Experimental Investigation of Axial Flow Horizontal Axis Water Turbine with Fix Vane Angle

[1]Dharmesh D. Jariwala, [2]Vimal K. Patel, [3]Nirmal Kumar
[1]Reasearch scholar, [2]Assistant Professor, [3]Assistant Professor
[1]Thermal Engineering,
[1] SVMIT, Bharuch-392001, Gujarat, INDIA,
[1]Jariwalad876@gmail.com, [2]vimal.svnit@gmail.com, [3]nirmalkumar19851@gmail.com

***Abstract*—River current generation uses a generator to produce energy, changing the kinetic energy of current into a turning force by setting a water turbine in the river current. Presence of rivers or canals are observed in most of the parts of India almost throughout the year with full of water current. However, development towards use of kinetic energy from river current is not explored. An innovative axial flow turbine is introduced for utilization of river current of flowing fluid. The broad objective of the report is to explore efficient utilization of kinetic energy of water resources available in India in form of flowing river and canal by using innovative axial flow hydrokinetic turbine. The prime objective of the report is to enhance performance of axial flow turbine for fixed vane angle. Experimental set up was developed using axial flow turbine. Experiment is done in Ukai-Kakrapar irrigation canal at Palsana region for 60^0 vane angle. An experiment indicates maximum 16% coefficient of power (*Cp*) at 4.04 Tip Speed Ratio (*TSR*).**

***Index Terms*— River current generation, Horizontal axis turbine, Axial Flow Turbine, Hydrokinetic turbine**

Nomenclature

D_T = Tip diameter of rotor	θ= vane angle
D_H = Hub diameter of rotor	V_∞= Free stream velocity
R_M = Mean radius of rotor	u= Tangential velocity
A_F = Frontal Area of rotor	λ = Tip speed ratio (TSR)
r = Radius of shaft	C_P = Co-efficient of power
ρ = Density of fluid	C_{Pmax} = Maximum Co-efficient of power
n = Revolution	P_{rotor} = Power develop by runner
N = Revolution per minute	P_{hyd} = Hydrokinetic power
t = time	W = Weight load
ω = Angular velocity	S = Spring load

Subscript
1 inlet
2 outlet

I. Introduction

Energy and environmental problems are related each other and needed to discuss comprehensibly. For the solution of these issues, the utilization of renewable energy becomes the target of global attention. Hydropower has been used since ancient times as one of the major renewable energy. However, the “dam type” hydropower generation is difficult to apply strongly because high head hydropower area has been already developed and makes large impact for ecological system. On the other hand, low head hydropower area, where the head takes less than 2 m, has remained as undeveloped. The utilization of low head hydropower has an advantage that the transmission loss of electricity becomes lower because it is located near the consuming area, however low energy density makes the cost of generation higher. Thereby it is demanded to improve the turbine performances and to decrease the equipment cost for achievement of “the cost-advantage” and “environmental friendly”. [1]

Water turbines can be classified by the type of generator used, or the water resources in the installed place. A water-head turbine is the most generally used system, and this makes the turbine rotate by converting the potential energy of the water in to kinetic energy. This turbine has the advantage of high efficiency, but the construction cost for a dam or waterway is high and can cause significant environmental problems. Water stream turbines are rotated by the force of the river or the ocean current. These turbines are essentially like wind turbines underwater, except that the density of water is 800 times greater than air. [2]

