Experimental Investigations of Hydrokinetic Axial Flow Turbine

Vimal Patel, Dixit Savalia, Mohit Panchal and Nisarg Rathod

***Abstract*— with the extinction of conventional sources of energy and with the emergence of renewable energy, the study of different mechanical devices to extract energy from these renewable sources has been increased drastically in recent era. In this context, to extract the kinetic energy of the flowing water, hydrokinetic turbines have become popular in these days. There are several turbines which are used as hydrokinetic turbine, like Savonius turbine, Darrieus turbine and Axial flow turbine. Among these turbines, Axial flow turbine draws special attention due to its high co-efficient of power (C_P). In spite of higher C_P, this turbine is not explored much like Darrieus and Savonius turbine. So, in present study, it is decided to evaluate performance of turbine by experimental investigations.**

The aim of the present investigation is to investigate performance evaluation of turbine in various depth of submersion. In this regard, experimental setup with 5 blades and 360 mm diameter impeller is prepared. Experimental results are represented by non-dimensional parameters Co-efficient of power (*Cp*) and Tip Speed Ratio (*TSR*). Results indicates that with 50% raise in submersion depth, 65% enhancement in maximum power output is observed, However, there is only 19% enhancement in coefficient of power recorded, based on fully submerged rotor case.

***Index Terms*— Axial flow turbine, Hydrokinetic Turbine, Propeller Turbine, Zero head turbine**

I. Introduction

HYDROKINETIC turbines, also called free-flow turbines, generates electricity from the kinetic energy present in flowing water, rather than the potential energy from the head. The prime advantage of these type of turbine is, it doesn't require heavy structure dam, and it provides power output directly from kinetic energy from flowing water.

Hydrokinetic turbines can be categorized into two main groups, namely the axial flow turbine and the cross flow turbine. The propeller type turbine is an example of an axial flow turbine. Darrieus and Savonius turbines belong to the cross flow category.

A Darrieus turbine is a high speed, low torque machine suitable for generating electricity. Darrieus turbine has poor starting characteristics therefore some external power source requires. Darrieus has vertically oriented blades revolving around a vertical shaft. Fig. 1 indicates H-type lift driven vertical axis Darrieus turbine rotor.

A Savonius vertical-axis turbine is a slow rotating, high torque machine with two or more vanes. Most wind turbines use lift generated by aerofoil-shaped blades to drive a rotor, the Savonius uses drag and therefore cannot rotate faster than the approaching fluid speed. Fig. 2 indicates conceptual diagram of Savonius turbine rotor.

An axial flow propeller turbine is basically combined lift and drag force driven horizontal axis turbine. The conceptual representation of this turbine rotor is shown in Fig. 3. These type of turbine rotor is extensively used in low head high flow type of conventional turbine, like Kaplan turbine rotor. However, its performance as a hydrokinetic turbine, i.e. as a zero head condition, is still not explored. Major drawbacks for the early designs (Savonius and Darrieus) included the significant torque variation during each revolution, and lower power coefficients.

