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Design of Blade for 5kW Propeller Turbine

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Abstract: Hydropower is one of the most cost effective solution for the production of electricity and thus preventing global warming. Micro-hydro power scheme can be designed and build by local staff and small organizations by using materials that can be available at local marketing. In this paper, the design of 5kW propeller turbine is presented. The available head and flow rate for turbine are 2.2 m and 0.38 m^3/s. The required speed to produce desired output power is 762rpm.The calculated specific speed for this turbine is 727. The main important parts of turbine such as runner, guide vanes, casing and draft tube. In this design the runner blade is mainly intend. The detail design of the runner blade profile is calculated by using Microsoft Excel .Runner blades are divided five sections and three dimensional blade profiles are drawn by SolidWorks software. The calculated runner diameter is 0.310 m and hub diameter is 0.124 m.

Keywords: propeller turbine; runner blade; guide vanes; blade profile; SolidWork.

1. INTRODUCTION

Water power has enormous potential. It is one of the most cost effective solution for the production of electricity and thus preventing global warming. By using of hydro-electric power , it no need to worry far environmental such as green house effect ad acid rain. Many countries in world are now encouraging the development of hydro power to full fill their electrical energy need.

Many new turbine manufacturers appearing and the older ones trying to a new expansion. Hydro power is a great option to choose instant of polluting energy sources. Hydraulic machine which convert either hydraulic energy (energy possessed by water) into mechanical energy (which is further converted into electrical energy) or mechanical energy into hydraulic energy.[3]

Turbines are defined as the hydraulic machine which converts hydraulic energy into mechanical energy. The kinetic energy of flowing water turns blades or vanes in hydro turbines, and then energy is change to mechanical energy. Depending on the capacity of water sources and flow of water by force of gravity, hydropower plant may be large, small, mini, micro and pico. Propeller turbines are low head and low cost for installation.

2. MAIN COMPONENTS OF PROPELLER TURBINE

There are four main components of propeller turbine. These are runner , guide vane , casing and draft tube.

i) Runner blades

Runner blades are main components of turbine that converts water power to the rotational of the shaft power.

ii) Guide Vanes

Guide vanes are fitted at entrance of runner. The primary section of the guide vanes is to convert the pressure energy of the fluid into the moment energy (kinetic energy).
Flow which is coming from the casing, meets stay vanes, they are fixed.

iii) Casing

Spril casing is the best type and provided at lower head as well. The runner is completely enclosed in casing. The casing and runner are always full of water.

iv) Draft Tube

The water, after passing through the runner, flow down through a tube called draft tube. It convert kinetic energy to flow energy because pressure different exist between the working fluid (water) in the turbine and atmosphere.[5]

3. APPLICATION OF PROPELLER TURBINE

When the vanes are fixed to the hub and they are not adjustable , the turbine is known as propeller turbine. This turbine is suitable where a large quantity of water at low head is available. In this turbine , allow the fluid to enter the runner axially and discharge the fluid axially.

The turbine having a propeller shape is known as propeller turbine ,which is an axial flow reaction turbine. The propeller turbine usually has three to six blades .On a vertical shaft and water flow parallel to the axis of turbine. The turbine wheel , which is completely under water , is turn by the pressure of water. Guide vanes regulated the amount of water reaching the wheel and the water flows from higher pressure to lower pressure.[8]

4. RUNNER DESIGN

After knowing the designed head, the specific speed can be calculated from the following equation

$$N_S = \frac{885.5}{H^{0.25}} \tag{1}$$

Speed of the turbine,

$$N = \frac{N_S H^{1.25}}{\sqrt{P}} \tag{2}$$

Where

N = speed of turbine, rpm

N_s= specific speed, rpm

And then the value of periphery coefficient can be determine by the following equation

$$\varphi = 0.0242 \times N_S^{2/3} \tag{3}$$

The runner discharge diameter,

$$D = \frac{84.5 \times \varphi \times \sqrt{H}}{N} \tag{4}$$

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. The number of blade is four.