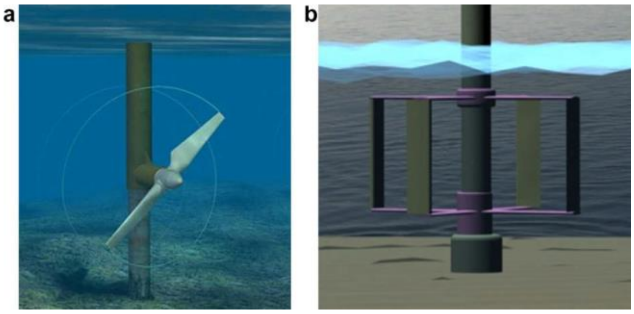

Fig 1. (a) Horizontal Axis Water Turbine (b) Vertical Axis Water Turbine

There are two types of water stream turbines; horizontal axis turbines and vertical axis turbines. Fig 1 (a) shows a horizontal axis water turbine using a propeller. It consists of two or three blades and a single or twin rotor system. The rotor is rotated by the lift force generated by the fluid flow. The turbine can generate in one way flow or two way flow, according to the geometric shape of the rotor blade and pitch control mechanism. Fig 1 (b) shows a vertical axis water turbine, also known as a cross-flow turbine. This turbine is based on the Darrieus wind turbine which is rotated by the lift and drag forces. The vertical axis type has the advantage that the rotor can be rotated regardless of the flow direction. [3]

II. LITERATURE REVIEW

In Seong Hwang [2] was carried out by CFD analysis, with various characteristics including different number of blades, chord length variations, variety of tip speed ratios, various hydrofoil shapes, and changing pitch and phase angles. These characteristics enable the turbine to self-start and produce high electric power at a low flow speed, or under complex flow conditions. Also works for improvement of the rotor performance by adopting an individual blade control method.

Priyono Sutikno [4] research was carried out in order to develop a hydro turbine to be used for specific site of lower Head as run of river, which has head less than 1.2 meters. This paper presents an application of the minimum pressure co-efficient and free vortex criterions for axial-flow hydraulic turbines cascade geometry design.

Mitsuhiro Shiono [5] is carried out experiment using seven types of helical blade water turbines, devised for this study, for obtaining the starting torque and load characteristics. The helical blade water turbine is better in starting, while the straight blade water turbine is better in energy production. The highest water turbine efficiency is seen at 0.4solidity.

Kai Shimokawa [1] work on Experimental study on simplification of Darrieus-type hydro turbine with inlet nozzle for extra-low head hydropower utilization and conclude that (1) Provided the inlet nozzle is installed to obtain effective generated torque in the high efficiency blade rotating positions, it is possible to simplify the runner casing drastically with Keeping the turbine performances higher. (2) The performance of simplified Darrieus-type hydro turbine is affected by downstream water level.

Fernando Ponta [7] worked on Water-Current Turbines (WCTs) are non-polluting electricity generation plants that harness the kinetic energy of natural water courses, using several kinds of rotors. A channeling device, integrated into the ovation system, is used to modify own conditions in the neighborhood of the rotor. This system was developed from theoretical modeling and small-scale model testing in a hydrodynamic test canal. The principal advantages of this kind of machine include reduced need for fixed civil works, ease of transport and relocation and autonomous, self-regulated operation, and it is expected to be a low-cost and long-lifetime system.

Ki-Pyoung Kim[9] developed Numerical experiments were performed using the commercial CFD code ANSYS-CFX to study the performance of a bi-directional cross-flow turbine by simulating two cases of (1) a single turbine and (2) a number of equally spaced turbines. It was found that the Coefficient of Power can be increased significantly by employing a larger area of the channel.

Chul Hee Joa[12] was performed the shape design of a tidal current power turbine from turbine design theory and a 3-D flow analysis by CFD. He concluded that (1) As tip speed ratio increases, negative pressure acting on the suction side increases (2) More than optimal tip speed ratio, the output decreases because negative pressure occurs on the pressure side.(3) less than optimal tip speed ratio, output decreases due to turbulence on the suction side (4) over the optimal tip speed ratio, the output is reduced by the turbulence of the trailing edge and the significantly generated wake affects the flow of fluid.

III. EXPERIMENTAL SETUP AND ITS COMPONENTS

Following are the various components of horizontal axis water turbine.

Frame

A frame is a structural system that supports other components of a physical construction likes, bearing, shaft, dynamometer, supporting plate for the bearing, impeller. The design is selected as per experimental set up and parameters which is to be used. It depends on the water discharge and the force generated by the water flow. It is the main part of project which has to withstand a load as well as also maintain the position of impeller and dynamometer. Frame is shown in Fig.2.

