INTERNATIONAL JOURNAL OF ADVANCE RESEARCH AND DEVELOPMENT

IJARnD

(Volume 5, Issue 4)

Available online at: www.ijarnd.com

Design calculation of Kaplan Turbine Runner Blade for 15kw Micro Hydropower Plant

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ABSTRACT

This paper deals with the design of the runner blade profile for Kaplan Turbine. The world has a huge potential of small hydro Kaplan turbine power plants. The world energy demands are increasing. In this micro hydro Kaplan power plants gains special attention. The development of micro hydro Kaplan power plants on large scale will generate enough energy for the world inhabitants. This paper presents the runner of a low head Kaplan turbine which the net head and rated flow of water is 2.4m and 0.8 m^3/s respectively. The turbine is single regulated Kaplan turbine with runner diameter 560 mm, hub diameter is 220 mm, and net power capacity is 15 kW. Major component of Kaplan turbine are spiral casing, guide vane mechanism and runner.

Keywords— *Kaplan Turbine, Runner Blade, Micro Hydro*

1. INTRODUCTION

Hydropower systems use the energy in flowing water to produce electricity or mechanical energy. In hydro power plants the kinetic energy of falling water is captured to generate electricity. A turbine and a generator convert the energy from the water to mechanical and then electrical energy. According to the head, hydropower schemes can be classified in three categories.

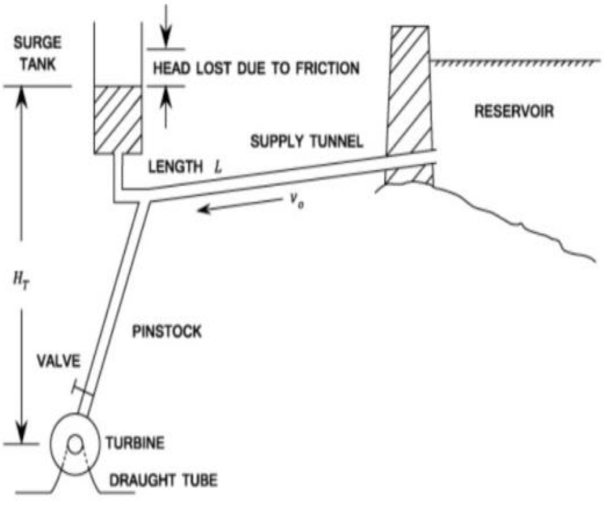

Fig. 1: Impoundment System of Hydropower Plant

They are:

(a) High head,
(b) Medium head,
(c) Low head.

As shown in figure 1, an alternative is to convey the water by a low-slope canal, running alongside the river, to the pressure intake or fore bay, and then in a short penstock to the turbines. If the topography and morphology of the terrain does not permit the easy layout of a canal, a low- pressure pipe, with larger latitude in slopes, can be an economical option.

1.1 Types of hydraulic turbines

A turbine is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The work produced by a turbine can be used for generating electrical power when combined with a generator. Turbines are also divided by their principle of operation and can be divided into impulse and reactions turbine. The impulse turbine generally uses the velocity of the water to move the runner and discharges to atmospheric pressure. Reaction turbines are pressure type turbines that rely on the pressure difference between both sides of the turbine blades. For micro-hydro applications, the Kaplan turbine is suitable for relatively small dimensions combined with rotational speed, favorable progress of the efficiency curve and large overloading capacity.

1.2 Kaplan Turbine

The Kaplan turbine is suitable for low heads and high discharge conditions. The main parts of the Kaplan Turbine shows in figure-2. These are penstock, scroll casing and guide blade system are similar to those used in Francis turbine but the runner is entirely of different design. It resembles a propeller. The runner has only a few blades radial oriented on the hub and without an outer rim. The water flows axially through. The runner blades have a slight curvature and cause relatively low flow losses. This allows for higher flow velocities without the rotational speed more than two times higher than for a Francis turbine for the corresponding head and discharge. In this way the generator dimensions as well become comparatively smaller and cheaper. The comparatively high efficiencies at partial loads and the ability of overloading are obtained by a co-ordinate regulation of the guide vanes and the runner blades to obtain optimal efficiency for all operations.

