Optimum Runner Design of 10kW Propeller Turbine

DR. HTAY HTAY WIN[1], DR. THAN THAN HTIKE[2], MG PHYO MAUNG MAUNG KYAW[3]
[1,3] Department of Mechanical Engineering, Mandalay Technological University
[2] Department of Mechanical Engineering, Yangon Technological University

Abstract-* *Renewable energy is necessary for reducing poverty and promoting rural areas by providing basic energy need for rural household. Hydropower plant has always been an important part of the world's electricity supply providing reliable cost effective electricity and it will continue to be so in the future. Hydropower is a largely untapped renewable energy source in the world. The generation of electricity from hydropower is clean and not depleting. These features make it an important energy source for global power production. The main purposes of this research are to develop and to supply the electrical energy by using hydropower turbine and to distribute the technologies of hydropower turbine to the remote area which are far from national electrical grid. The feasibility of hydraulic turbines, theory of propeller turbine and detailed design calculation of 10 kW propeller turbine were described in this research. This research contains a complete set of detailed drawings for blade profile of propeller turbine. It can be used at sites which head is 2.5 m and flow rate is 0.75m³/s. The required head and flow rate data are collected from Kula micro-hydropower plant which is located in Kyaukse Township, Mandalay Division. The blade profile of propeller turbine is satisfied to produce required 10kW power. For the given capacity, the diameter of propeller blade is 0.443 m and the number of blade is 4. The propeller turbine is designed to generate electrical power from the natural source of water.

I. INTRODUCTION

Hydropower is a proven technology and a renewable source of energy. It reduces our reliance on the use of fossil fuel and nuclear fuels and is flexible for meeting demand on the national electricity grid. Hydropower is efficient and reliable, and once projects are developed, they remain in operation for a long time. Although the investment cost for hydropower project is higher than others, they can run for a long time and operation and maintenance costs are lower. Thus for the long term operation, this project is safe for economical point of view.

Propeller turbine is axial flow reaction turbine, generally used for low head. The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube. The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates just upstream of the propeller. This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part flow efficiency of fixed-blade propeller turbines tends to be very poor. Fixed blade propeller turbine do not have any flow regulating mechanism which results in lower part load efficiency and hence they are better suited for the site which does not have much variation in discharge . The amount of production of electricity from a hydropower installation depends on the quantity of water passing through a turbine, the volume of water flow on the height from the water fall, the amount of head. The greater the flow and head, the more electricity is produced. The role of hydro plants becomes more and more important in today's global renewable energy

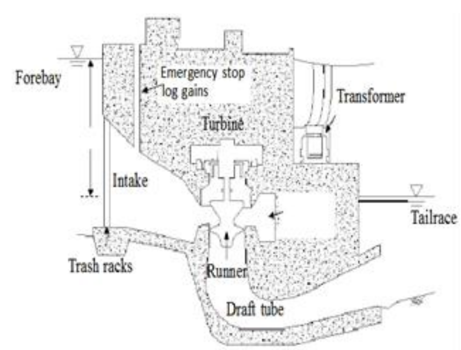

Figure 1 Propeller Turbine [78Ham]

II. CLASSIFICATION OF HYDROPOWER PLANT

Type of turbine can be classified by the following cases:
Classification Based on Capacity: The hydro power plant can be classified based on capacity. They are:

1) Small-Power Plant (500 kW to 1000 kW)
2) Mini-Power Plant (100 kW to 500 kW)
3) Micro-Power Plant (50 kW to 100 kW)
4) Village (1 kW to 50 kW)
5) Pico (< 1 kW)

According to the head, hydropower schemes can be classified in three categories.
They are:

1) Low Head Plant (< 60 m)
2) Medium Head Plant (60 m to 250 m)
3) High Head Plant (> 250 m)

Hydraulic turbines are the machines which use the energy of water and convert it into mechanical energy. A turbine converts energy in the form of falling water into rotating shaft power. Turbines are divided by their principle way of operating and can be either impulse or reaction turbine. In contrast, an impulse turbine runner operates in air, driven by a jet (or jets) of water. The water remains at atmospheric pressure before and after making contact with the runner blades. The most common types of impulse turbine are Pelton turbine, Turgo turbine and Cross-flow turbine. The reaction turbine can often be compiled directly to an alternator without requiring a speed-increasing drive system. Typical type of reaction turbines are Francis turbine, Bulb turbine, Kaplan turbine and Propeller turbine. Table 1 shows classification of turbine type.

