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Design and Computational Analysis of 1 kW Tesla Turbine

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Abstract- Conventional turbines are mostly reaction and impulse type or both. Often technical challenge faced by conventional turbines in Himalaya is erosion by sediment. Financial feasibility of power plants is depended upon innovations to prevent erosion of mechanical equipments or alternatives which better handle these conditions.

Tesla turbine is an unconventional turbine that uses fluid properties such as boundary layer and adhesion of fluid on series of smooth disks keyed to a shaft. It has been garnering interest as Pico turbine where local communities could manage such stations in low capital. It provides a simple design which can be produced locally and maintained at low cost. It can be useful in plants for pumping of water and other viscous fluids. Tesla Turbine pump has been used as a blood pump. Due to its uniqueness it has its own cliché uses giving importance to identify the scope of use of Tesla Turbine in Nepal.

This paper is presented in context of research project at Kathmandu University to understand working of Tesla Turbine. For this design and computational fluid dynamics (CFD) analysis of 1 kW tesla turbine was carried out. The models thus created were used for computational analysis. The proposed uses of Tesla Turbine in Nepal have been suggested.

Index Terms- Tesla Turbine, Boundary layer, Tesla pump, CFD

I. INTRODUCTION

Tesla Turbine is a bladeless turbine consists of a series of discs with nozzle through which gas or liquid enters towards the edge of the disc. Momentum transfer between fluid and disc takes place due to fluid properties of viscosity and adhesion. Discs and washers, that separate discs, are fitted on a sleeve, threaded at the end and nuts are used to hold thick end-plates together. The sleeve has a hole that fits tightly on the shaft. Openings are cut out around center of the discs to communicate with exhaust ports formed in the side of the casing.

Hence tesla turbine is described as a multi disc; shear force or boundary layer turbo machinery that works with compressible and incompressible fluid. Fluid enters radially and exits axially through the ports.

Tesla turbine has advantages of ease of production, versatility and low maintenance. Fluid used can be steam or water. It is unaffected by sediment erosion due to lack of vanes. A challenge related to Tesla turbine is low efficiency. Tesla turbine claims high rotor efficiency for optimum design, but experimentally many difficulties has been found to achieve high efficiencies in nozzles and rotors.

The design of a 1 kW Tesla turbine was carried using iterative process for head and discharge for main dimensions of the turbine.

II. PREVIOUS WORK

Tesla Turbine was patented by Nikola Tesla in 1903.His turbine used 22.5 cm disc and the entire rotor was 5 cm thick producing 110 Horsepower and used steam as propulsive fluid. Tesla pump was patented in 1909 which uses smooth rotating disc on volute casing. Tesla conducted experiments of his turbine between 1906 and 1914, and then there was little activity on this field until a revival of interest began in the 50´s [1].

Rice [2] developed a simple initial analysis using pipe flow theory with bulk coefficients for friction that gives some qualitative understanding through graphs as it is shown in Figure 1 and Figure 2. With this graphs it is possible to obtain approximate values of efficiencies for different flow rates, but for the specified geometry $\frac{r_o}{b} = 50$

r_0= outer radius of disc

b= disc spacing between two discs

Ω = angular velocity of fluid

Q = volumetric flow rate for single disc spacing

Figure 2 shows that high efficiencies is only obtain for very low flow rates at values of $\frac{Q}{\Omega r_0^3} = 0.0001$ and the second turbine tested by Rice has a value of $\frac{Q}{\Omega r_0^3} = 01256.03$ then, the efficiencies are expected to be under 40% as it is shown in Figure 1. Figure 2 depicts the change of pressure, for higher tangential velocities, the change of pressure is higher, and for higher flow rates the change of pressure is lower, this is because the change of pressure occurs only in the boundary layer due to the effects of viscosity and with the increase of flow rate, the velocity increase and the thickness or region of the boundary layer diminishes [3].

Allen came with an analytical model for fluid flow between parallel, co-rotating annular disks from conservation of mass and conversation of momentum principles. Through the assumption of fully developed boundary layer flow a closed form solution is found for the components of velocity and the pressure. The model can be used to analyze the fluid disk system in either a turbine or pump configuration. The accuracy of result improves in both cases as the dimensionless parameter R* increases. A R* on the order of 1 or greater than indicates that the viscous effects are important and the model is accurate [4].