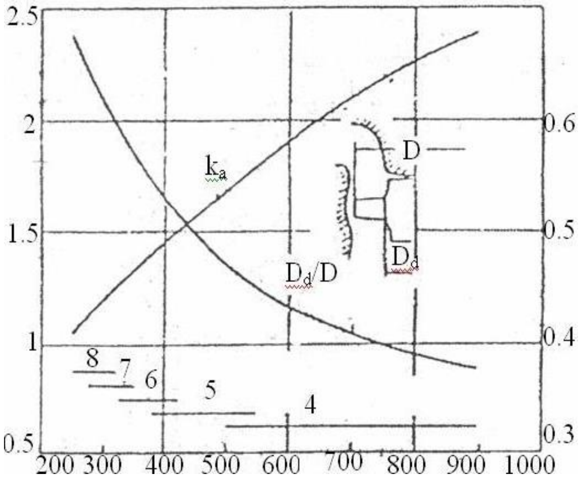

Figure 1. Relation Between Specific Speed and Number of Blade **[1]**

The power developed by a turbine is given by the following equation

$$P = \rho g Q H \eta_o \tag{5}$$

Where,

P = turbine output power , k W

Q = flow rate, m^3/s

ρ = density of water, kg/m^3

η_o = Overall efficiency of the turbine

H = Design head, m

Then, the flow velocity through with the runner can be determined from the following continuity equation[9].

$$Q = AV_f \tag{6}$$

Where,

A = Flow area, m^2

V_f = Flow velocity ,m/s

$$A = \frac{\pi}{4}(D^2 - d^2) \tag{7}$$

Where,

D = Runner diameter, m

d = Hub diameter, m

Table 1. Result Table of Propeller Turbine

Description	**Symbols**	**Calculated Result**	**Units**
Power output of turbine	P	5	kW
Speed of turbine	N	762	rpm
Runner discharge diameter	D	0.310	m
Runner hub diameter	d	0.124	m
Flow rate	Q	0.38	m^3/s
Flow velocity	V_f	5.98	m/s
Number of blade	z	4	-

4.1 Guide vane design

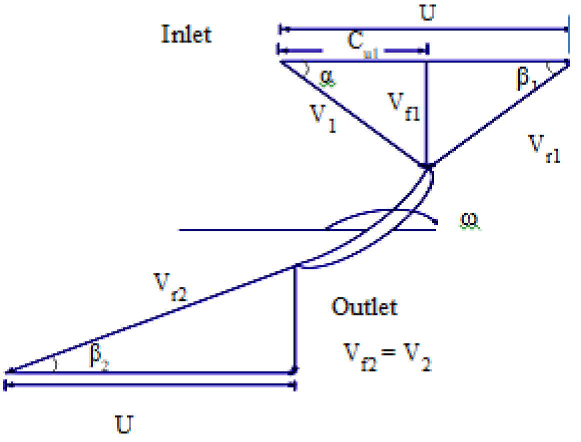

Figure .2 Inlet and Outlet Velocity Triangle of Propeller Turbine[7]

To calculate the Guide Vane angle α ,it is need to know the flow velocity and inlet whirl velocity

$$\alpha = \tan^{-1}\frac{V_{f1}}{V\omega 1} \tag{8}$$

Where the inlet whirl velocity can be calculate by the following equation,

$$V_{\omega 1} = \frac{\eta_h gH}{U} \tag{9}$$

The hydraulic efficiency of turbine can be calculated,

$$\eta_h = \frac{\eta_o}{\eta_m} \tag{10}$$

The tangential velocity of outer runner diameter can be calculated by the following equation

$$U = \frac{\pi DN}{60} \qquad (11)$$

The diameter of guide vane can be calculated,

$$D_v = 1.5D \qquad (12)$$

So , The number of guide blade can be evaluated as follow

$$Z_1 = \frac{1}{4}\sqrt{D} + 5 \qquad (13)$$

Then, the length of guide vane can be calculated by the following equation.

$$L = \frac{1.5D - D}{2\sin\alpha} \qquad (14)$$

5. DESIGN OF BLADE PROFILE

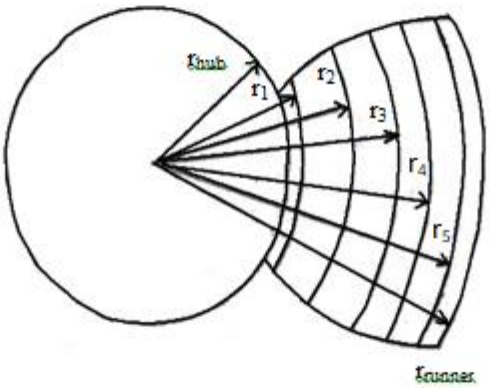

Figure . 3 Five Sections of Blade[4]

Runner can be divided into five cylindrical sections .These section can be calculated the following equation.