Table 1. Classification of Turbine Type

Type of Turbine	Turbine Type	Head Ranges(m)
Impulse	Pelton	59<H<1300
	Turgo	50<H<250
	Cross-Flow	3<H<250
Reaction	Francis	10<H<350
	Kaplan	2<H<40
	Propeller	2<H<40

III. DESIGN CALCULATION OF PROPELLER TURBINE

A. Design Procedure

Specification Data

The required generator output power, P = 10 kW
Generator efficiency, $\eta_g = 0.8$
Generator speed, Ng = 1500 rpm
Design head of turbine, H_d= 2.5 m
Mechanical efficiency, η_m= 0.85
The required shaft power, $BP = \dfrac{Generator\ Output}{\eta_m \eta_g}$

$$= \frac{10}{0.8 \times 0.85} = 14.7kW$$

The specific speed of the turbine can b calculated from the water head as below;
Ns=

$$\frac{N\sqrt{P}}{H_d^{1.25}} \quad (1)$$

The speed of the turbine can be calculated from the following equation

$$N = \frac{N_s H_d^{1.25}}{\sqrt{P}} \quad (2)$$

The runner discharge diameter can be known from the peripheral coefficient.

$$\phi = 0.0242 \times N_s^{2/3} \quad (3)$$

And then $D = \dfrac{84.5 \times \varphi \times \sqrt{H_d}}{N}$ (4)

According to the specific speed, the number of blade and the ratio of hub and outer diameter of propeller turbine can be read from Figure 2. The number of blade is four.

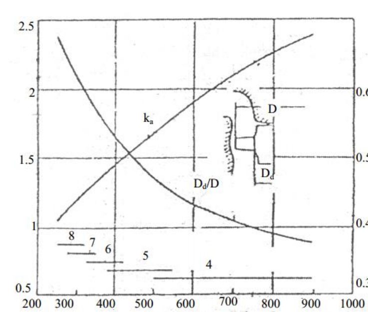

Figure 2. Relationship between Speed Ratio and Specific Speed [7].

B. Design Calculation of Guide Vane

The function of the guide vanes is to regulate the quantity of water supplied to the runner and direct water onto the runner at an angle appropriate to the design. The flow velocity can be determined from the following equation

$$A = \frac{\pi}{4}(D^2 - d^2) \quad (5)$$

$$Q = AV_f \quad (6)$$

The magnitude of the whirl velocity can be obtained by the following formula.

$$C_{U1} = \frac{\eta_h \, g \, H}{U} \quad (7)$$

The guide vane angle can be determined from the velocity triangle. Figure 3 shows inlet and outlet velocity triangle of propeller turbine.

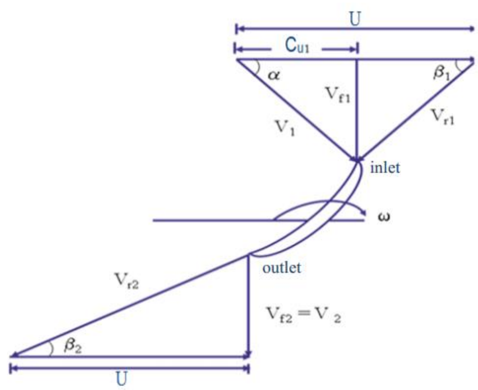

Figure 3. Inlet and outlet velocity diagram of propeller turbine [7]

The guide vane angle, $\tan\alpha = \frac{V_f}{C_{u1}}$ (8)

To find the number of guide vane, the following equation is used.

$$z_1 = \frac{1}{4}\sqrt{D'} + 4 \quad (9)$$

C. Geometric Characteristics of Airfoils

The most important geometric characteristics of the airfoil which is shown in Figure 4 is taken from the profile N.A.C.A (National Advisory Committee for Aeronautics) 2412. In this series, the geometric characteristics are shown in the following relation.