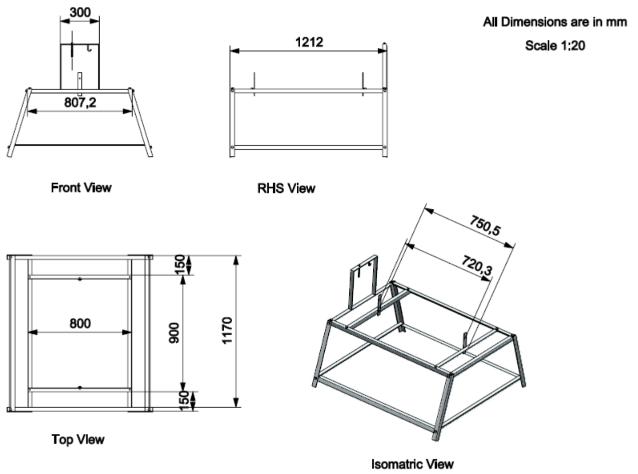

Fig 2.Structure for the experiment set up

Impeller

As per requirement, a light weight heavy duty impeller, made from the plastic. It is selected the ring frame fan for sustain load or to withstand against the water force. For the experiment setup, cut all blades of impeller and after that finished the lower surface of the blade for fit up maintain a radial shape to the bottom part of it. To achieve an angular motion of the blade setup, bottom portion of the blade joint with the help of L type angle at the hub and top portion is fixed by nut bolt arrangement. So easily change the vane angle for HAWT.

Fig 3.Impeller

Fig 4.Aligment bolt

Alignment Bolt

The function of alignment bolt is to keep whole experimental setup in horizontal plane irrespective of canal ground surface.

IV. Experimental Set-Up and Procedure

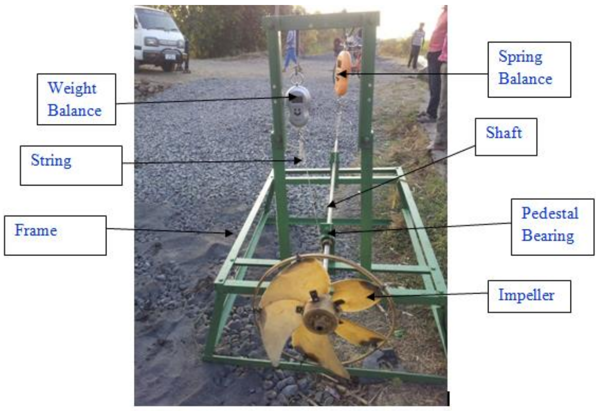

Fig 5.Experiment Setup of Axial flow rotor and structure

Fig 5 shows the experimental set-up of axial flow turbine with rotor and structure. The Structure is fabricated using angle plate and nut bolt arrangement. Outline of physical model the detail of experiment set up is given in table1. Rotor shaft is mounted on two bearings (F 204and UC 204) with Plummer block. A self-aligned bearing is used to support and to avoid unwanted frictional torque.

A rope brake type dynamometer is used for measuring the torque and subsequently power developed by the axial flow turbine rotor. Free stream velocity of water can be measured by using current velocity meter, water stage recorder, Pitot tube, etc. In the present work, because of unavailability of such instruments, it is necessary to used simple distance-time measurement technique. The spring balance and weight balance (accuracy of 10 Grams) are connected by a nylon string of 1 mm diameter. Friction is an important parameter that affects the measurement of torque of the rotating Axial Flow rotor.

Table 1.Axial flow turbine rotor geometry detail

Sr. No.	*Name of the components*	*Dimension (mm)*
1	Diameter of rotor	360
2	Diameter of hub	104
3	Diameter of shaft	20
4	Top width of structure	800
5	Bottom width of the structure	1000
6	Length of the structure	1200
7	Height of the structure	550
8	Length of bolt	200

The experiment setup is placed in a stream line flow of water in the canal. Initially the turbine rotor is allowed to rotate without any load and then rotor is loaded gradually to record spring balance reading, weights, and rotational speed of the rotor. For each load, rotation speed is calculated 3 times, and this is done for the purpose of getting the maximum possible accuracy in the results.

The experiments related to axial flow turbine are conducted in Ukai-KakraparYojana, Village Sanki, Dist- Surat. The details of canal are given in table 2.

