known that the turbine will perform in various operating conditions and there may be the case that the BEP isn't achieved at all times in the Turbine. So by this hill chart it can be analyze the efficiency at those particular operating conditions. And this is necessary because all the time the turbine will not be operating at a single condition. From the graph in hill chart it is known that the BEP is achieved at discharge factor 0.2 (0.044 m^3/s discharge) and speed factor 38 (453 rpm) at the head of 10m. Similarly for different opening the BEP at different speed factor can be achieved

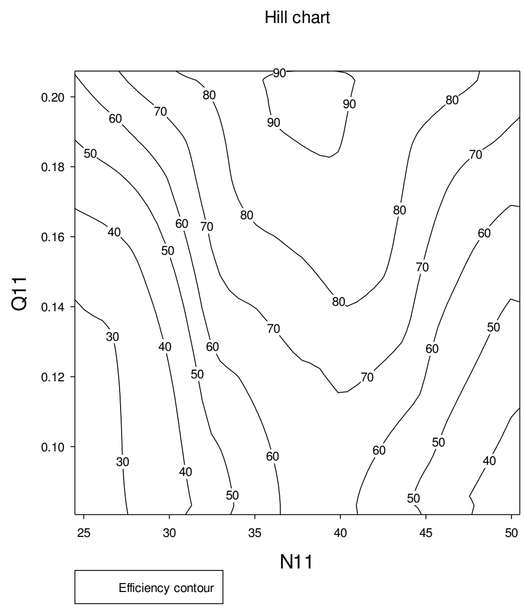

Figure 13. Hill chart curve

4. Conclusion

The design of the turbine was prepared using handbook of Turgo turbine, which was then modeled using SolidWorks. The domains were created using Creo Parametric 2.0, and meshing was carried out by using ICEM CFD 13.0 and Work Bench 13.0. Finally, ANSYS CFX was used for all the computational analysis.

The simulations of the Turgo turbine at different opening conditions which has given the performance curve as indicated in the Results. Similarly, 7sets of simulations were performed for every opening in order to obtain performance curves at different speed factor. The simulation of the CFD problem has resulted in performances curve which has been analyzed to form the points in Hill Chart. Such curves generated from different opening with varying load conditions results in the contour plot of Hill Chart. From the graph in hill chart it is known that the BEP is achieved at 0.044 m^3/s discharge and 453 rpm speed at the 10m head.

The results were obtained using computers with low computational capacity which took more time for simulations. Further work can be done in parallel cluster in order to reduce the computational time and to obtain the accurate result.

Acknowledgement

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