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TURBINE DESIGN OF CROSS-FLOW TYPE MICRO-HYDRO POWER PLANT TO GENERATE POWER OF 2700 WATT

M. Dwi Trisno[a*], Muhammad Firdausi[b], Eddy Djatmiko[c], Dahmir Dahlan[d]

[a,b] *Mechanical Department, National Institute of Science and Technology (ISTN)*
[a,b] *Jl. Moh. Kahfi II, Jagakarsa, Jakarta 12640*
[a,b] *Phone: +62-21-7270092, Fax: +62-21-7866954*
[c,d] *Mechanical Department, University of Pancasila*
[c,d] *Jl. Raya Lenteng Agung, Jagakarsa, Jakarta 12640*
[c,d] *Phone: +62-21-7272608*
[a] *e-mail; m_dwitris@yahoo.co.id*

Abstract

To meet the needs of electricity in areas that have a potential flow of water, Turbine design has been done for Micro-hydro Power Plant that can generate power of 2.700 Watts. The turbine is designed to be easy to carry and move, easy to install and operate, with minimal maintenance. Type of turbine is a Cross-Flow for low head. The turbine operates at impulse pressure, where the water potential energy is converted to kinetic energy through the nozzle to drive the turbine front blades. This type of turbine has long life durable, cheap investment, cheap operating costs, easy to dismantle pairs, do not damage the environment and free of waste, i.e; Head (H) = 2 m; Water discharge (Q) = 0.2 m3 / s; Turbine rotation (plan) (n) = 214 rpm; Turbine efficiency (ηt) = 68%; The water density (ρ) = 997.8 kg / m3. Based on calculation results, specification of turbine design as follows: water fall (H) = 2 m; water discharge (Q) = 0.2 m3 / s; turbine efficiency (ηt) = 68%; power (N) = 2.7 kW; rotation speed (n) = 214 rpm; specific speed (ns) = 678,74 rpm; blades diameter (DL) = 0.40 m; diameter of naaf (Dn) = 0.04 m; width of the guide blade (B) = 0.032 m; number of blades = 26 pieces.

Keywords: Cross-Flow Turbine, head, debit, turbine power, nozel, blades.

Introduction

Micro-hydro power plant is one solution to overcome the electricity needs in an area that has not reached the electricity supply but has a potential source of water flow. The development and operation of MHP can be done by involving local resources. In its development micro-hydro plants can be designed and built by local resources and smaller local technological organizations by following looser regulation and use.

Technically, the micro-hydro generator has three main components: water as energy source, turbine, and generator. Water flowing with a certain capacity is channeled from a certain height to the generation plant. the installation of water will pound the turbine blades, where the water energy is converted into mechanical energy through turbine spinning. The rotating shaft is then transmitted to the generator by using the clutch. From the generator will be generated electrical energy that will enter the control system of electric current before flowed to homes or other purposes (load).

The objective of the research is to design a PLTMH turbine engine that can produce 2,500 - 3,000 Watt power. The machine is capable of being carried and moved easily, capable of being installed easily, easy to operate, with minimal maintenance. Turbines are designed based on field survey results data in Palasari Village, Bogor District, West Java Province. The design is an improvement of the previous design by modifying the intake pipes to the turbine load turbine control.

Methodology

2.1. Selection of turbine type.

Turbine classification is determined by the type of runner and head pressure (table-1). The turbine type is selected based on the discharge characteristics and head, as shown in Figure 2.

Table-1: Turbine classification

Turbin Runner	Head Pressure		
	High	Medium	Low
Impulse	• Pelton • Turgo • Multi-Jet Pelton	• Crossflow • Turgo • Multi-Jet Pelton	• Crossflow
Reaction		• Francis • Pump-As-Turbine	• Propeller • Kaplan

Source: Micro-Hydro Desiqn Manual, IT Penerbitan, 1993

Based on table-1 the selected turbine type is a cross-flow. The type of turbine is used for low head. Cross-flow water turbine using blades with fixed blades:

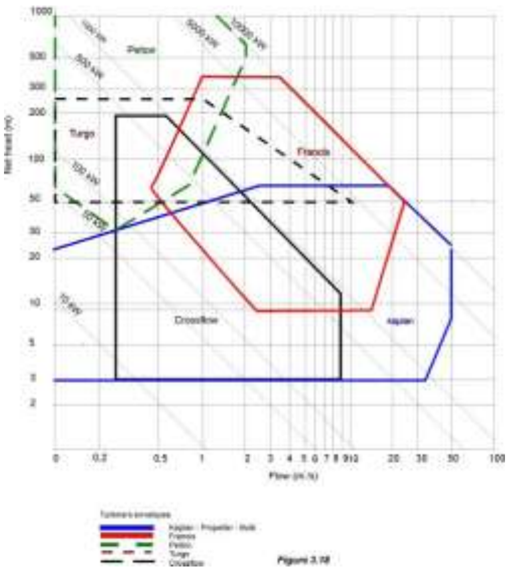

Figure-1. Specify of turbine type

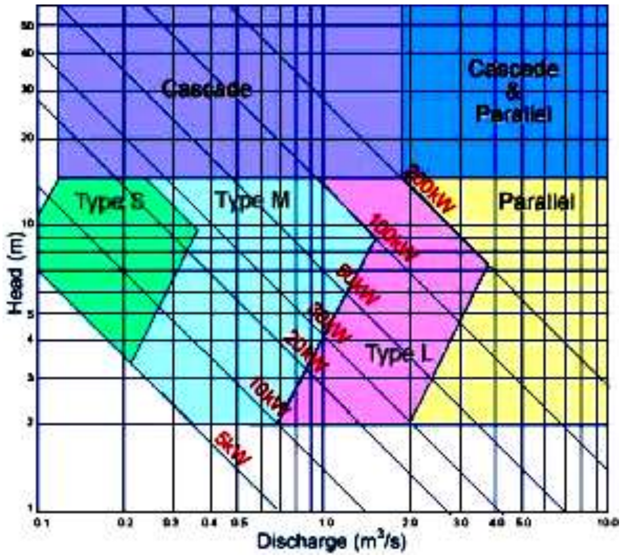

Figure-2. Types of turbine.

Turbine operates at the reaction pressure, where the potential energy is converted first through the nozzle into kinetic energy in the form of high-speed water bursts that push the turbine front blades. In addition, this type of turbine has a long life wear, cheap operating costs, low investment, easy to dismantle pairs, and do not damage the environment and free of waste. Figure 3 shows a schematic image of a cross-flow water turbine.

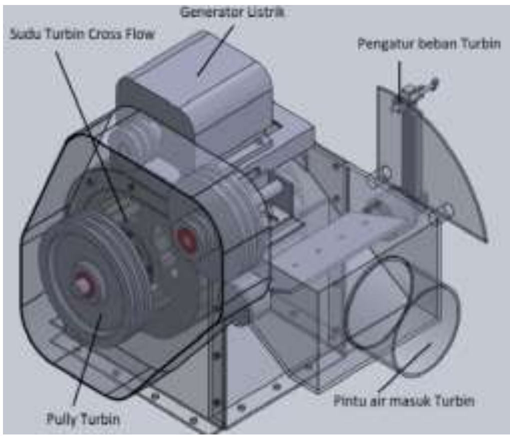

Figure-3. Turbine schematic diagram

2.2. Measurement of discharge and high drops of water.

Installation of turbine is adjusted the actual condition in the field. A practical flow measurement of flow discharge is possible with the dam technique as shown in Figure 4.

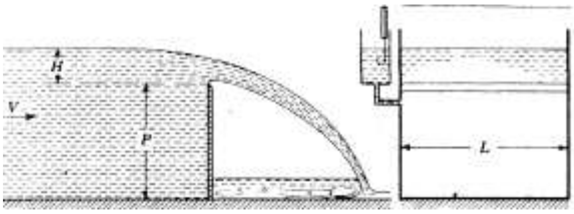

Figure-4. Debit measurement using Dam Method [1]

According to [1] the magnitude of the flow Q can be approximated by the relationship:

$$Q = 1{,}84\, LH^{3/2} \quad (m^3/s) \tag{1}$$

2.3. Determine the basic design of the main dimensions of the turbine.

Basic design of the main dimensions tailored to the data obtained from survey results and calculations as follows:

- Head, $H = 2{,}0\ m$
- Flow, $Q = 0{,}2\ m^3/s$
- Rotation speed, $n = 214\ rpm$
- Turbine efficiency, $\acute{\eta}_t = 68\%$
- Water density, $\rho = 997{,}8\ kg/m^3$
- Gravity, $g = 9{,}81\ m/det^2$

2.4. Calculation of Dimension

2.4.1. Basic calculations

To design a water turbine at a particular location, it takes minimal head location and water discharge data, and then do the basic calculation with the following formula:

a. Power, N

$$N = [Q \text{ x } H \text{ x } \acute{\eta}_t \text{ x } \rho)/75]\ (HP) \tag{2}$$

b. Specific turbine rotation by Q, n_q

$$n_q = \frac{n\sqrt{Q}}{H^{3/4}} \text{ (rpm)}, \tag{3}$$

Σ valve = 28 pieces ; $n = 214\ rpm.$

c. Specific turbine rotation by N, n_s

$$n_s = \frac{n\sqrt{N}}{H^{5/4}}\ (rpm) \tag{4}$$

Design calculation and design analysis;

d. Velocity of water burst

$$C_1 = k\,(2.g.H)^{1/2}\ (m/s)\ ;\ k = 0{,}98 \tag{5}$$

e. Velocity of turbine wheel

$$U_1 = \tfrac{1}{2}.\, C_1.\, Cos\ \alpha_1\ (m/s)\ ;\ \alpha_1 = 12{,}6^{O} \tag{6}$$

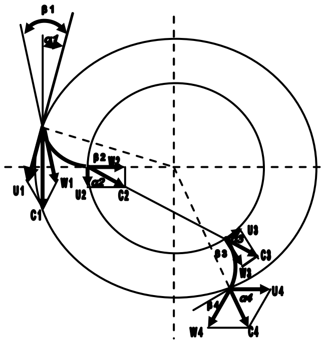

Figure-5. Speed triangle on inteke water burst

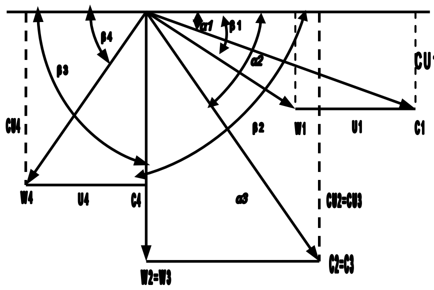

Figure-6. Triangle of rotatiaon speed

f. Relative angle of stage I

$\tan \beta_1 = 2 \tan \alpha_1.$ (7)

g. Maximum turbine efficiency

$\eta_t = \text{Cos}^2\, \alpha_1 \ (\%)$ (8)

h. Outside diameter of wheel

$$D_1 = \frac{60.U_1}{\pi.n} \quad (9)$$

i. Comparing factor of blades wheel

$$X = \left[\frac{1-2D_3 Cos\beta_1}{D_1}\right]^{1/2} \ ; \ D_3 = 0{,}326.\ D_1 \quad (10)$$

j. Diameter of inner turbine wheel

$D_2 = X.\ D_1$ (*mm*) (11)

Diameter of inner turbine wheel by another calculation:

Jika, $a = 0{,}17\ D_1$, Maka $D_2 = D_1 - 2.a$ (*mm*)

k. Absotule angle of water flow output

$$\alpha_2 = \text{arc.tan.} \frac{(2\tan\alpha_1)}{X_2} \ ; \ \alpha_2 = \alpha_3 \ ; \ \alpha_4 = 90^0 \quad (12)$$

l. Relative velocity into lavel-1 blades

$$W_1 = \frac{U_1}{Cos\beta_1} \ (m/s) \quad (13)$$

m. Velocity of water out

$$U_2 = \frac{\pi.D_2.n}{60} \ (m/s) \quad (14)$$

n. Relative velocity of water out from blades

$W_2 = U_2 \tan \ \alpha_2$ (m/s)

o. Absolute velocity of water from blades

$$C_2 = \frac{W_2}{Sin\alpha_2} \ (m/s) \quad (15)$$

when, $C_2 = C_3$; $W_2 = W_3$; $U_2 = U_3$; $U_4 = U_1$; $W_4 = W_1$

p. Absolute velocity of water out from wheel baldes

$C_4 = W_1$ Sin β_1 (*m/s*) (16)