For section I,

$$r_1 = \frac{d}{2} + 0.015D \qquad (15)$$

For section II,

$$r_2 = r_1 + \frac{r_3 - r_1}{2} \qquad (16)$$

For section III,

$$r_3 = \frac{D}{2}\sqrt{\frac{1 + (\frac{d}{D})^2}{2}} \qquad (17)$$

For section IV,

$$r_4 = r_3 + \frac{r_5 - r_3}{2} \qquad (18)$$

For section V,

$$r_5 = \frac{D}{2} - 0.015D \qquad (19)$$

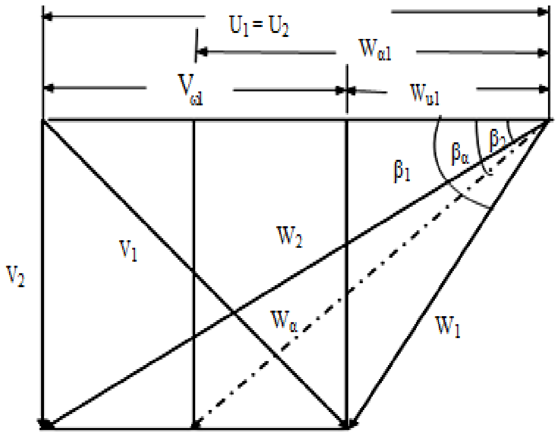

Figure. 4 Velocity Triangle of Propeller Turbine [6]

To find the Tangential speed,

$$U = \frac{\pi r_1 N}{30} \qquad (20)$$

From Velocity diagram, The inlet whirl velocity, $V_{\omega 1}$ can be calculated

$$V_{\omega 1} = \frac{\eta_h gH}{U} \qquad (21)$$

And then ,the blade inlet angle and outlet angle at section I can be calculated as follow,

$$\tan\beta_1 = \frac{V_{f1}}{U - V_{\omega 1}} \qquad (22)$$

$$\tan\beta_2 = \frac{V_{f2}}{U} \qquad (23)$$

Then, the average blade angle is

$$\tan\beta_\alpha = \frac{V_f}{W_{\alpha 1}} \qquad (24)$$

Where, $W_{\alpha 1}$ is the average value of tangential component of relative velocity and it can be determined by the equation;

$$W_{\alpha 1} = U - \frac{V_{\omega 1}}{2} \qquad (25)$$

And then average relative velocity can be evaluated by the following equation,

$$W_\alpha = \frac{W_{\alpha 1}}{\cos\beta_\alpha} \qquad (26)$$

The spacing of the blade can be determined by the following equation.

$$t = \frac{2r_1\pi}{z} \qquad (27)$$

Then, to obtain the angle of attack we have to consider the efficiency of turbine equation

$$\eta_h = uw_\alpha \frac{l}{t}(k_z - \frac{k_x}{\tan\beta_\alpha}) \tag{28}$$

From the above equation, it can be written by

$$(k_z - \frac{k_x}{\tan\beta_\alpha}) = \frac{\eta_h}{uw_\alpha \frac{l}{t}} \tag{29}$$

Where,

$$k_x = Mc_x$$

$$k_z = Mc_z$$

$$c_z M\tan\beta_\alpha - c_x + \frac{c_z^2}{6\pi} = \frac{\eta_h}{uw_\alpha \frac{l}{t}}\tan\beta_\alpha \tag{30}$$

To calculate the RHS of equation (29) we have to determine the following parameter

$$u = \frac{U}{\sqrt{2gH}} \tag{31}$$

$$w_\alpha = \frac{W_\alpha}{\sqrt{2gH}} \tag{32}$$

And then, select $\alpha = 14°$,

The lattice angle, β will be greater by the angle of attack,

$\beta = 90 - \beta_\alpha$

And then, $\beta = 90 - \beta_\alpha + \alpha$ (33)

In this case, the following value can be obtained the appendix fig A.

