
Design and Performance Test of Squirrel Cage Hydrokinetic Turbine**Yin Yin Aye¹**dryinn2025@gmail.com¹¹Department of Mechanical Engineering, Mandalay Technological University, Myanmar

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Abstract

This paper focuses on the design and performance test of squirrel cage hydrokinetic turbine. The design water flow velocity is 1.2 m/s and the designed water turbine has 3 blades. Turbine design is calculated by changing the aspect ratio. According to design calculation, maximum torque is found on aspect ratio 0.5. Squirrel cage hydrokinetic turbine is constructed by using the calculated design data. The turbine design diameter is 0.925m and height is 0.463 m. The turbine performance is tested at a canal near Mandalay Technological University. The experimental test results of rotational speed, angular velocity and turbine power for water velocity 1.2 m/s are 29 rpm, 3 rad/s and 68.2 W respectively. Moreover, theoretical and experimental test results of rotational speed, angular velocity and turbine power are compared by changing water velocity. According to the theoretical and experimental results, if the water velocity is increased, the rotational speed and turbine power are gradually increased.

A. Introduction

Nowadays, energy is one of the most important factors needed in our world. Renewable energy can be extracted from variety of natural resources. One of them can take advantage of energy source from water. Free flow of water from a river, a lake and an irrigation canal are sources of renewable energies among other sources like solar and wind energy. Hydropower is the cheapest and the biggest energy in the world. Water turbines were developed in the 19th century and were widely used for industrial power to electrical grids.

A water turbine is a rotary machine that converts kinetic energy and potential energy of water into mechanical work. Water turbines are mostly found in dams to generate electric power from water potential energy. Figure 1 shows the scheme of hydrokinetic technologies. Hydrokinetic turbines are kinetic energy conversion devices, which can extract energy from the flowing water. This type of turbine is the completely open type of turbine no casing or cage is required. Hydrokinetic turbines are classified as the vertical axis and horizontal axis based on the alignment of the shaft. There are two most common hydrokinetic concepts, axial flow, and cross flow, turbines are used frequently in small-scale hydrokinetic energy conversion.

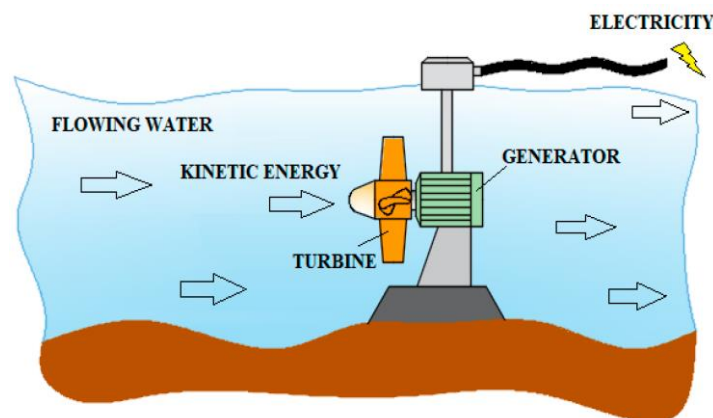


Figure 1. Scheme of Hydrokinetic Technologies [12]

Hydrokinetic turbines are classified as the vertical axis and horizontal axis based on the alignment of the shaft. There are two most common hydrokinetic concepts, axial flow, and cross flow, turbines are used frequently in small-scale hydrokinetic energy conversion. Squirrel cage hydrokinetics turbine is the one type of cross flow turbine. Squirrel Cage hydrokinetic is a water turbine evolved from the Darrieus turbine designed by altering it to have end plate. This type of turbine is proposed for low-head micro hydro installations.

B. Research Method

The purpose of this paper is to design and performance test of squirrel cage hydrokinetics turbine. The first step is to calculate the turbine design by changing the aspect ratio. The second step is to construct and the performance test of the squirrel cage hydrokinetics turbine. The third step is to compare the theoretical and performance test of rotational speed and power output by changing water velocities.

Design Consideration of Squirrel Cage Hydrokinetics Turbine

The design calculation is divided into three parts. First is to design the rotor of the turbine by changing aspect ratio, second is to detail design of blade parameter and the turbine shaft design for the Squirrel Cage turbine. The required design data of squirrel cage hydrokinetic turbine are as follows:

Power , $P_e = 100W$

Density of Water , $\rho = 1000kg/m^3$

Generator Efficiency, $\eta_g = 0.9$

Blade Number , $B = 3$

Tip Speed Ratio, $\lambda = 2$

Water Velocity , $V_w = 1.5 m/s$

Power Coefficient , $C_p = 0.3$

Rotor Solidity Ratio, $\sigma = 30 \%$

Rotor area is calculated from power equation. Power equation is shown in Equation (1).

$$P_e = \frac{1}{2} \rho A V_w^3 C_p \eta_g \quad (1)$$

Rotor area is $0.428 m^2$. Aspect ratio (AR) refers to the ratio of the turbine height to diameter. In hydrokinetic turbines, aspect ratio is usually between "0.5 to 1.5". So, we changed the values of aspect ratio to predict the performance of hydrokinetic turbine.

