Analyzing Geometries for Inlet Flow Channels to Gravitational Water Vortex Chamber

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Abstract - Considering present energy requirement, it is clear that focus of power generation should move towards renewable energy resources. Among many options available for electrification of rural areas, micro hydro power plants are crucial considering their rated flow. Gravitational Water Vortex (VTX) Turbine has been developed which uses low kinetic head to generate power. Another advantage of this turbine is that it doesn't require dam construction; also, it doesn't force a terrestrial ecosystem to transform itself into an aquatic ecosystem. The perennial rivers and large irrigation canals in India have great scope for installation of VTX turbine. These rivers and canals have high flow rates and low kinetic head. These go unutilized which can however be used for power generation. Classical VTX turbine uses straight inlet channel to supply water to the turbine and the chamber used to generate vortex is cylindrical. To get better results, design of vortex chamber was transformed from cylindrical to conical. But there has been very little work done for the size and shape of the inlet channel. This paper suggests the use of Brachistochrone Curve for inlet channel and a conical vortex chamber.

Keywords: Brachistochrone Curve Inlet Water Vortex Chamber, Straight Inlet Water Vortex Chamber, velocity streamlines, velocity vectors, flow field, inlet flow channels

I. INTRODUCTION

A vortex is a region in a fluid in which the flow streamlines revolve around an axis. It could be straight or curved. Vortices are formed in stirred fluids and could also be observed in smoke rings, whirlpools, etc. Vortices are a crucial component of a turbulent flow. The distribution of velocity, vorticity as well as the concept of circulation is used to characterize vortices. The angular velocity of fluid particles is greatest at the rotational axis and is inversely proportional to the distance from the axis.[5]

In the absence of external forces, viscous friction within the fluid tends to organize the flow into a collection of irrotational vortices, possibly superimposed to larger-scale flows, including larger-scale vortices. A moving vortex carries with it some angular and linear momentum, energy, and mass.

Gravitational Water Vortex (VTX) Turbine has been developed which uses low kinetic head to generate power.[2][8] in cylindrical chamber the speed at the entry of turbine is less than conical chamber thus conical chamber is preferred. However the inlet channel used is a straight channel.[1] This paper suggests the use of conical chamber and brachistochrone curve for inlet channel A brachistochrone curve or curve of fastest descent, lies on plane between a higher point (say point A) and a lower point (say point B). Point B doesn't lie exactly below point A. The curve is such that when a small body, like a bead, slides over it in a uniform gravitational field with no friction, the time of travel is least. The curve is independent of both the mass of the test body and the local strength of gravity. By using the brachistochrone curve, for same inlet parameters, the whirl velocity at turbine entry increases when compared with straight inlet channel. Thus the torque obtained is also higher, implicating more power generation.

II. BRACHISTOCHRONE GEOMETRY

According to Fermat's principle, the actual path between two points taken by a beam of light is one that takes the least time. Johann Bernoulli used this principle to derive the brachistochrone curve by considering the trajectory of a beam of light in a medium where the speed of light increases following a constant vertical acceleration (g). [6][7]

By the conservation of energy, the instantaneous speed of a body v after the fall a height y in a uniform gravitational field is given by:

$$v = \sqrt{2gh}$$

The speed of motion of the body along an arbitrary curve does not depend on the horizontal displacement.[7]

Bernoulli noted that the law of refraction gives a constant of the motion for a beam of light in a medium of variable density:

$$\frac{\sin\theta}{v} = \frac{1}{v}\frac{dx}{ds} = \frac{1}{v_m}$$

Where v_m is constant and θ represents the angle of the trajectory with respect to the vertical.[6][7]

Assuming for simplicity that the particle (or the beam) with coordinates (x,y) departs from the point (0,0) and reaches maximum speed after falling a vertical distance *D*:

$$v_m = \sqrt{2gD}$$

Rearranging terms in the law of refraction and squaring gives:

$$v_m^2 dx^2 = v^2 ds^2 = v^2\,(dx^2 + dy^2)$$

This can be solved for dx in terms of dy:

$$dx = \frac{v dy}{\sqrt{v_m^2 - v^2}}$$

Substituting from the expressions for v and v_m above gives:

$$dx = \sqrt{\frac{y}{D-y}}\,dy$$

Thus, above equation represents an inverted cycloid of Diameter D. [6][7]

III. FLOW ANALYSIS

The CAD models were made in SOLIDWORKS. The meshing and simulations were done in ANSYS Fluent 19.2. Initially, the CAD model was meshed uniformly over the entire volume. After that it was improved at the high turbulence regions. Mesh was generated for both the CAD models (straight inlet and brachistochrone curve inlet). Tetrahedron mesh was used in both cases.

