DESIGN AND PERFORMANCE TESTING OF 5KW AXIAL FLOW TURBINE FOR HYDROPOWER

Ei Mon
Department of Mechanical Engineering, Yangon Technological University, Myanmar

Abstract: Hydropower is a renewable resource that can satisfy an important percentage of the global energy demand. There are many hydropower plants in Myanmar such as Ye' Ywar, Kha Paung, Paung Long and Zaw Gyi plants. The design data get from the Ma Mya Dam Project. Design conditions for this turbine are 2.5m head and flow rate of 0.331m3/s. It is carried out to study and performance not only the theories of blade, draft tube and spiral casing but also their design procedure calculation and performance testing. After testing the turbine, the actual output power is 2.9kW at 670 rpm under the same head 2.5m. There are some losses in the turbine, draft tube, casing and generator. Power reduces due to another important factor is insufficient water flow rate.
Keywords: blade; draft tube; spiral casing; design calculation; performance testing

I. INTRODUCTION

The demand for increasing the use of renewable energy has risen over the last few years due to environmental issues. The high emissions of greenhouse gases have led to serious changes in the climate. Although the higher usage of renewable energy would not solve the problems over night, it is an important move in the right direction. The field of renewable energy includes, wind power, solar power and water power. The design of a hydraulic turbine is searched to satisfy a flow rate and a small waterfall. The turbine is made to work in a small amount of power, so the important thing is that the turbine has a good adaptation to the hydraulic condition. The main goal is the realization of the design of the main turbine and every component of the power station, like the dam, scroll casing, the water intake gates and the blades. Axial Flow type Kaplan turbine is suitable for low head and large flow rate. This paper will demonstrate the possibility to design hydro turbine easily, just with some calculations. Among them, this paper is based on the theoretical calculation of the turbine to adapt it to the real condition of all parts involved. The realization of this paper is motivated by personal interest of the author in renewable energy and nature in general. Every element calculation with direct influence in the operation of the turbine calculations will be provided. This paper will not correspond to the calculation of the electrical components.

II. LOCATION OF MICRO-HYDROPOWER PLANT

Micro-hydropower plants were constructed at drops structures of Ma Mya Dam Project. Ma Mya Dam Project is located at about one mile north-west of Myinwataung Village on the Pathein Monywa Highway in Myan Aung Township, Ayeyarwady Division. Ma Mya Dam was constructed across the Ma Mya River to supply the town with purified water. The water is over-floating from the dam and this make a fall or head of about 2.5 meter. The flow rate of water is about 0.331m3/s.

Fig. 1 Location of Ma Mya Dam in Myan Aung Township

III. COMPONENTS OF HYDROPOWER SYSTEM

The principal components of hydropower are shown in Fig.2. Each of these components serves specific purposes. But all of these components are not needed for micro-hydropower plants.

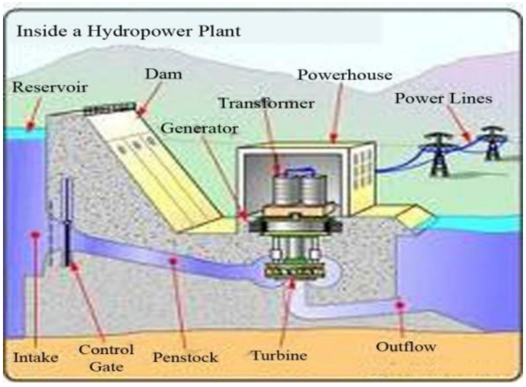

Fig. 2 Typical Components of Hydropower System

IV. AXIAL FLOW KAPLAN TURBINE

Kaplan turbine is axial flow reaction turbine, generally suitable for low head. The individual runner blades are pivotally mounted in the hub so that their inclination may be adjusted during operation, by the governor, simultaneously with the adjustment of the guide vanes, to meet the demands and changes in head. The Kaplan usually has three to six blades there in the case of very low head unit. This kind of Kaplan turbine is known as an adjustable blade axial flow turbine [3].