Aspect ratio, AR:

$$AR = \frac{H}{D} \quad (2)$$

$$A = D \times H \quad (3)$$

Where, AR is aspect ratio, A is the area of turbine, H is turbine height and D is turbine diameter.

Rotor tip angular velocity:

$$\omega = \frac{\lambda V_w}{R} \quad (4)$$

Where, ω is the rotor tip angular velocity, λ is tip speed ratio, v_w is water velocity and R is the radius of turbine.

Rotor Speed:

$$N = \frac{60\omega}{2\pi} \quad (5)$$

Where, N is rotor speed and ω is the rotor tip angular velocity.

Blade width:

$$c = \frac{\sigma \pi D}{B} \quad (6)$$

Where, c is blade width, B is the blade number, D is turbine diameter and σ is rotor solidity ratio.

Torque of the turbine:

$$T = \frac{1}{2} \left(\frac{C_p \rho A V_w^3}{\omega} \right) \quad (7)$$

Where, T is the torque of turbine, ω is the rotor tip angular velocity, ρ is density of water, v_w is water velocity, c_p is the power coefficient and A is the area of rotor.

Turbine power:

$$P_t = T\omega \quad (8)$$

Water Power:

$$P_w = \frac{1}{2} \rho A V_w^3 \quad (9)$$

Where, P_t and P_w is turbine power and water power, T is the torque of turbine, ω is the rotor tip angular velocity, ρ is density of water, A is the area of rotor and v_w is water velocity.

Table 1. Result Data of Squirrel Cage Turbine by Changing Aspect Ratio

No	Identity	Aspect Ratio			Unit
		0.5	1	1.5	
1	Swept area, A	0.428	0.428	0.428	(m ²)
2	Diameter of turbine rotor, D	0.925	0.654	0.534	(m)
3	Height of turbine rotor, H	0.463	0.654	0.801	(m)
4	Rotational speed of turbine, N	49	70	85	(rpm)
5	Number of blades, B	3	3	3	-
6	Blade width, c	0.162	0.205	0.16	(m)
7	Maximum torque, T	21	15	12.6	(Nm)

Since the aspect ratio variation of a vertical axis hydrokinetic turbine cause torque of the turbine variation, any changes in the power coefficient can also be studied to derive how aspect ratio variations affect turbine performance. From a geometrical point of view, the torque of the turbine rises which improves the turbine performance. So, chooses the number of aspect ratio is 0.5.

Calculation of Shaft Diameter of the Turbine

The transmission shaft in a hydrokinetic turbine is the first component to receive the power generated at the turbine blades. The role of the transmission shaft is to transmit the torque generated at the turbine blades to the generator. The shaft can also be made hollow in order to save weight. The design of shaft diameter can be calculated by using Equation (10) which is ASME shaft equation.

$$d^3 = \frac{32n_s}{\pi\sigma_s} \sqrt{M^2 + T^2} \quad (10)$$

Safety factor for turbine shaft is 3 as it is rotating component and allowable shear stress for mild steel is 205 MPa. Assume, bending moment, $M=0$. For appropriate design and industrial product limitation, turbine shaft is selected 14 mm.

Calculation of Water Power and Turbine Power

Water power and turbine power are calculated by changing the different water velocity. The calculated results data of water power and turbine power are shown in Table 2.

Table 2. Theoretical Results of Power for Different Water Velocity

Water Velocity (m/s)	Speed (rpm)	Angular Velocity (rad/s)	Water Power (W)	Turbine Power (W)
0.2	8.25	0.86	1.72	33
0.4	16.5	1.72	14	43.82
0.6	24.7	2.58	46	56.85
0.8	33	3.45	110	72.29
1	41.29	4.32	214	90.32
1.2	49.5	5.1	370	100
1.4	57.8	6.1	587	134.82
1.6	66	6.9	876	161.62

Table 2 shows the theoretical results data of water power and turbine power by changing water velocity. . If the water velocity is increased, the water power and turbine power is gradually increased.