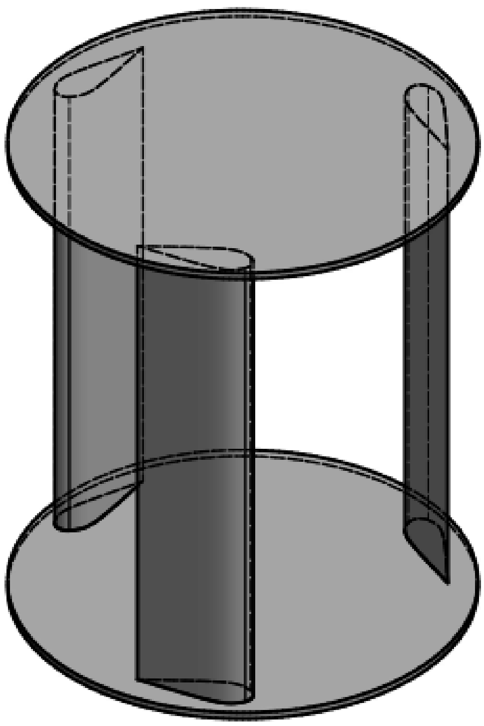

Fig. 1 Darrieus Turbine Rotor

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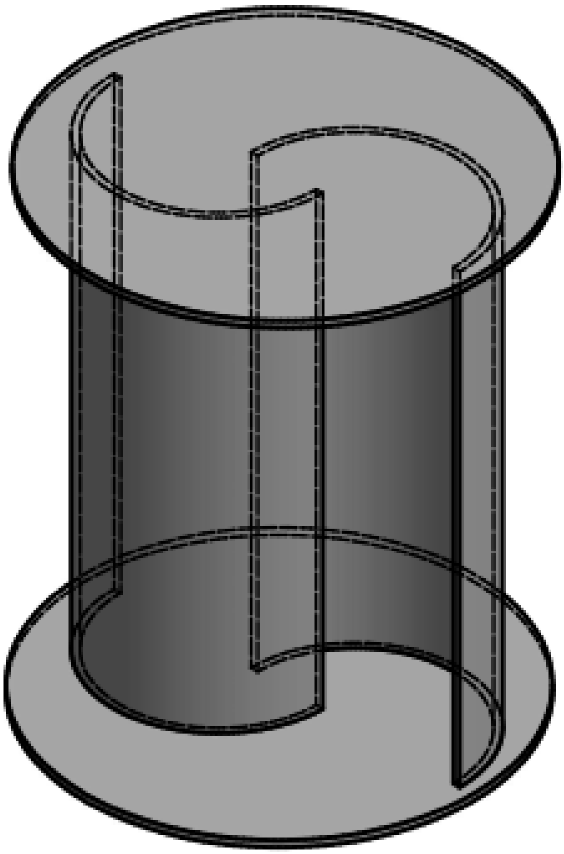

Fig. 2 Savonius Turbine Rotor

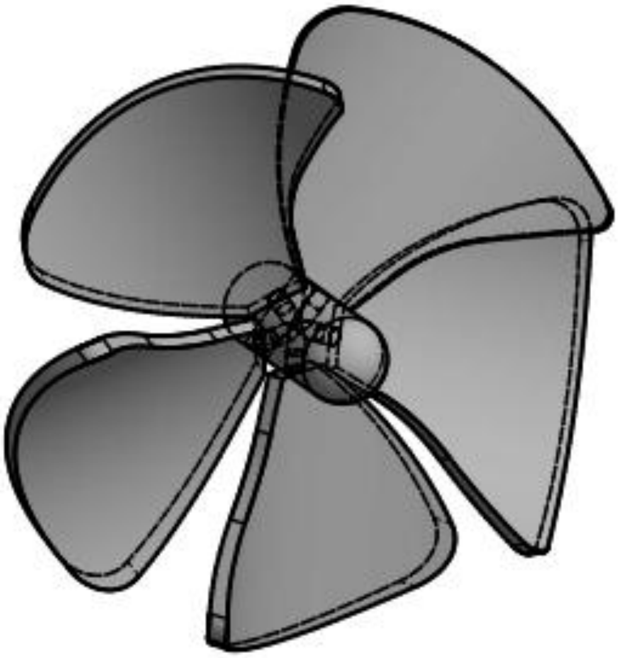

Fig. 3 Axial flow Turbine Rotor

II. Literature review and aim of the present work

A. Literature review

Punit Singh *et al.* [1] concluded that the influence of blade number is much more than that of blade height and also that by reducing the exit blade tip angle the flow rate and output power increases. Yasuyuki Nishi *et al.* [2] studied that the turbine efficiency due to various collection devices remain almost same but the power co-efficient increases 2.76 times. Pengfei Liu *et al.* [3] determined that materials with poor rigidity (for e.g. nylon) are not suitable for rotor models and also, plastic rotors have power output of about 40% less than metal ones.