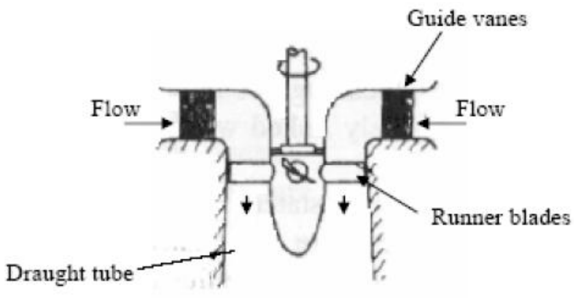

Fig. 3 Kaplan (axial) turbine

V. COMPONENTS OF AXIAL FLOW TURBINE

The basic Axial Flow turbine consists of five main parts. They are:

- Spiral Casing
- Runner
- Guide Vane
- Draft Tube
- Drive Shaft

Spiral Casing

Casing may also be used for very low heads and are always used for high heads. Its areas of the waterway decreases as the case encircle the guides, because only a limited portion of the water flows clear around the enter the further part of the circumferences. The main purpose of the spiral casing is to provide a uniform flow to the guide vane [1].

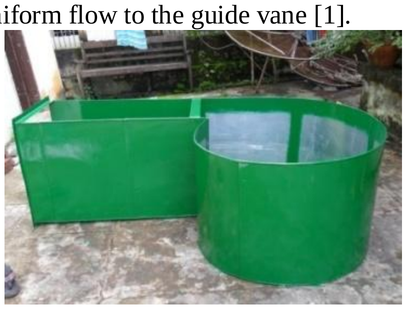
Fig. 4 Spiral Casing

Runner

Runner is the main component of the turbine that converts water power to the rotation of shaft power. For low head, the use of flow rate is increased and therefore the runner is designed pure axially. The runner is keyed to a shaft which is usually of forged steel. The water passes through the runner blades in axial direction both at inlet and outlet [1].


Fig. 5 Runner

Guide Vane

The guide vanes duct must have a constant contraction to have a steady rise of water velocity. It is needed to a cross section of the guide blade so as to have a steady rise of water velocity. So it is prefer to employ air-foil properties. The inlet end of the guide vane lies as a rule under as angle of from 60° to 70° to the tangent of the circle [1].


Fig. 6 Guide Vane

Draft Tube

The purpose of the draft tube is to reduce the outflow loss and thus to improve the efficiency of the plant. Draft tube is an integral part of mixed and axial flow turbine. The total power available is that due to the fall from head water level to tail water level [1].

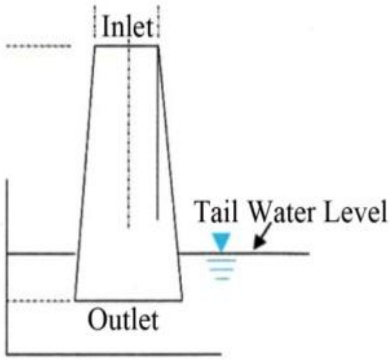

Fig. 7 Draft Tube

Drive Shaft

The turbine shaft will transmit the rotary motion of the runner to the generator via the drive system. It most cases the shaft has circular cross-section and is subject to either pure torsion [1].


Fig. 8 Drive Shaft

VI. DESIGN THEORY OF 5KW AXIAL FLOW TURBINE

The design of the Axial Flow turbine is considered by the following formula.

Turbine Output Power

The turbine output power can be calculated by the equation,

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

where, P_t = required shaft power (kW)
η_m = mechanical efficiency (%)
η_g = generator efficiency (%)

Power from Water

The flow rate can be calculated by the equation,

$$\text{Power} = \gamma Q H_d \eta_o \quad (2)$$

where, P = shaft power (kW)
Q = flow rate ($m^3/_s$)
H_d = design head (m)
η_0 = overall efficiency (%)

Applicable Specific Speed

To determine the specific speed, the formulate suitable for low head turbine is the following equation,

$$N_s = \frac{885.5}{H_d^{0.25}} \quad (3)$$

where, N_s = specific speed (rpm)
H_d = design head (m)

Applicable Turbine Speed

The turbine speed can be calculated by the equation,

$$N = \frac{N_s H_d^{1.25}}{\sqrt{P_t}} \quad (4)$$

where, N = turbine speed (rpm)

Number of Pole for Generator

The no: of pole for generator can be calculated by the following equation,

$$p = \frac{60f}{N} \quad (5)$$

where, p = no of poles
N = turbine speed(rpm)
f = frequency (50Hz)

Runner Diameter

The runner diameter can be calculated by the equation,

$$D = \frac{84.5 \times \emptyset \times \sqrt{H_d}}{N} \quad (6)$$

where, D = runner diameter(m)
ϕ = periphery coefficient

The periphery coefficient can be calculated by the equation,

$$\emptyset = 0.0233 \times N_s^{1.5} \quad (7)$$

Blade Profiles

In the space of the runner, it can be divided into five cylindrical sections.