Table 2.Details of canal used for experiments

Canal	*Width (mm)*	*Water level (mm)*	*Average velocity of water (m/s)*
Ukai-Kakrapar Yojana, Village Sanki, Dist-Surat.	3600	800	0.5

Fig.6 Photograph at site-Sanki Canal, Palsana, Dist-Surat.

V. Experimental Results and Discussion

The experiments were conducted to identify the maximum coefficient of power and torque for axial flow turbine at vane angle 60°. The input parameters given in table 3 are used for calculation of coefficient of power and torque. The measured free stream water velocity is 0.5 m/s. The experiment is conducted in the canal and the readings of spring balance and revolutions of rotor are obtained at different loading condition.

Table 3.Input parameter for fix vane angle 60^0

Sr. No.	Parameter	Value
1	Diameter of rotor (*m*)	0.36
2	Velocity of water(*m/s*)	0.5
3	Vane angle	60°
4	Shaft radius (*m*)	0.01
5	Density of fluid (Kg/m^3)	1000
6	Diameter of hub (*m*)	0.104

The readings obtained from experiments are given in table 4. (Palsana Canal, Vane Angle 60°)

Table 4.Observation table for fix vane angle 60^0

Sr. No.	Load(W) (Kg)	Spring Balance(S) (Kg)	Revolution (n)	Time(t) (Sec)
1	0.34	0	20	19.2
2	0.51	0.02	20	20.19
3	0.73	0.02	25	25.25
4	1.05	0.02	25	27
5	1.36	0.02	26	29.18
6	1.91	0.03	25	27.98
7	1.92	0.09	25	29.55

The calculated parameters are indicated in Table 5. (Palsana Canal, Vane Angle 60°)

Table 5.Calculated parameters for experimental results of fix vane angle 60^0

Sr. No.	RPM of rotor	Torque (N-m)	protor (Watt)	Phyd (Watt)	C_P	Ω (rad/sec)	TSR (λ)	Net load (N)
1	62.500	0.033	0.218	5.831	0.037	6.545	2.356	3.335
2	59.435	0.048	0.299	5.831	0.051	6.224	2.241	4.807
3	59.406	0.070	0.433	5.831	0.074	6.221	2.240	6.965
4	55.556	0.101	0.588	5.831	0.101	5.818	2.094	10.104
5	53.461	0.131	0.736	5.831	0.126	5.598	2.015	13.145
6	53.610	0.184	1.035	5.831	0.178	5.614	2.021	18.443
7	50.761	0.180	0.954	5.831	0.164	5.316	1.914	17.952

The experimental data recorded in table 5.are used to find the rotor power and subsequently co-efficient of power (C_P). Fig 7 shows the experimental values of P_{rotor} and how it varies with Speed. As the net load is decreased there is an increase in rotor speed and accordingly the rotor power is obtained. As the rotor speed increases the power of the rotor increases up to certain value. But then after though the speed of the rotor increases the power decreases. It can be clearly seen from the graph that maximum power of turbine is of 1.03 *watt* is recorded at 53.60 *RPM*.

Fig 8.shows the experimental values of P_{rotor} and how it varies with net Load. It can be observed that power is increased up to certain value of the load and then after it decreases. It can be seen that maximum power of turbine of 1.03 *watt* is recorded at 18.44 *N*.