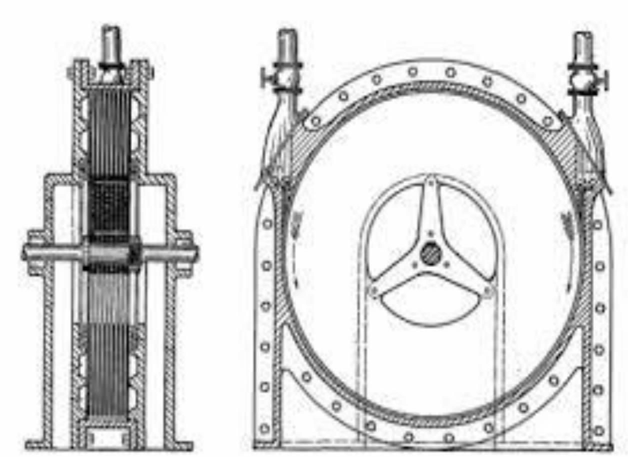

Figure 1 Original sketch of Tesla turbine [1]

Conservation of Mass:

$$\dot{\rho} + \vec{\nabla}.(\rho\vec{u}) = 0 \qquad (1)$$

Conservation of Momentum:

$$\dot{\vec{u}} + (\vec{u}.\vec{\nabla})\vec{u} = \frac{-1}{\rho}\vec{\nabla}P + \vec{g} + v\nabla^2\vec{u} = 0 \qquad (2)$$

u = Radial velocity
P = Pressure
v= Tangential Velocity
∇ =Gradient Function

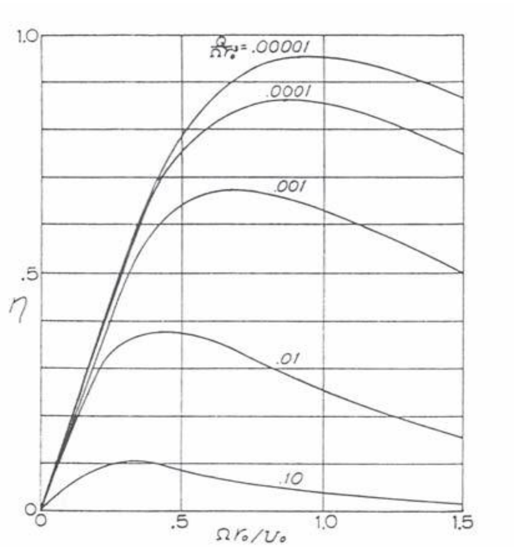

Figure 2 Typical results for maximum efficiency as a function of flow rate and parameter. Plotted for f=0.05 ro/b= 50[3]

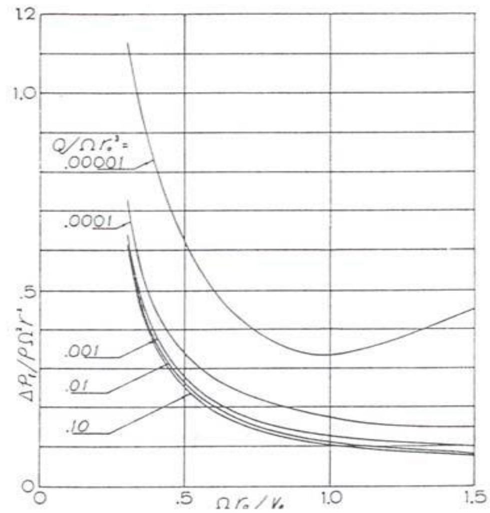

Figure 3 Typical results for pressure-change parameter as a function of flow rate and speed parameters. Plotted for f= 0.05, ro/b= 50[3]

III. Calculations

A. Design parameters

Flow rate $\frac{Q}{\Omega r_o^3}$ was selected as 0.0001.Iteration of r_o and Ω was carried out to find volumetric flow rate Q for single disc spacing. Q was multiplied by total number of disc n to find total volumetric flow rate Q' the disc configuration can handle giving acceptable values of efficiency and torque.

Head and flow rates were iterated. Fluid enters turbine through the nozzle and is directed in between the disks. The fluid strikes the disk almost tangentially at an angle to the rotor periphery. This was used to find absolute and radial velocity of jet. Torque and power produced was calculated. Finally efficiency of rotor assembly was calculated.

Absolute velocity: $V = \sqrt{2gH}$ (3)

Radial Velocity: U= $\frac{\pi DN}{60}$ (4)

Torque: $(u_o v_0 - u_i v_i)Q'\rho$ (5)

Efficiency: $=\frac{T\omega}{QgH}$ (6)

Table 1 defines the rotor configuration of the turbine. Values of power output and efficiency are provided. Figure 5 and 6 represent Tesla disc and rotor assembly respectively.