Section 1, $$r_1 = \frac{d}{2} + 0.015d \quad (8)$$

Section 3, $$r_3 = \frac{D}{2}\sqrt{\frac{1+D_d^{\,2}}{2}} \quad (9)$$

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

Section 4, $$r_4 = r_3 + \frac{r_5 - r_3}{2} \quad (11)$$

Section 5, $$r_5 = \frac{D}{2} - 0.015D \quad (12)$$

Guide Vane& Guide Vane Angle

The no of guide vane can be calculated by the equation,

$$z = {}^{1}/_{4}\sqrt{D} + 6 \quad (13)$$

where, z = no of guide vane

The guide vane angle can be calculated by the equation,

$$\tan\alpha = \frac{V_f}{C_u} \quad (14)$$

where, α = guide vane angle
v_f = flow velocity
c_u = tangential component of absolute velocity

Spacing of blade

Spacing of blade can be determined following equation,

$$t_s = \frac{2\pi r}{z} \quad (15)$$

where, t_s = spacing of blade
z = no of blade

Circulation

Circulation can be determined following equation,

$$\Gamma = t_s(V_{u1} - V_{u2}),\ V_{u2} = 0 \quad (16)$$

where, Γ = circulation
v_{u1}= tangential component of absolute velocity

Angle of attack

According to Equation, angle of attack in relation to the direction of the velocity w_α can be determined,

$$\eta_h = u w_\alpha \frac{t}{l}\left(k_z - \frac{k_x}{\tan\beta_\alpha}\right) \quad (17)$$

The profile N.A.C.A.2412 , which means that the profile will exhibit the values m/l=2%, L/l=4%, t/l=12% which is defined by the following equation.

$$c_z = \frac{\partial c_z}{\partial \alpha}(\alpha - \alpha_0) \quad (18)$$

$$c_x = c_{xv} + \frac{\partial c_x}{\partial c_z^{\,2}} c_z^{\,2} \quad (19)$$

$$\alpha_\alpha = \alpha - 57.3\frac{c_z}{6\pi} \quad (20)$$

where, w_α = average relative velocity,
c_z = coefficient of lift
c_x = coefficient of resistance
α_α = angle of attack
η_h = hydraulic efficiency

Lattic Angle

$$\beta = 90 - \beta_\alpha + \alpha_\alpha \quad (21)$$

where, β = lattic angle
β_α = average angle

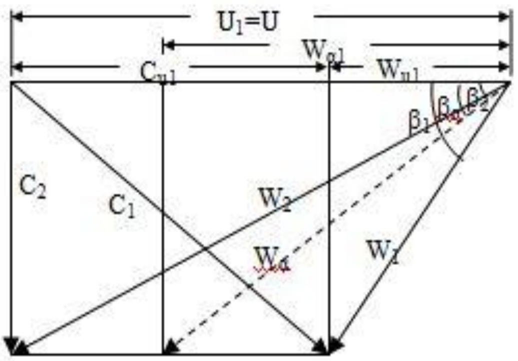

Fig. 9 Velocity Triangle of Axial Flow Kaplan Turbine

Spiral Casing

The Spiral Casing can be calculated by the following equation, the dimensions below are related to the runner discharge diameter

$A = 1.45D$ (22)
$B = 1.5D$ (23)
$C = 1.9D$ (24)
$E = 2.05D$ (25)
$F = 1.6D$ (26)
$G = 1.25D$ (27)
$H = 1.85D$ (28)
$I = 0.4D$ (29)
$J = 0.76D$ (30)
$K = 0.38D$ (31)

Draft Tube

The Draft tube can be calculated by the following equation, the dimensions below are related to the runner discharge diameter.