Table 1: Number of Nodes and Elements

Straight Inlet	
Nodes	65984
Elements	346862
Brachistochrone Curve Inlet	
Nodes	124936
Elements	391104

The simulation has been done for a steady flow to analyze the water path and vortex velocity distribution based on different inlet geometries. Water was considered as working fluid with incompressible flow. The density of water was taken as 998.2 kg/m^3, and the viscosity was 1.03 x 10^{-3} kg/m-s. For both cases, Transition SST model was used to analyze the flow pattern.

The computer simulation was run with no-slip conditions.[3][4] The pressure at the outlet is taken as atmospheric pressure (1.01325 bars). The velocity at is taken as 1.5m/s.

For solving the discretized equations, SIMPLE method was used while second order upwind method was used in solving the momentum equations.

A. Straight inlet:

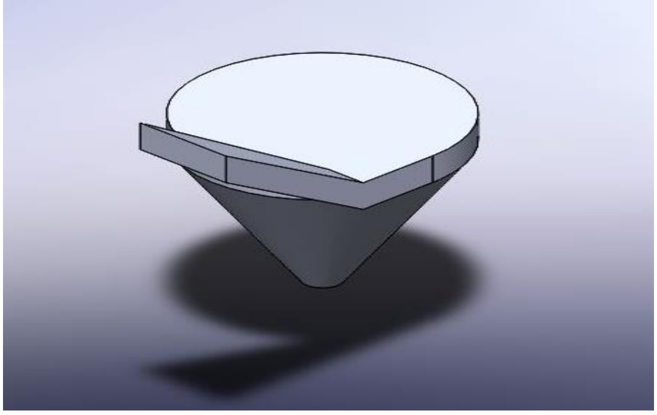

Figure 1: CAD Model of Straight Inlet Water Vortex Chamber

The previous model (Fig-1) was made using SOLIDWORKS2017. The model defines the flow of river water into the vortex chamber.

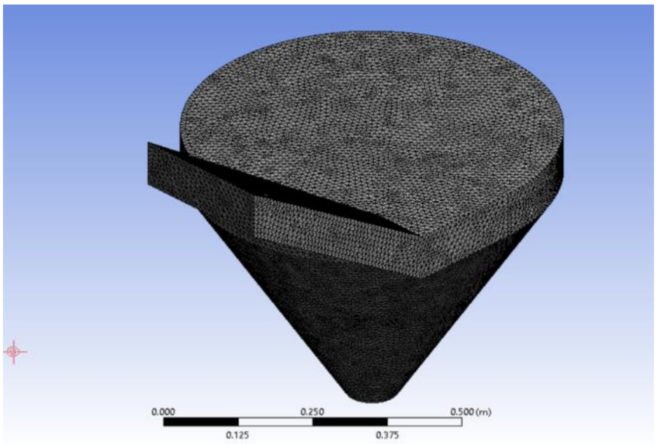

Figure 2: Meshing for Straight Inlet Water Vortex Chamber

The meshing of Straight Inlet Water Vortex Chamber led to 65984 nodes and 346862 elements.

B. Brachistochrone Curve Inlet:

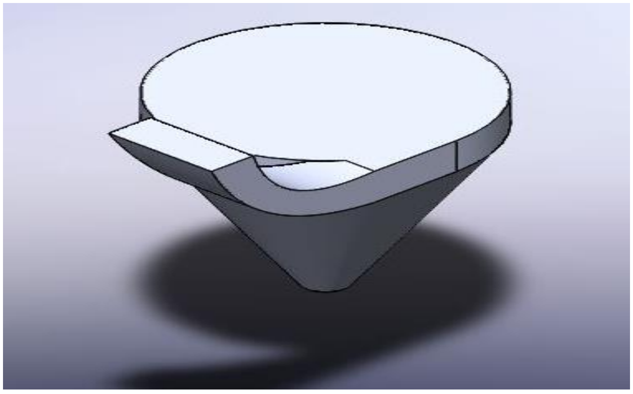

Figure 3: CAD Model for Brachistochrone Curve Inlet Water Vortex Chamber

The previous model (Fig-3) was made using SOLIDWORKS2017. The model defines the flow of river water into the vortex chamber via Brachistochrone Curve Inlet.