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Table 1 Design parameters

Parameters	Values
Angle of nozzle α	10^{o}
Outer radius r_o	127 mm
Inner radius r_i	35 mm
Disk spacing δ	2.54 mm
No of discs n	9
No of spacers	10
Revolution	800 rpm
Total length	43.688 mm
Torque T	9.18 Nm
Power P	777.16 W
Efficiency	77.7 %

Figure 4 Tesla disc

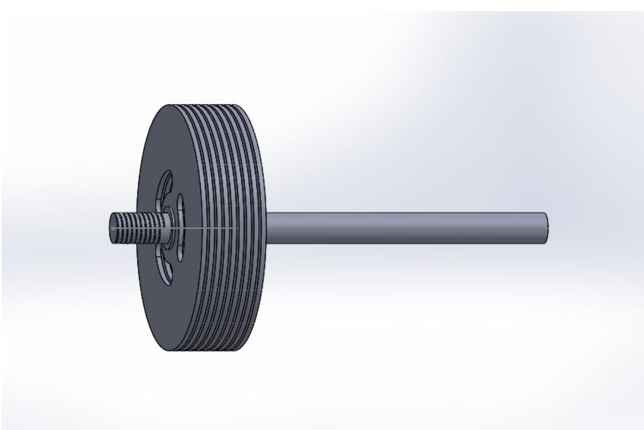

Figure 5 Tesla turbine rotor assembly

B. Analytical Model

The fluid model described by Allen uses the differential forms of the conservation of mass and the conservation of momentum principles only.

$$R = \frac{-\lambda_3}{2\lambda_1}\frac{\nu}{\delta^2 rU} \qquad (7)$$

ν= kinematic viscosity
r= radius of disc

R* is dimensionless system constant which is ratio of rotor configuration to the viscous/momentum force balance. A R* on the order of 1 or greater than indicates that the viscous effects are important and the model was accurate.

$$R^* = Rr^2 \qquad (8)$$

Reynolds number based on disk spacing

$$Re_\delta = \frac{Ur}{\nu} \qquad (9)$$

Radial Reynolds number

$$Re_r = \frac{U\delta}{\nu} \qquad (10)$$

a is radial constant dependent on boundary conditions.

$$U = \frac{a}{r} \qquad (11)$$

In a turbine configuration the flow is radially inward, the radial velocity is negative hence a is negative.

Table 2 Fluid parameters

Parameters	Values
Laminar Flow coefficient value λ_1	$\frac{8}{15}$
Laminar Flow coefficient value λ_2	$\frac{2}{3}$
Re_δ	1.31e04
Re_r	4.39e05
Mass flow rate $\dot{m}$	7.28 kg/s
a	-0.456
R^*	-0.042
Specific speed	26.23

C. CFD Analysis

Two domains were created in Solidworks2013. Rotating domain consisted of rotor assembly and the stationary domain consisted of outer casing with a simplified nozzle [5]. Table 3 shows the meshing data for the domain created. Table 4 presents parameters selected for CFD analysis. Figure 6 shows the setup of two domains.

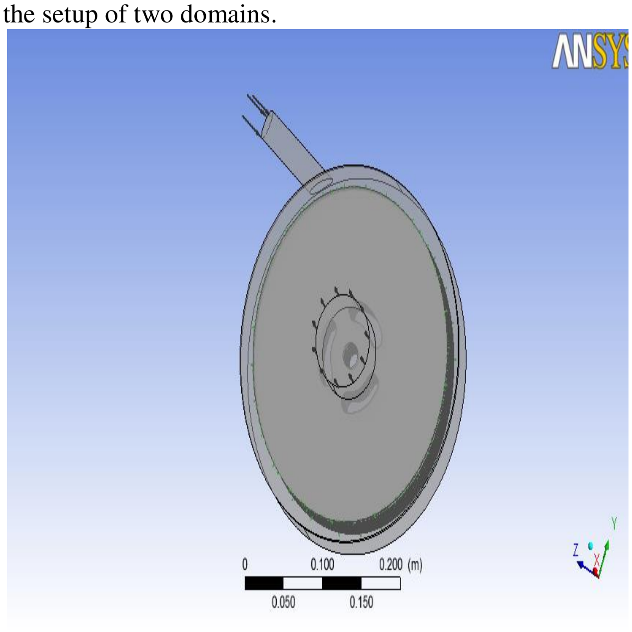

Figure 6 Inlet and outlet conditions

Table 3 Meshing data for domains

Meshing data	
Rotating domain	
Nodes	483462
Elements	2011811
Stationary domain	
Nodes	244141
Elements	1282278