$T=0.6D$ (32)
$T=D$ (33)
$Y= 2.5D$ (34)
$Y=3D$ (35)

VII. CALCULATED RESULT OF 5KW AXIAL FLOW TURBINE BLADE

Initial requirement data are as following;

The required generator output power ,P_g = 5kW
Design head of turbine , H_d = 2.5m
Mechanical efficiency ,η_m = 0.9
Generator efficiency ,η_g = 0.85
Overall efficiency ,η_0 = 0.8

TABLE I
Calculated results for runner diameter

Symbol	Quantity	Calculated Result	Unit
P_t	Turbine output power	6.5359	kW
Q	Flow Rate	0.331	$m^3/_s$
N_s	Specific Speed	704	rpm
N	Turbine Speed	866	rpm
D	Runner Diameter	0.2956	m
d	Hub Diameter	0.13	m

TABLE II : Calculated results for blade profile

Parameters	1	2	3	4	5
$R_1=R_2$(m)	0.0649	0.0851	0.1053	0.1221	0.1389
$U_1=U_2$(m/s)	6.07	7.96	9.86	11.42	13
V_f(m/s)	6.4	6.4	6.4	6.4	6.4
β_1	66.42	48.1	37.5	34	29.6
β_2	44.76	36.93	31.17	29.33	26.28
c_u(m/s)	3.59	2.74	2.21	1.91	1.68
w_α(m/s)	5.25	7.96	9.85	11.42	12.99
β_α	50.69	38.87	33.07	29.33	26.28
w_α(m/s)	8.298	10.229	11.763	13.105	14.497
t_s(m)	0.1019	0.1336	0.1654	0.1917	0.2181
Γ (m^2/s)	0.3663	0.3663	0.3663	0.3663	0.3663
l/ t_s	1.1	1.0125	0.925	0.84	0.74
l = l/ t_s * t_s(m)	0.116	0.153	0.158	0.166	0.167
β	49.64	63.69	71.24	76.25	80.13
α	14.29	16.05	15.7	16.13	16.49

TABLE IIII: Calculated results for spiral casing & draft tube

Symbol	Quantity	Calculated Result	Unit
A	Spiral Casing Dimensions	0.4286	m
B		0.4434	m
C		0.56164	m
E		0.6059	m
F		0.47296	m
G		0.3695	m
H		0.54686	m
I		0.1182	m
J		0.2246	m
K		0.1123	m
T	Draft Tube Dimensions	0.1774	m
T		0.2956	m
Y		0.739	m
Y		0.8868	m

Drawing For 5kw Axial Flow Turbine

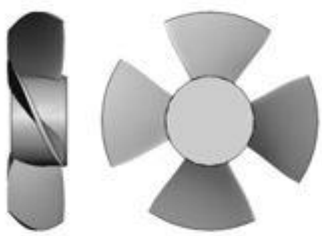

Fig. 10 Top View and Side View of Blade Axial Flow Turbine

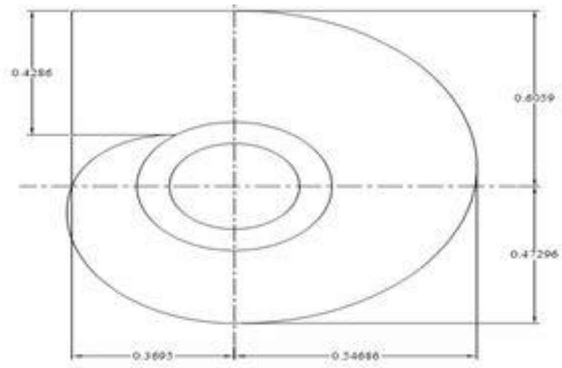

Fig11. Spiral casing of axial flow turbine

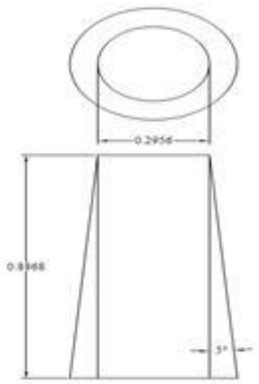

Fig12. Draft tube of axial flow turbine

VIII. PERFORMANCE TESTING OF 5KW AXIAL FLOW TURBINE

Turbine generator set is designed for the head of 2.5m to generate 5kW and constructed only for household use in rural areas. Most of houses are situated through the canal with a small water fall around 2.5m high. 5kW Axial Flow turbine was tasted at Myinwataung Village which is situated in Myan Aung Township. Before being tested, the turbine casing, draft tube and generator assembly must be set properly. The effective head can be obtained by using a measuring tape. The flow rate through a known cross-sectional area can be obtained by the product of cross sectional area of canal and velocity of water. Firstly, the turbine is tested at no load condition. The speed of turbine is measured by means of a tachometer. At that time, the speed of turbine is 1300rpm. And then, the load is gradually increased and results are recorded. The generator output can easily be measured by using various loads because of the lack of Watt meter.