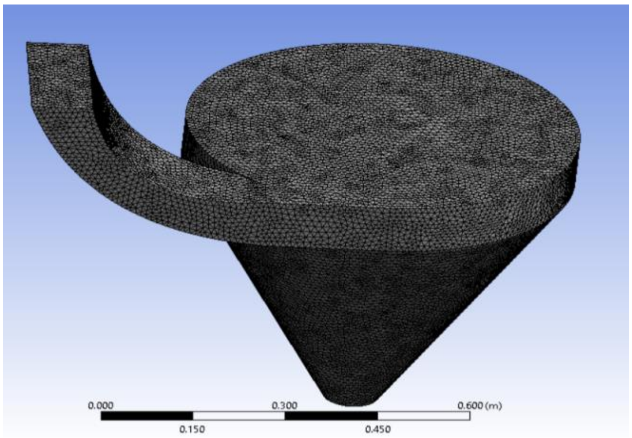

Figure 4: Meshing for Brachistochrone Curve Inlet Water Vortex Chamber

The meshing of Brachistochrone Curve Inlet Water Vortex Chamber led to 124936 nodes and 391104 elements.

IV. RESULTS

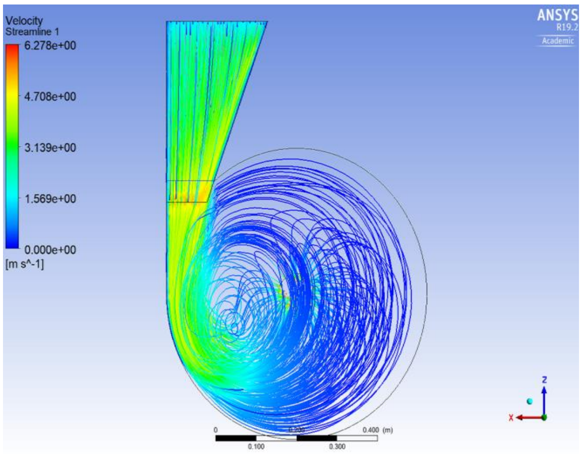

Figure 5: Velocity Vectors for Straight Inlet Water Vortex Chamber

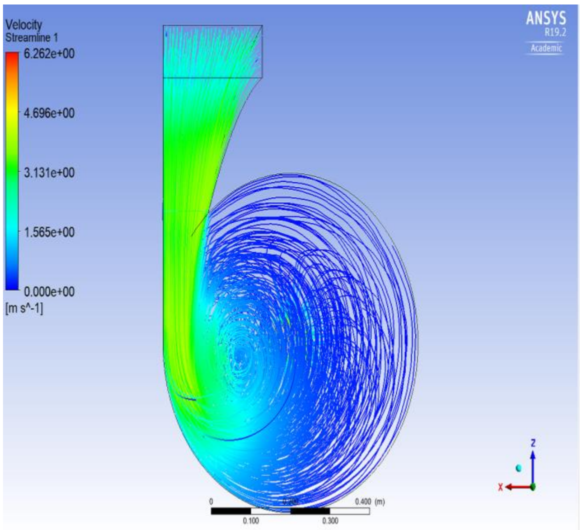

Figure 6: Velocity Vectors for Brachistochrone Curve Inlet Water Vortex Chamber

Since the flow is downwards, the flow streamlines will take the shape of the helix as demonstrated by flow simulation (Fig no. 5&6). The potential to extract energy through well-developed vortex would be significant for flow utilization. The average velocity for Brachistochrone Curve Inlet Water Vortex Chamber was found to be greater than that of the Straight Inlet Water Vortex Chamber. The values are as follows:

Table 2: Average Velocities for the chambers

Straight Inlet Water Vortex Chamber	0.58919 m/s
Brachistochrone Curve Inlet Water Vortex Chamber	0.616272 m/s

Table 3: Arithmetic Sum of velocity vectors at vortex chamber entry

Arithmetic Sum of all velocity vectors at entry of vortex chamber for:	
Straight Inlet Water Vortex Chamber	4380 m/s
Brachistochrone Curve Inlet Water Vortex Chamber	5307 m/s

V. CONCLUSION

The performance of water flow through two different inlet flow channels for Gravitational Water Vortex Turbine was studied. It was found that the vortex formation in Brachistochrone Curve Inlet Water Vortex Chamber was felicitous when compared with Straight Inlet Water Vortex Chamber. The average velocity and spread of velocity streamlines implies that energy extraction could be efficient in Brachistochrone Curve Inlet Water Vortex Chamber than Straight Inlet Water Vortex Chamber. Thus it is recommended to use Brachistochrone Curve Inlet Water Vortex Chamber for optimization of flow channel.

VI. REFERENCES

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