Experimental setup

A small-scale model of squirrel cage hydrokinetic turbine is constructed in Mechanical Department Workshop at Technological University (Sagaing). Firstly iron sheets are cut to made blades according to blade width and high of turbine. Building the full size of turbine blades are chosen for three reasons: mechanical (strength, toughness, etc.), corrosion resistance in salt water and cost and feasibility. Turbine blade mounts were chosen to be designed as end plates. Thin iron sheets are cut to made upper and lower discs for rotor. The iron sheets also had three set screws offsets by 120° , for friction fitting the turbine to the shaft to prevent rotation and slippage. Figure 2 shows the blade components of the turbine.

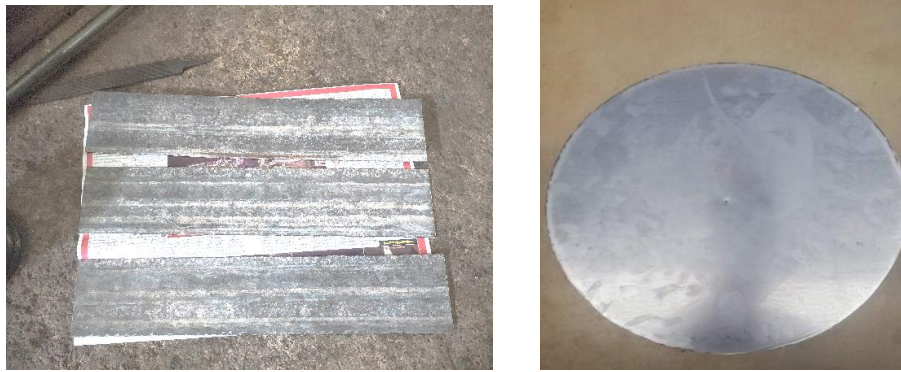


Figure2. Iron Sheet Cutting for Blade and End Blade

And then, the end plate is drilled using a lathe machine and assembly the component of the turbine. One endplate was mounted on the appropriate shaft, and the blades were individually clamped in place to it. The second endplate was then fit onto the shaft. Once blade mounting pads were aligned in recesses in both endplates, the second endplate was then friction fit to the shaft by welding. The blades, which were now “sandwiched” between both endplates, were clamped to each endplate on each end. The iron sheets endplates and mounting pads of the blades were then drilled and tapped in place, while clamped. Figure 3 shows the assembly of turbine.



Figure 3. Assembly of Squirrel Cage Turbine

The traditional method is used for water velocity measurement. Measured a length of stream, and mark the start and finish points. The longest length without changing stream conditions is desired to obtain the most accurate measurement. Figure 4 shows the metering a length of stream at a canal near Mandalay Technological University site location.



Figure 4. Metering the Length of Steam

A more accurate and conventional method of measuring RPM is using a device called a tachometer, which can precisely measure the speed of up to thousands of RPM. There are namely two types of tachometers, the “contact” and “non-contact” tachometers. The contact tachometer is physically attached to the shaft, and providing an RPM reading.



Figure5. Performance Test of Turbine

Figure 5 shows the performance test of squirrel cage turbine in a canal near Mandalay Technological University site location.

Table 3. Performance Test Results for Different Water Velocity

Water Velocity (m/s)	Speed (rpm)	Angular Velocity (rad/s)	Turbine Power (W)
0.2	4.5	0.47	25.2
0.4	8	0.83	29.8
0.6	15	1.5	37.8
0.8	18	1.9	47.2
1	24	2.5	56.1
1.2	29	3	68.2

1.4	32	3.4	82.0
1.6	37	3.9	97.5

Table 3 shows the experimental results data of speed and turbine power by changing water velocity. If the water velocity is increased, the speed and turbine power is gradually increased.

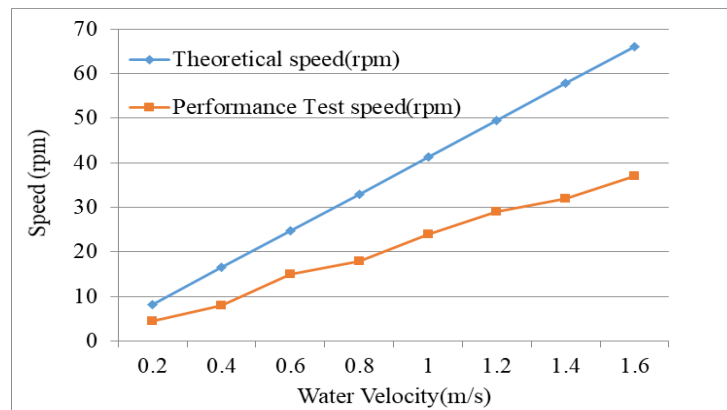


Figure 6. Theoretical and Performance Test of speed

Figure 6 shows the comparison of theoretical and experimental results data of speed by changing water velocity. If the water velocity is increased, the speed and turbine power is gradually increased.