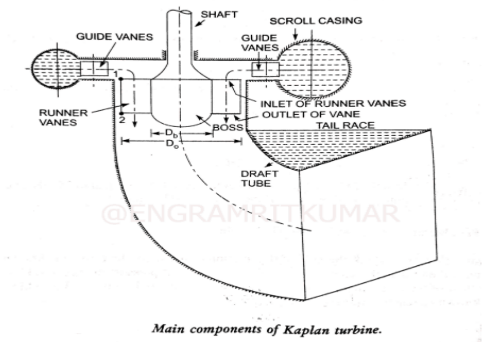

Fig. 2: Main component of Kaplan Turbine

Kaplan turbine is axial-flow reaction turbines, generally used for low heads. The Kaplan turbine may or may not brave adjustable guide vanes. If both blades and guide-vanes are adjustable it is described as double-regulated. If the guide-vanes are fixed it is single-regulated. Unregulated propeller turbine is used when both flow and head remain practically constant.

The flow enters radial flow inward and makes a right angle turn before entering the runner in an axial direction. The control system is designed so that the variation in blade angle is coupled with the guide-vanes setting in order to obtain the best efficiency over a wide range of flows. The blades can rotate with the turbine in operation, through links connected to vertical rod sliding inside the hollow turbine axis.

1.3 Selection of turbines

There are different designs specified for different head values. The type of hydropower turbine selected for a project is based on the height of standing water referred to as head and flow, or volume of water, at the site.

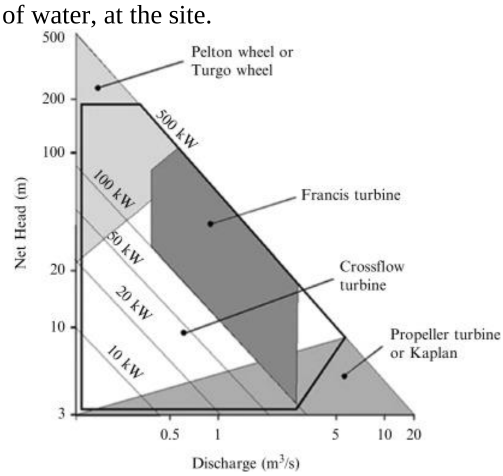

Fig. 3: Selection of Turbine

The selection of the turbine depends upon the site characteristics, principally the head and flow available, plus the desired running speed of the generator and whether the turbine will be expected to operate in reduced flow conditions. The selection of turbine based on head and flow rate.

1.4 Design consideration of Kaplan Turbine runner blade

Table 1: Specification Data for Kaplan Turbine Blade

Description	Symbol	Value	Unit
Generator output power	P	15	kW
Flow rate	Q	0.3	m^3/s
Generator efficiency	η_g	0.85	
Design head	H_d	2.4	m
Mechanical efficiency	η_m	0.8	
Hydraulic efficiency	η_h	0.88	
Specific weight of water	γ	9810	kN/m^3

The effective head and power available of this kaplan turbine is considered at 2.4m and 15kW. The power developed by a turbine is given by the following equation.

The required shaft power,

$$BP = \frac{\text{generator output}}{\eta_m \times \eta_g} \quad (1)$$

The specific speed can be calculated from the following equation.

$$N_s = \frac{885.5}{{H_d}^{0.25}} \quad (2)$$

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

$$N = \frac{N_s {H_d}^{1.25}}{\sqrt{P}} \quad (3)$$

Runner Discharge Diameter and Hub Diameter can be calculated from the following equation.

$$D = \frac{84.5 \times \emptyset \times \sqrt{H_d}}{N} \quad (4)$$

where,

$$\emptyset = 0.0242 \times {N_s}^{2/3} \quad (5)$$

Guide Vane Angle can be calculated from the following equation.

$$\tan \alpha = \frac{V_f}{C_{u1}} \quad (6)$$

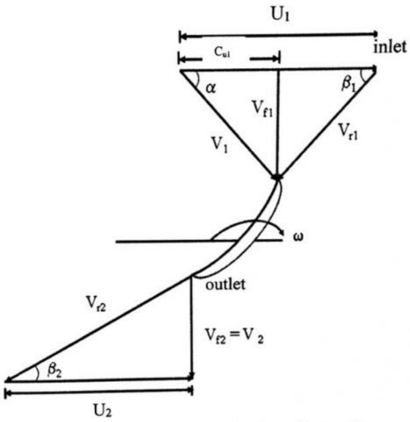

Fig. 4: Inlet and Outlet Velocity Triangle of Kaplan Turbine

The number of guide blade,

$$z_1 = 1/4\sqrt{D`} + 5 \quad (7)$$

Blade profile can be designed from the following equation.