$t/l = 0.86$, $M = 0.55$

Then, the value of above parameter can be substitute the RHS of the equation (29).

$$c_z M\tan\beta_\alpha - c_x + \frac{c_z^2}{6\pi} = 1.67$$

To satisfy the L.H.S and R.H.S of the equation (29)

Selected the profile N.A.C.A 2412 which satisfied the given direction for the selection of the cross section, by equations

$$c_z = \frac{\partial c_z}{\partial \alpha}(\alpha - \alpha_0) \tag{34}$$

$$c_x = c_{xv} + \frac{\partial c_x}{\partial c_z^2} c_z^2 \tag{35}$$

From the figure in Appendix A

$\alpha_o = -2°$

$$\frac{\partial c_z}{\partial \alpha} = 0.075$$

$$c_{xv} = 0.0094$$

$$\frac{\partial c_x}{\partial c_z^2} = 0.0566$$

$$\alpha_\alpha = \alpha^\circ - 57.3 \times \frac{c_z}{6\pi} \tag{36}$$

And then, the lattice angle, β is

$$\beta = 90 - \beta_\alpha + \alpha_\alpha \tag{37}$$

Table. 2 Result Data of Blade Profile

Symbols	I	II	III	IV	V	units
R	0.067	0.092	0.118	0.134	0.150	m
U	5.32	7.37	9.42	10.70	11.99	m/s
$V_{\omega 1}$	3.82	2.76	2.16	1.61	1.69	m/s
β_1	76	52	39	33	30	Degree
β_2	48	39	32	29	26	Degree
β_α	60	45	36	31	28	Degree
$W_{\alpha 1}$	3.14	5.99	8.34	9.90	11.15	m/s
W_α	6.88	8.46	10.26	11.56	12.65	m/s
t	0.105	0.145	0.185	0.211	0.236	m
Vf	5.98	5.98	5.98	5.98	5.98	m/s
l/t	1.16	0.99	0.91	0.88	0.86	-
l	0.121	0.144	0.169	0.186	0.204	m
β	40	48	56	59	63	degree
α_α	10.35	3.14	1.86	1.09	1.01	degree

After Calculating the blade profile , the three dimensional runner blade are drawn by SolidWorks Software. The standard NACA 2412 airfoil is used for blade profile.

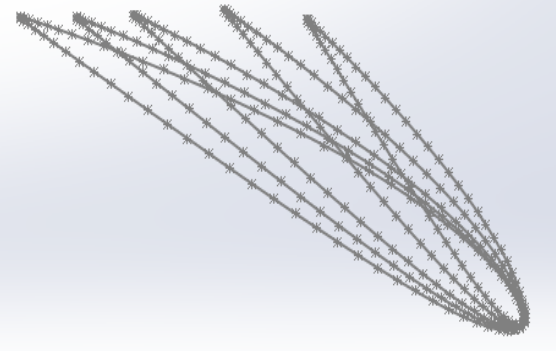

Figure . 5 Blade profile [11]

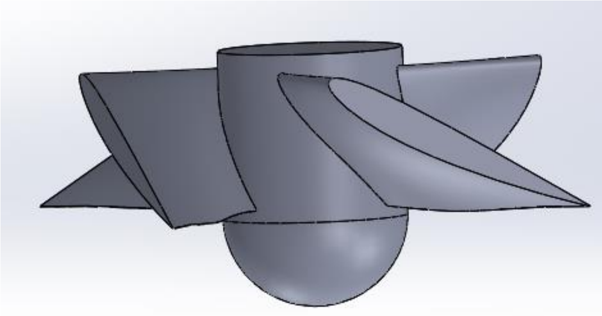

Figure . 6 Isometric View of Turbine Blade

6. CONCLUSION

Pico hydro power can be a suitable support to promote living standard and electrification development for rural area.[10] The required head and flow rate data are collected from the drop structure of irrigation canal of Ma Mya Dam in Irrawaddy Division, in Myanmar .In this paper, propeller has 4blade runner. The specification of turbine having rated capacity of 5kW , flow rate is $0.38m^3/s$ and 2.2m head. The detail design of the blade that is divided in five cylindrical sections is presented. The next paper will describe the simulation result upon on the blade and compare with simulation result and theoretical result .

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