$$\frac{m}{l} = 0.02 \qquad \frac{L}{l} = 0.40 \qquad \frac{t}{l} = 0.21$$

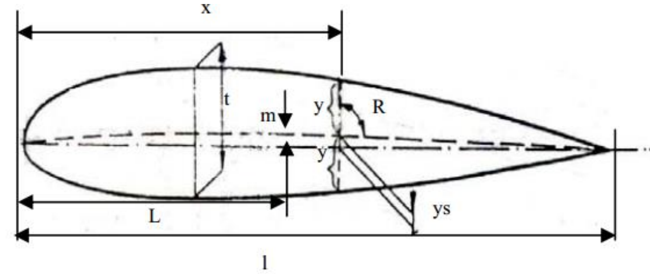

Figure 4. Geometric characteristics of airfoils [6]

D. Design of Blade Profile

In the space of the runner, it can be divided into five cylindrical sections. This sections are can be calculated by the following equation. Figure 5 shows five sections of the blade.

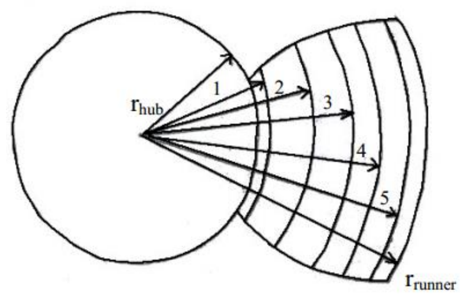

Figure 5. Five sections of the blade

For section I, $r_1 = \frac{d}{2} + 0.015d$ (10)

For section III, $r_3 = \frac{D}{2}\sqrt{\frac{1 + D_d^2}{2}}$ (11)

For section II, $r_2 = r_1 + \frac{r_3 - r_1}{2}$ (12)

For section V, $r_5 = \frac{D}{2} - 0.015D$ (13)

For section IV, $r_4 = r_3 + \frac{r_5 - r_3}{2}$ (14)

Calculation of runner angle at outlet and inlet blade at various diameters, tangential speed and whirl velocity must be known.

The tangential speed at the hub diameter

$$U = \frac{\pi \, r_1 \, N}{30} \quad (15)$$

The blade inlet angle

$$\tan \beta_1 = \frac{V_{f1}}{U - C_{u1}} \qquad (16)$$

The blade outlet angle, $\tan \beta_2 = \frac{V_{f2}}{U}$ (17)

The spacing of the blade can be determined by the following equation $t_s = \frac{2\, r_1\, \pi}{z}$ (18)

Circulation can be determined by the following equation

$$\Gamma = t\,(C_{u1} - C_{u2}) \qquad (19)$$

The average angle (β_α) can be known from Figure 7

$$\tan \beta_\alpha = \frac{V_f}{W_{\alpha 1}} \qquad (20)$$

Wα1, can be obtained by the following equation

$$W_{\alpha 1} = U - \frac{C_{u1}}{2} \qquad (21)$$

The average relative velocity Wα can be determined by Equation (22)

$$W_\alpha = \frac{W_{\alpha 1}}{\cos \beta_\alpha} \qquad (22)$$

Figure 6 shows velocity triangle of propeller turbine. Figure 7 shows circulation around the blade

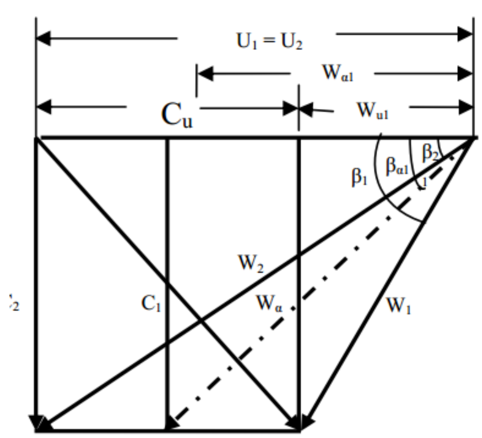

Figure 6. Inlet and Outlet Velocity Triangle

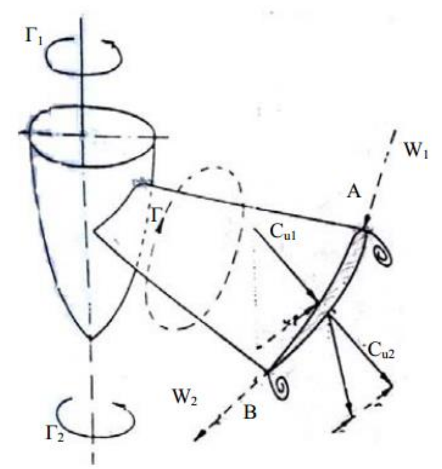

Figure 7. Circularation around the blade

The high of the hub or boss of the runner can be known from $h_1$and h_2 as shown in Figure 8.