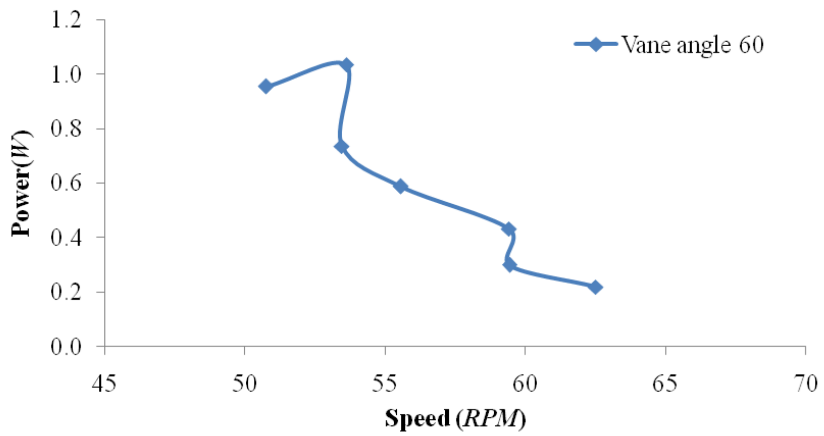

Fig 7.Power with reference to Speed

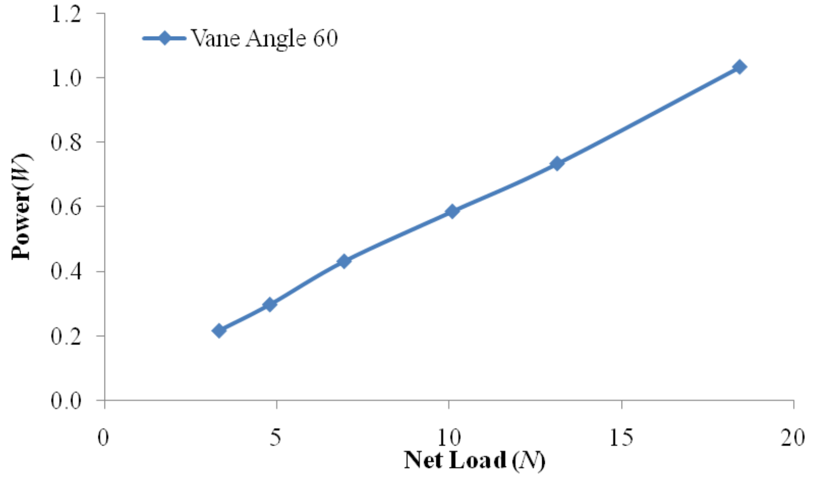

Fig 8.Power with reference to Net Load

Fig 9.shows the experimental values of C_P and how it varies with *TSR*. As the net load is decreased there is an increase in rotor speed and accordingly the rotor power is obtained. As the *TSR* increases, the co-efficient of power (C_P) increases up to certain value. But then after though the *TSR* increases co-efficient of power (C_P) decreases. It can be clearly seen from the graph that maximum co-efficient of power (CP) is of 0.177 is recorded at 2.02 TSR.

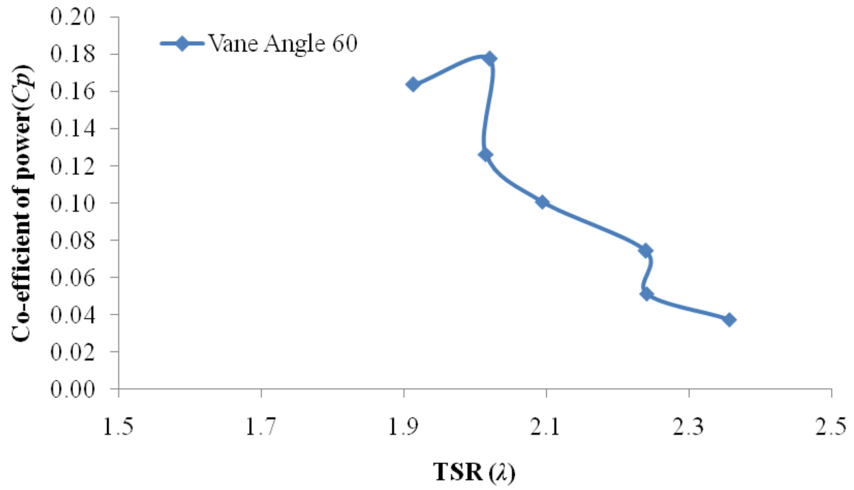

Fig 9.Co-efficient of power With reference to TSR

VI. CONCLUSION

From the experiments, rising trend observed for power output as net load is increases. Maximum power output of nearly 1*W* is achieved at 18 *N* loads and at 54 *RPM*. Again, as the *TSR* increases the value for the co-efficient of power (C_P) initially increases and after reaching the maximum C_P then again it decreasing though the *TSR* increases. Maximum co-efficient of power (C_P) is of 0.178 is achieved at *TSR* of 2.021.

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