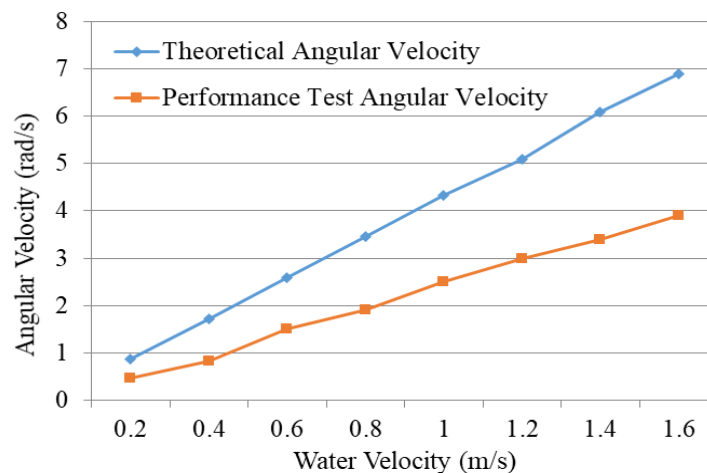


Figure7. Theoretical and Performance Test of speed

Figure 7 shows the comparison between theoretical and performance test results of angular velocity (rad/s) at various velocities.

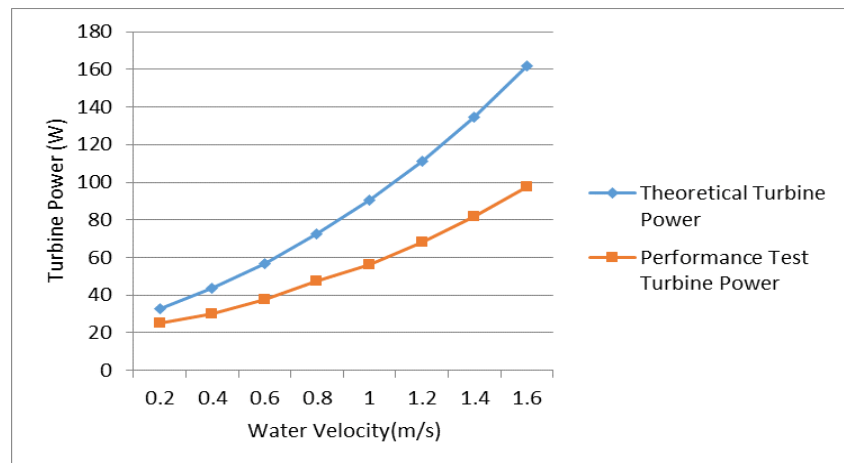


Figure 8. Theoretical and Performance Test of Turbine Speed

According to Figure 8, the theoretical results of turbine power output are greater than the performance test results. If the water velocity is increased, the greater the turbine power output. So, rotational speed, angular velocity and turbine power output are depend on the water velocity.

C. Result and Discussion

In this research, the design water flow velocity is 1.2 m/s and the designed water turbine has 3 blades. The theoretical electrical power output is to be 100W through the Squirrel Cage hydrokinetic turbine with the design of 0.925m diameter of iron sheet rotor, 0.014 m diameter of solid steel shaft and three iron sheets blades. Blade design is calculated based on aspect ratio. Maximum Torque 21 Nm is found that on aspect ratio 0.5. Theoretical and experimental test of speed, angular velocity and turbine power are calculated by changing water velocities 0.2 m/s to 1.6 m/s. Experimental test results of speed, angular velocity and turbine power for water velocity 1.2 m/s are 29 rpm, 3 rad/s and 68.2 W respectively.

D. Conclusion

In this paper, design and performance test of squirrel cage turbine are calculated by changing water velocity. Turbine designs are calculated based on aspect ratio 0.5 to 1.5. Design data are getting from aspect ratio 0.5. Shaft diameter is also calculated from ASME shaft equation. And then, constructed the squirrel cage hydrokinetics turbine. Experimental test of squirrel cage turbine is performed in a canal near Mandalay Technological University site location. Moreover, theoretical and experimental test results of rotational speed, angular velocity and turbine power are compared by changing water velocity. According to the theoretical and experimental results, if the water velocity is increased, the rotational speed and turbine power are gradually increased. Theoretical power output is greater than the experimental results.

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