Geometry of balade from inside:

q. Central radius of the blade curvature

$$R = \left(R_2^2 + R_3^2\right)^{1/2} \text{ (mm)} \tag{17}$$

r. Central angle of the blades radius

$$\delta = \text{arc.Sin } \frac{R_3}{R} \tag{18}$$

$$\delta_1 = \text{arc.Cos } \left[\frac{R_1^2 + R - R_3^2}{2.R_1.R}\right]$$

$$\delta_2 = \delta. - \delta_1$$

s. Length of bowstring (AB)

$$\text{AB} = \sqrt{\left[R_2^2 + R_1^2 - 2.R_2.R_1.Cos\delta_2\right]} \quad (mm). \tag{19}$$

t. Angle of blades curvature

$$\theta = \text{arc.Cos } \left[\frac{2.R_3^2 - AB}{2R_3^2}\right] \tag{20}$$

u. Jari-jari pusat titik berat sudu

$$\varepsilon + \tfrac{1}{2}\theta. = 180^0 - \beta_1 - \delta_1 \tag{21}$$

$$R_4^2 = R^2 + R_3^2 - 2.R.R_3.Cos.\varepsilon$$

Geometry of blades from outside

v. Length of C, (*mm*) (22)

$$C = \sqrt{\left(R_1^2 + R_2^2 - 2R_1R_2COS(\beta_1 + \beta_2)\right)}$$

w. Value of **ε** : (23)

$$\varepsilon = \arcsin\left\{\frac{R_2 \sin\left(\beta_1 + \beta_2\right)}{c}\right\}$$

x. Value of **ζ** :

$$\zeta = 180^o - (\beta_1 + \beta_2 + \varepsilon) \tag{24}$$

y. Value of φ :

$$\varphi = \beta_1 + \beta_2 - (180^o - 2\zeta) \tag{25}$$

z. Value of *d (mm):*

$$d = \left\{\frac{R_2 \sin\left(\beta_1 + \beta_2\right)}{2\sin\left(180 - \zeta\right)}\right\} \tag{26}$$

aa. Angle of blades curvatutre:

$$\delta = 180^o - (\beta_1 + \varepsilon) \tag{27}$$

bb. Radius of blades curvature, *rb (mm)*

$$rb = \left\{ \frac{d}{\cos(\beta_1 - \varepsilon)} \right\} \tag{29}$$

cc. Radius of blades curvature centre, *rp (mm)*

$$rp = \sqrt{\left(rb^2 + R_1^2 - 2.rb.R_1 \cos\beta_1\right)} \tag{30}$$

=148.2017073

dd. Thickness of baldes:

$$T = R_3 - rp \tag{31}$$

$= 6.32\ mm \approx 6.6\ (mm)$

bb. Average curvature angle:

$$\gamma = (\theta + \delta)/2 \tag{32}$$

ff. Number of blades

$$\theta^0 = \frac{360}{Z} \Rightarrow 26 \text{ pieces} \tag{33}$$

gg. Distance between the bales

$$\delta_0 = \frac{\pi.D_1}{Z} \tag{34}$$

δ_0 = 48,30769231 (mm).

Number of contacted blades

$$Z = \frac{85}{360}.26;\ \text{transmit angle } 85^{O}. \tag{35}$$

Z = 6,138 ≈ 6 pieces

hh. The shape of transmit pipe

The radius need to calculation every 5^0 dari $\phi = 0^0$ s/d 90^0.

a. $K = \tan \alpha_1$

b. Chenge to angle value, $\phi = 360 = 2\pi$

c. $\gamma_0 = e^{\tan \alpha_1 (\theta) \text{rad.}}$

d. $R_0 = \gamma_0 . R_1$

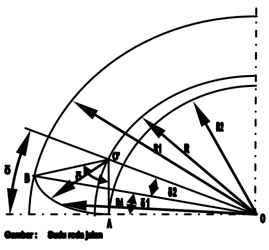

Figure-7. Wheel blades.