TABLE IV: performance results for 5kw axial flow turbine

Load (Watt)	Speed (rpm)	Flow Rate ($m^3/_s$)	Head (m)
Free Load	1300	0.1	2.5
1000	945	0.1	2.5
1200	900	0.1	2.5
1400	876	0.1	2.5
1500	870	0.1	2.5
1900	845	0.1	2.5
2000	839	0.1	2.5
2200	816	0.1	2.5
2500	780	0.1	2.5
2800	727	0.1	2.5
2900	670	0.1	2.5
2700	637	0.1	2.5

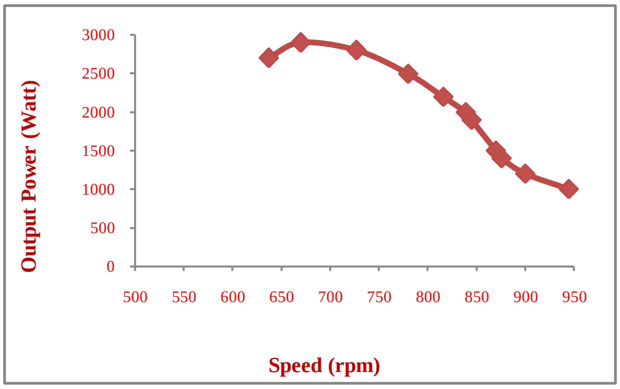

Fig. 13 Performance Curve of 5kW Axial Flow Turbine

Fig. 14 Drop No.5 (5kW x 2 No)

Fig. 15 Water Gate Opening

Fig. 16 Performance Testing of 5kW Axial Flow Turbine

IX. CONCLUSION

The axial flow Kaplan turbine can also be used for electricity highly demands which are far from the national grid system. It can be used for low head of water for simple technology, locally designed and built, by utilizing local materials with low cost. Blade is designed for 5kW axial flow turbine with the head of 2.5m and flow rate of 0.331m3/s. Design calculations are based on the overall efficiency 80% that has been assumed. Before testing the turbine is connected with the generator. 5kW generator (8 poles, 750 rpm) is used to determine the output power. Plant output can be determined by using electric bulbs and hot plate. The maximum turbine output power is 2.9kW at 670 rpm and flow rate 0.1m3 per sec. Although the design power is 5kW at 866 rpm, the actual output power is 2.9kW at 670 rpm under the same head 2.5m. Therefore, there are some losses in the turbine, draft tube, casing and generator. Power reduces due to another important factor is insufficient water flow rate. To produce 5kW output power, the required flow rate is 0.331 m3 per sec but the maximum available flow rate at drop No(5) is 0.1 m3 per sec. So, if the required flow rate is available, the design output power, 5kW will be expected to produce.

Acknowledgment

The author is highly grateful to Dr. Aye Myint, Rector of the Yangon Technological University for her permission to summit this paper. The author would like to thank Dr. Mi Sandar Mon (Professor and Head),and Dr. Mya Mya Khaing (Professor) and all teachers from Department of Mechanical Engineering, Yangon Technological University for their kindness, graceful, attitude and permission to do this paper.

REFERENCES

[1] Adam Harvey, "Micro-Hydro-Hydro Design Manual" Intermediate Technology Development Group, Publishing, IT Power, 1991, pp. 153-197.
[2] Allen Inversion. No Date. Micro Hydropower Source Book, pp. 23-50.
[3] Streeter, Wylie, Bedford, Fluid Mechanics, Ninth edition. McGraw-Hill International Edition., Ch.5
[4] R.A. Higgins, Engineering Metallurgy, Sixth edition. pp, 158-217.
[5] Scaum's Outlines Series, "Theory of Machine Design", 1982. pp, 70-85.
[6] http://www.british-hydro-org/micro-hydro