Mohammad Shahsavarifard *et al.* [4] studied that maximum power enhancement of 91% is obtained with straight wall duct compared to convergent-divergent duct. Martin Anyi *et al.* [5] studied the effect of clogging of debris and to remove them with the help of swinging blades. Kyu-Jung Chae *et al.* [6] deliberate the influence of Net head and turbine blade pitch in a semi Kaplan hydraulic turbine experimentally. A detailed experimental analysis of the effects of exit blade geometry on the part-load performance of low-head, axial flow propeller turbines is presented by Punit Singh and Franz Nestmann [8]. Priyono Sutikno *et al.* [19] presented an application of the minimum pressure coefficient and free vortex criterions for axial-flow hydraulic turbines cascade geometry design.

From rigorous literature review, it is observed that, performance evaluation of axial flow propeller type turbine is not exploded much specifically for hydrokinetic turbine applications. Further performance evaluation of partially submerged rotor of axial flow propeller turbine is still not investigate.

Hence, in present investigation it is decided to evaluate the effect of partially submerged rotor, on power output and coefficient of power, of axial flow hydraulic turbine in an open channel.

III. Experimental setup

The experimental set up is prepared using supporting frame, shaft, rotor, bevel gear, and nylon rope with dynamometer arrangement as shown in Fig. 4. Frame is a rigid structure that forms a skeleton to hold all the major parts together. Shaft is mounted on the frame, which transmits the rotational energy from rotor to bevel gear. There after power finally transmits to vertical shaft for power measurement by dynamometer. Total five vanes are used in rotor. 360 mm diameter of rotor is used in present experimental set up. All vanes are kept at uniform 35^0 from the plane of rotation. It is mounted in the front of the frame on a shaft. Bevel gear transmits the rotational energy from horizontal shaft to vertical shaft. A nylon rope is tied around the vertical shaft. It is connected to the hook on one side and with bolt on the other side. The tension on rope, and subsequently torque on shaft, can be vary with help of tightening and loosing the bolt, provided at the end of rope. On the top of frame load cells are attached for torque measurement on shaft.

The experiments are carried out in conventional irrigation canal. The details of canal parameters are shown in Table I.

TABLE I
DETAILS OF CANAL

Sr. No.	Width	Depth	Velocity
1	1 m	0.9 m	0.7 m/s

Fig. 4 Experimental Setup

IV. Experimental Procedure

The setup is kept in water canal facing rotor towards upstream of turbine to ensure undisturbed flow impingement on rotor. The complete set up is horizontally aligned on structure-foundation bolts such that rotor completely submerged with flowing water. The rotor is gradually loaded by increasing the rope tension with the help of tightening of bolt. The tension T_1 and T_2 are measured on both sides of the rope by load cells. Simultaneously, the time taken (*t*) for specific revolutions of the rotating vertical shaft is also recorded. It is measured using stopwatch. The angular velocity of rotor can be evaluate using the revolution of rotor per unit time. The method is repeated for different load conditions. The load on rotor is altered by changing the rope tensions. The method is repeated till rotor rotation stopes.

After completion the set of experiments for fully submerged rotor case, height experimental set up is raised using foundation bolts. Height is raised such that some fraction of rotor come out from water surface, till specific partial submersion height of rotor reached. Again above method is repeated and required reading are recorded. The conceptual representation of variable evaluated (Height of submersion), in present experiments, are indicated in Fig. 5. Fig. 6 indicates the experimental setup during experiments.

Performance of turbine is investigated for different six different height of submersion and obtained results are plotted with non-dimensional parameters Coefficient of power (*Cp*) and Tip Speed Ratio (*TSR*).