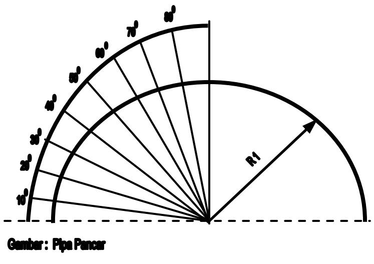

Figure-8. Transmit pipe

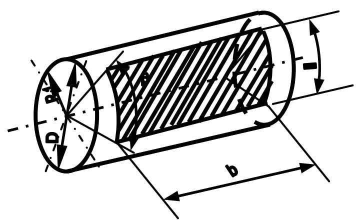

Figure-9. Wheel

ii. Angle of turbine transmit

Based on simulation, $\theta = 85^0$ R_0 = 278,67 mm.

jj. Wide of transmit pipe, *s*

$$s = \frac{D1}{k}; \quad k = 0{,}075 - 0{,}3 \tag{36}$$

kk. Wide of wheel (b)

$$L = \frac{\beta}{360}.\pi.D_1 \ mm \tag{37}$$

$$b = \frac{\varphi}{L.C_1.Sin\alpha_1} \quad mm$$

ll. The relationship between theoretical efficiency, power and torque moment to the turbine

a. $$\eta_t = \frac{4\left(\varphi_1 C_1 Cos\alpha_1 - \varphi_1^2\right)}{C_1^2} \tag{38}$$

b. $$P = \rho.\varphi\left[2U_1 C_1 Cos.\alpha_1 - 2\right]U_1^2 \tag{39}$$

c. $$T = \frac{60.P}{2.\pi.n} \tag{40}$$

d. $$U_1 = \frac{\pi.D_1.n_{put}}{60} \tag{41}$$

Calculation and Design Results

3.1. Data of Calculation Result

Based on the design result of the main dimension of Turbine Type Cross-Flow-Vanes, the following data are obtained as design data:

- Head, H = 2 (m)
- Water discharge, Q = 0.2 (m3 / s)
- Turbine rotation (plan), n = 214 (rpm)

With reference to review the literature and survey results data, it can be calculated and designed water turbine type propeler vanes, with the results as presented in table-2.

Table-2. Result of turbine design Calculation

Item	Satuan	Hasil
Power	*HP*	3.626666667
Torsi	*kg.mm*	12313.78741
Nq	*rpm*	56.9057661
Ns	*rpm*	678.7415189
V water (2.g.h)^1/2	*m/s*	6.264183905
Area	*m2*	0.031927543
D canal	*mm*	201.6730748
D turbine shaft	*mm*	35
Shaft weight, *w*	*kg*	1.851797485
Twist angler	^{O}*/meter*	6.41522E-07
n critical	*rpm*	20013.99326

3.2. The design of turbines

Based on table-2, the turbine design is shown as shown in figures 7 to 10.