Table 4 CFX Pre parameters

Flow State	**Transient**
Boundary Conditions	Mass flow rate as inlet Atmospheric pressure at outlet
Turbulence model	K-epsilon
Mass flow rate	7.2 kg/s
Static atmospheric pressure	1 atm (Outlet condition)
Phase	Single(water)
RPM	800

Table 5 Solver criteria

Coefficient loop	
Min iteration	1
Max iteration	10
Residual Type	RMS
Residual Target	1e-4

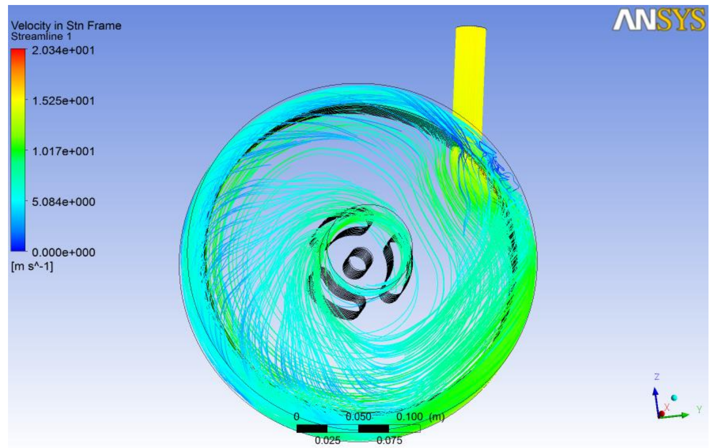

Figure 7 Velocity streamline in stationary domain

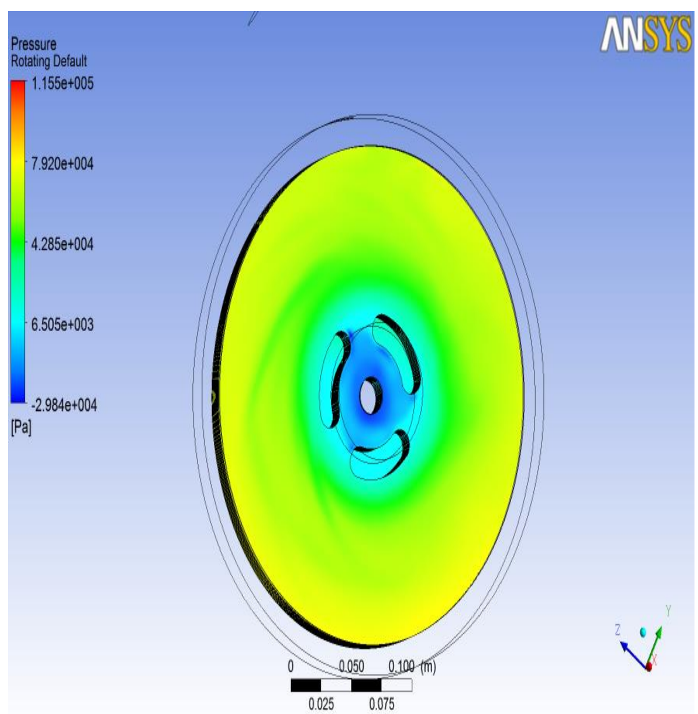

Figure 8 Pressure gradient in rotating domain

IV. RESULTS

Fluid parameters describing the interaction of disc with water were given. Value of dimensionless system constant R^* was found to be -0.042 which shows acceptable accuracy of model and that viscous effects are significant. Efficiency considering simplified nozzle was 77.7%.Figure 7 and 8 shows the velocity streamlines and pressure gradient respectively.

V. CONCLUSION

Tesla turbine is a versatile turbine. It can be used in Pico hydropower which can be locally produced and managed by village communities. It can be used as pumped storage systems. It can be used as radial ventricular devices which are ‘gentle’ on blood pumps and doesn’t causes loss of platelets because of its energy transfer mechanism. Tesla pump has been reported to handle different kinds of industrial and agricultural and waste fluids [6]. It can also be alternative to Improved Water Mill (IWM). It can be concluded that the study on Tesla turbine has yielded important understanding of the turbine. There are still many rooms for improvement which makes it interesting topic for further research.

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