$$\frac{h_1}{D_3} = 0.094 + 0.00025\, N_s \qquad (23)$$

$$\frac{h_2}{D} = \frac{1}{3.16 - 0.0013 N_s} \qquad (24)$$

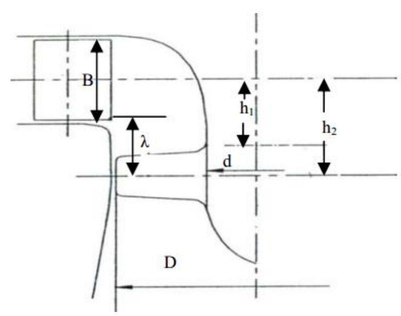

Figure 8. Section View of Propeller Turbine

The height of the hub or boss = 2(h2-h1) (25)

Table 2 shows the result data of blade profile and comparison of the design data and existing data of propeller turbine

Table 2. Result Data of Blade Profile

Parameters	I	II	III	IV	V
$R_1 = R_2$(m)	0.100	0.134	0.169	0.19	0.215
U_1= U_2(m/s)	6.042	8.097	10.21	11.60	13.00
V_f (m/s)	5.850	5.850	5.850	5.85	5.850
β_1(degree)	67.10°	47.12°	35.84°	30. 987°	27.28 6°
β_2(degree)	44.07°	35.84°	29.80°	26.760°	24.22°
C_{u1} (m/s)	3.572	2.665	2.113	1.860	1.660

$W_{\alpha 1}$ (m/s)	4.256	6.764	9.156	10.671	12.17
β_α(degree)	53.96°	40.85°	32.57°	28.732°	25.67°
W_α (m/s)	7.234	8.943	10.86	12.169	13.50
t (m)	0.157	0.211	0.266	0.302	0.337
Γ (m^2/s)	0.560	0.560	0.560	0.560	0.560
l/t	1.104	1.013	0.923	0.884	0.844
l= l/t $\times$t (m)	0.173	0.214	0.245	0.266	0.285
β(degree)	45.62°	52.54°	58.51°	61.584°	64.55°
α_α(degree)	9.580°	3.404°	1.088°	0.316°	0.223°

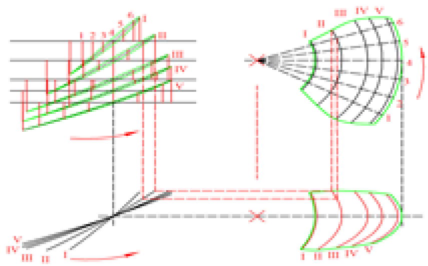

Figure 9. Section View of Blade

E. Optimum Design Calculation of Varying Runner Diameter

The prototype turbine has been designed to run at 577 rpm, and has a predicted power of 14.7 kW (10 kW produced by the generator) from a flow rate of 0.749 m3/s and a head of 2.5 m. This gives a specific speed of 704. Changing some geometric characteristic of the propeller turbine improves their performance. The performance curve shows the turbine performance as the head and size of the turbine is changed.

In this research, the various configuration of runner diameter is varied at constant turbine speed of 577 rpm, turbine blade inlet angle of 26.428˚ and guide blade angle of 74.6˚. It is concluded from the analysis of increasing runner diameter that head, power and flow rate of the turbine are increased but the efficiency of the turbine is decreased. The calculation method developed in this research is done by Microsoft Excel. Figure 10 represents the turbine performance curve at different runner diameter for efficiency and flow rate at constant turbine speed and Figure 11 shows the turbine performance curve at different runner diameter for head and power at constant turbine speed

In Figure 10, the flow rate values increased from 0.4 to 1.1m3/s as the runner diameter is increased from 0.36 to 0.5 m. On the other hand, efficiency values decreased slightly from 0.8 to 0.68 due to the runner diameter increased from 0.36 to 0.5 m.