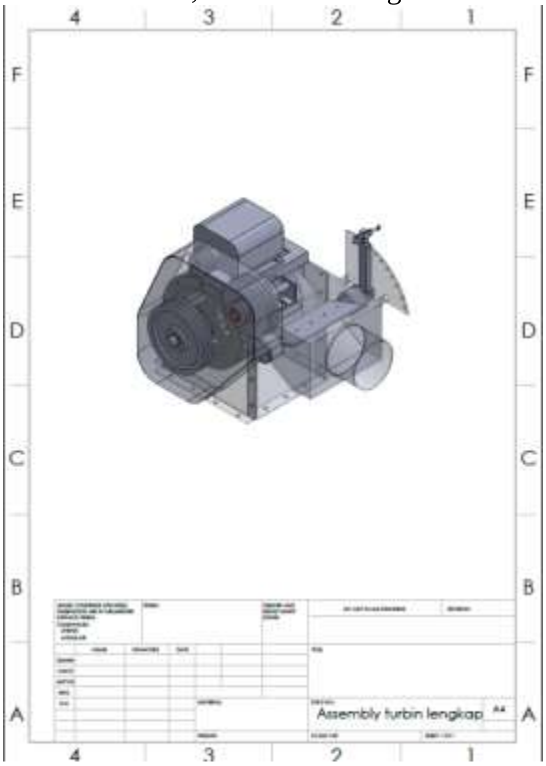

Figure-10. 2.7 kW Cross-Flow Turbine

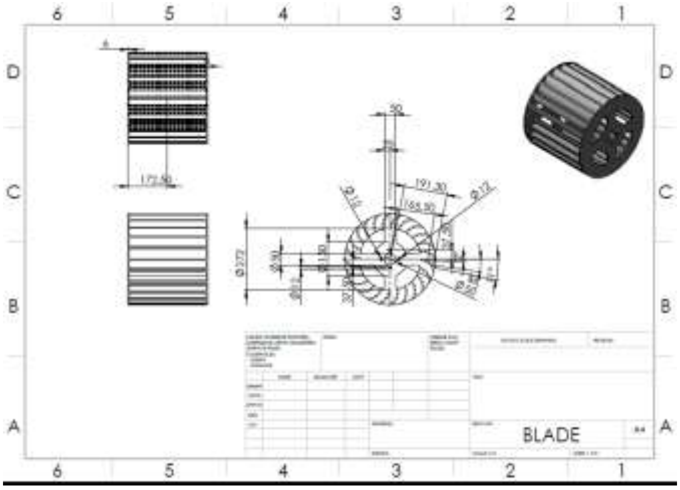

Figure-11. The Blades

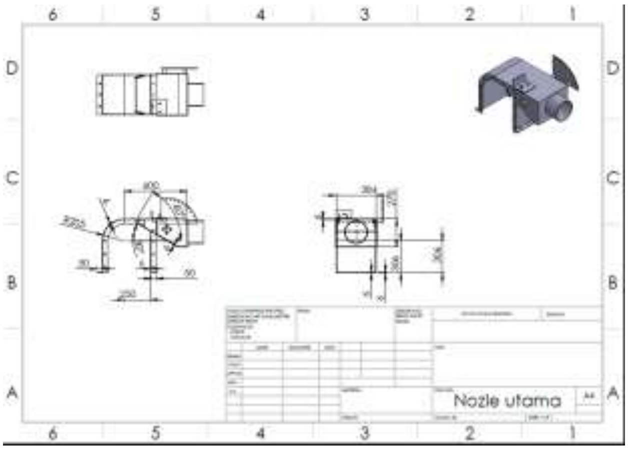

Figure-12. The Nozle

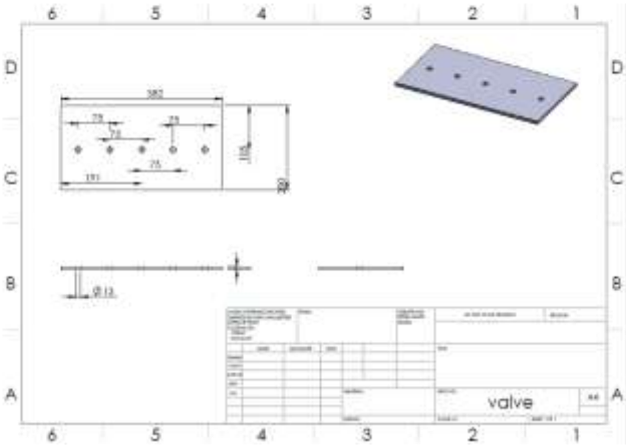

Figure-13. Valve Module

Conclusions

Based on the calculation results, the turbine specification is designed as follows:
- Type = Cross-Flow vertical axis
- High of water fall, *H* = 2 (m)
- Water discharge, *Q* = 0.2 (m3 / s)
- Turbine efficiency, ηt = 68%
- Mass of water type, ρ = 997.8 (kg / m ')
- Power, *N* = 3.6 HP = 2.685 (kW)
- Rotation speed, *n* = 214 (rpm)
- Specific speed, *ns* = 678,74 (rpm)
- The outer diameter of the wheel blade, *Dl* = 0.400 (m)
- Naaf diameter, *Dn* = 0.040 (m)
- The width of the guide blade, *B* = 0.32 m
- Number of blades = 26 pieces

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