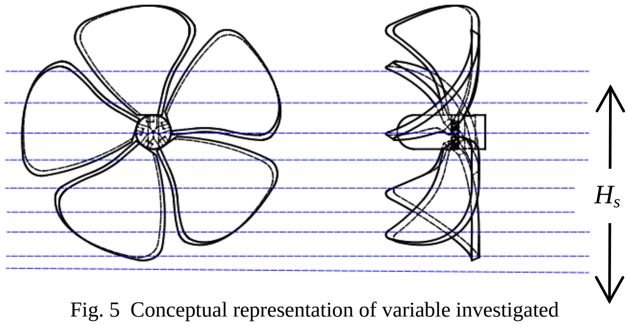

Fig. 5 Conceptual representation of variable investigated

Fig. 6 Experimental Setup in canal

V. Data Reduction

A. Power Output (P_o):

Power Output is the mechanical power obtained from the rotor shaft derived from the kinetic energy of flowing water.

$$P_o = \tau \times \omega = \left((T_1 - T_2) \times \frac{D_s}{2} \right) \times \left(\frac{2\pi \left(\frac{n}{t} \right)}{60} \right) \quad (1)$$

B. Coefficient of Power (C_P):

Coefficient of Power is the ratio of the mechanical power output obtained from turbine rotor to the available hydro kinetic power in same flow area.

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$$C_P = \frac{P_o}{P_i} = \frac{\tau \times \omega}{\frac{1}{2}\dot{m}v_f^2} = \frac{\left((T_1 - T_2)\times\frac{D}{2}\right)\times\left(\frac{2\pi\left(\frac{n}{t}\right)}{60}\right)}{\frac{1}{2}\rho A_w v_f^3} \quad (2)$$

C. Tip Speed Ratio (TSR):

Tip Speed Ratio is the ratio of the speed of the blade tip to the speed of the flowing water.

$$TSR = \frac{v_{tip}}{v_f} = \frac{\omega \times \frac{D}{2}}{v_f} = \frac{\left(\frac{2\pi\left(\frac{n}{t}\right)}{60}\right)\times\frac{D}{2}}{v_f} \quad (3)$$

A. Coefficient of Torque (C_T):

Coefficient of Torque the ratio of Coefficient of Power (C_p) to the Tip Speed Ratio (*TSR*).

$$C_T = \frac{C_P}{TSR} \quad (4)$$

VI. Results and Discussions:

The obtained results are plotted as a non dimensional parameters coefficient of power and tip speed ratio for different submerged height as shown in Fig. 7. Results indicates that, for specific height of submersion, initially coefficient of power improves with increment in load on turbine. Subsequently tip speed ratio falls. By further increment in load, value of C_p falls. Results also indicates that, there is no any appreciable amount of change observed for coefficient of power for different depth of submersion. However, for higher submersion height, coefficient of power is relatively higher.

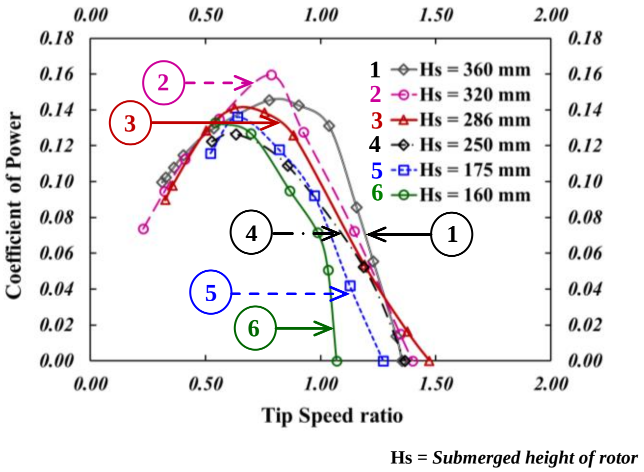

Fig. 7 Variation of Coefficient of power

Similarly Figure 8 indicates variation of coefficient of torque with Tip Speed Ratio. Coefficient of torque linearly varied with tip speed ratio for all submerged cases.