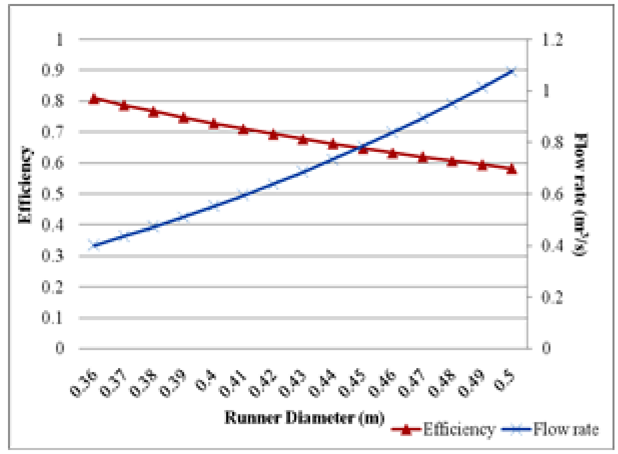

Figure 10. Turbine Performance Curve at Different Runner Diameter for Efficiency and Flow Rate at Constant Turbine Speed

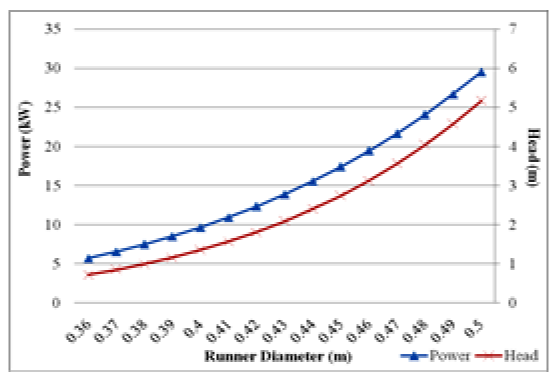

Figure 11. Turbine Performance Curve at Different Runner Diameter for Head and Power at Constant Turbine Speed

According to Figure 11 the runner diameter is directly linked to head and power of the turbine so that the greater the runner diameter, the higher the power and head. According to the performance curves, when the runner diameter is increased from 0.36 to 0.5 m, the power is significantly increased from 5 to 30 kW and head values increased from 1 to 5 m

IV. DISCUSSION AND CONCLUSION

Many types of hydropower plants are being used all over the world. Among them, micro-hydropower plants using low head water have always been an important part of the world's electricity supply providing reliable, cost effective electricity and it will continue to be so in the future. There are many low head water sites in Myanmar along irrigation channels. The available head from these irrigation channels are between 1 m to 3 m. Electricity can be produced well from these available low head. Turbine is the most important part to generate electricity. There are many types of hydraulic turbines. Among these turbines, propeller turbines are the best suitable for low head to generate electricity. The propeller turbine can be installed virtually anywhere as it is small in size and light weight. It can quickly and easily be moved to a new location or removed temporarily during flooding or other severe conditions.

In this research, all calculation of the data is based on the project of Kula village micro-hydropower plant. The turbine can be used for families in the village to produce 10 kW power easily and inexpensively. The runner blade profile is mainly modified and the other main parts such as guide vane, spiral casing and draft tube are designed in this thesis. The selected profile for the runner blade is NACA 2412. The blade is divided into five sections from the base of the hub to the outside diameter of the blade to obtain all diameters and vane angles for various sections of the runner. In this thesis, the spiral casing and conical draft tube were chosen for many advantages such as reduced cost, portable and simple to construct.

The available head of Kula canal is nearly 3m and the flow velocity is 5.85 m/sec. So propeller turbine type is chosen for 2.5m head to generate runner diameter is 443mm and the hub diameter is 182mm.The turbine has four blades. The calculated speed of the turbine is 577rpm, so it is needed to use pulley and belt drive for getting the operating speed of the generator. Then, the two dimensional data of runner blade is calculated by using MATLAB program and Microsoft Office Excel software. Auto CAD software is used to draw the result data. The type of three dimensional runner blades is also drawn for pattern making. The turbines in the market can produce maximum 5kW power and it is not sufficient for requirement. So larger turbine should be designed and constructed locally to use the energy source effectively. Therefore, 10kW propeller turbine parts and three dimensional runner blade profiles had been carried out. So, it is possible to construct this propeller turbine locally and can be produce electricity easily.

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