Section I,

$$r_1 = \frac{d}{2} + 0.015D \quad (8)$$

Section III,

$$r_3 = \frac{D}{2}\sqrt{\frac{1+{D_d}^2}{2}} \quad (9)$$

Section II,

$$r_2 = r_1 + \frac{r_3 - r_1}{2} \quad (10)$$

Section V,

$$r_5 = \frac{D}{2} - 0.015D \quad (11)$$

Section IV,

$$r_4 = r_3 + \frac{r_5 - r_3}{2} \quad (12)$$

Table 2: Result of Blade Profile

Parameters	I	II	III	IV	V
$R_1 = R_2(m)$	0.1184	0.1657	0.213	0.2423	0.2716
$U_1 = U_2(m)$	5.62	7.86	10.10	11.49	12.88
β_1	64.24	37.46	26.42	22.43	19.53
β_2	35.44	26.97	21.61	19.19	17.25
$C_{u1}(\frac{m}{s})$	3.69	2.64	2.05	1.8	1.6
$w_{\alpha 1}(\frac{m}{s})$	3.775	6.54	9.08	10.5	12.08
β_α	46.65	31.45	23.77	20.69	18.32

w_α	5.49	7.66	9.92	11.32	12.72
t_s	0.186	0.26	0.33	0.38	0.43
r	0.68	0.68	0.68	0.68	0.68
l/t	1.1	1.013	0.923	0.884	0.844
L=l/t× $t(m)$	0.205	0.263	0.305	0.336	0.36
β	58.33	71.25	76.65	77.45	77.54
$\alpha_\alpha{}^\circ$	14.984	12.7	10.42	8.14	5.86

The spacing of the blade,

$$t_s = \frac{2r\pi}{z} \quad (13)$$

The runner inlet and outlet blade angles can be calculated from the following equations.
Blade inlet angle,

$$\tan\beta_1 = \frac{V_{f1}}{U_1 - C_{u11}} \quad (14)$$

Blade outlet angle,

$$\tan\beta_2 = \frac{V_{f1}}{U_1} \quad (15)$$

$$\text{Circulation } (r),\ \Gamma = t(C_{u1} - C_{u2}) \quad (16)$$

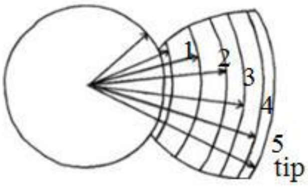

Fig. 5: Five Sections of the Blade

Forces on the blade can be calculated from the following equation.
Axial force,

$$F_a = g\,\rho\,H_d\,A_b \quad (17)$$

Tangential force,

$$F_t = \frac{P}{2\times\pi\times N\times z\times r_{cp}} \quad (18)$$

Resulting force,

$$F_r = \sqrt{Ft^2 + Fa^2} \quad (19)$$

The moment of inertia,

$$I_s = \frac{R_e{}^4 - R_i{}^4}{4} \times \left(\frac{\alpha_1}{2} - \sin\frac{\alpha}{2} \times \cos\frac{\alpha}{2}\right) \quad (20)$$

$$M_h = F_r \times e_y \quad (21)$$

After calculating the blade profile, three-dimensional runner blades are drawn by Solid works software.

Fig. 6: 3D View of runner blade

2. CONCLUSION

Kaplan turbine runner blade design was chosen depending on head, flow rate and desired power. The available head of Kyae Thee Project is maximum head of 2.4 m (8ft), flow rate is 0.8 m^3/sec to generate 15 kW of power. The calculated runner diameter is 560 mm, hub diameter is 220 mm and number of blade is four. The calculated speed of turbine is 453 rpm. The runner blade profile is divided into five cylindrical section. The three dimensional runner blades are also drawn by solid works software.

3. ACKNOWLEDGEMENT

The author is deeply grateful to Dr. Kyaw Aung, Professor and Head of Mechanical Engineering Department, Technological University (Mandalay) for his willingness to share his ideas helpful suggestions on this paper writing.

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