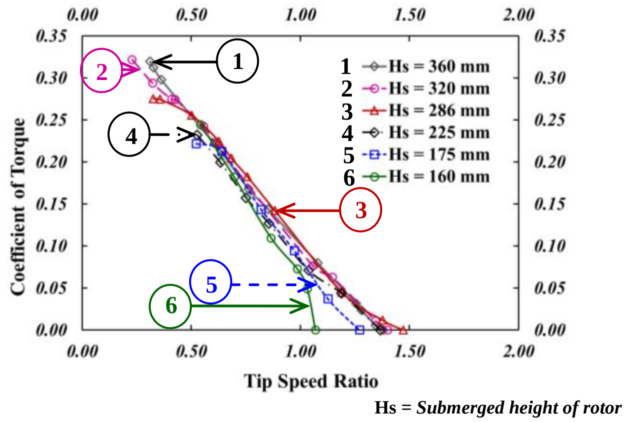

Fig. 8 Variation of Coefficient of power

To observe overall effect of height of submersion, graph of maximum coefficient of power is represented at different submerged height as shown in Fig. 9. Relatively the maximum coefficient of power enhances almost linearly as submersion height increases. However, absolute enhancement in coefficient of power is very trivial.

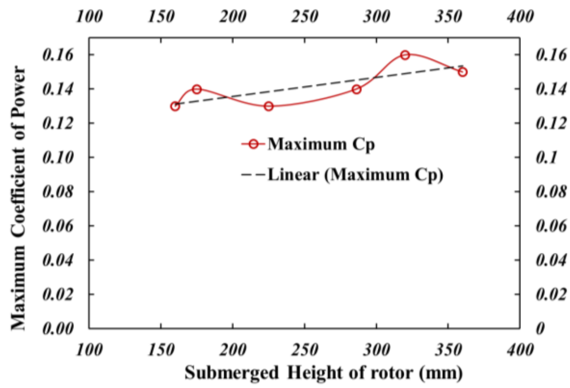

Fig. 9 Variation of Maximum coefficient of power

The value of maximum power P_{max} and maximum coefficient of power Cp_{max} obtained from different submersion height (H_s) is indicated precisely in table II. The appreciable change in maximum power output is observed by changing the depth of Submersion. However, variation of coefficient of power is very trivial.

Table II
Concluding Results

Submerged rotor height (*mm*) H_s	Maximum power obtained (*W*) P_{max}	Maximum coefficient of power obtained Cp_{max}
360	2.40	0.15
320	2.38	0.16
286	1.89	0.14
225	1.33	0.13
175	1.03	0.14
160	0.84	0.13

VII. CONCLUSION

The aim of the present investigation is to evaluate performance of axial flow propeller turbine with partially submerged rotor. Experiments are carried out for different six different height of submersion. Results indicates that with 50% fall in submersion depth leads to 65% fall in maximum power output, However, there is only 19% fall in coefficient of power, based on fully submerged rotor case. So, it can be concluded that, axial flow turbine maintains its consistence performance for different height of submersion, however, fall in power output is very significant.

VIII. NOMENCLATURES

Symbol	Term	Unit
A_w	Fraction of rotor area submerged in water	m^2
T_1	Rope tension on tight side	N
T_2	Rope tension on slack side	N
t	Time required for rotation of specific revolution of rotor vane	s
P_o	Power output from turbine	W
P_i	Hydrokinetic power available from rotor wetted area.	W
τ	Torque on turbine shaft	Nm
ω	Angular velocity of turbine shaft	rad/s
D_s	Diameter of shaft	m
n	Number of revolutions of shaft	rev
V_f	Free stream water velocity	m/s
V_{tip}	Tangential velocity of turbine vane at tip	m/s
Hs	Height of rotor submerged in water.	m

Symbol	Term	Equation
C_p	Coefficient of power	$C_P = \frac{P_o}{P_i}$
TSR	Tip speed Ratio	$TSR = \frac{v_{tip}}{v_f}$
Ct	Coefficient of torque	$C_T = \frac{C_P}{TSR}$

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