Design of microhidro turbine for electricity plants based on techno park in cimanggu village

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Abstract. The utilization of water as a natural resource of renewable energy for power plant is one of the alternative solutions to replace the need for fossil fuels.In Cimanggu village, there is a river that has a waterfall, which can be used to generate electricity. But the waterfall is currently used as a village tour. From observations and the calculation speed of the flow by using buoys, and river cross-sectional area obtained the total river debit Q more than 0.07 m3 / s. From the measurements is also obtained high fall the waterfall H = 22 m. Based on the existing height and debit of the water fall the major dimensions of a water turbine Pelton Micro Hydro type as the driving power generator was planned. The results of calculations for effective head = 18 m, with a water debit that is used to drive the runners Q = 0.07 m3/s, gained power generated by 7,0 kW. By the data is planned the main dimensions of micro turbine, Pelton outer runner diameter D = 250 mm, the diameter of the circle pin D_L = 346 mm, number of blades z = 12 with 2 nozzles, and a shaft diameter ds =30 mm. In planning this turbine, water is only directed to radiate to one side in order to replace the function of the waterfall. Because water is directed to one side, the shaft will experience an axial force (which is parallel to the shaft).

1. Introduction

Electrical energy is a mutual need of human life in all aspects, due to the reason various methods are used to explore the use of various alternative energy, one of them is natural water resources that can be used as a source of energy for electricity generation. In Cimanggu village, there is a waterfall that can be used to generate electricity which has been misused as a vacation spot.

Most of waterfall area could be used as scale power plants (micro-hydro), but there is no support from the local government, because it is more profitable to develop the waterfall area to be a tourism destination than building a power plant.

The design of turbine-based on techno park is created to to replace the function of the waterfall. The construction of the micro water turbine is able to produce electrical energy which can be used to increase tourist destination.

2. Theoretical Basis

2.1 Understanding Turbine

Turbine is a driving machine which is the fluid is used directly to turn the turbine wheel. Water turbines mean the water is a working fluid.
Classification of Water Turbines.
Water turbines can be classified based on several things, including:
1.   Based on work principles

    a. Action Turbine (Impulse)
    b. Turbine Reaction
2. By Head and debit
3. Based on Flow Direction
4. Based on specific speed

2.2 Pelton Turbine

Pelton turbines are included in the group of impulse turbines. The general characteristic is the entry as a flow of water into the runner at atmospheric pressure.

Micro-pelton turbines has capacity smaller than common pelton turbines. Micro shows the size of generating capacity which is between 5 kW to 50 kW.

Main components of Pelton Turbine:

1. Turbine House.

The turbine house besides being a place where the turbine is installed also functions to capture and bend the splash of water flow out of the bowl so that both the runner and the beam are not disturbed

2. *Runner*

Pelton turbine runners basically consist of chakras and a number of blade (bowls) mounted around it. The circumference velocity of the runner can be calculated by the equation:*(Eisenring. M,1994)*

$$u_1 = k_u (2.g.H_e)^{\frac{1}{2}} \quad \text{m/s}$$

Where:

u_1 = optimal circumference speed (m/s) g = Gravity acceleration (m/s^2)
k_u = coefficient 0.45- 0.49   He = High fall effective (m)

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

$$\textbf{Do} = \textbf{D} + \textbf{1.2 h (m)}$$

$$D = \frac{60.u_1.i}{\pi.n_G}$$

Where:

Do = Outer diameter of runner (m) i = Round comparison number
D = Stab circle diameter (m) n_G = Movable engine rotation (rpm)
h = Blade height (m)

3. Nozzle

The nozzle consists of a nose-like sheath that is mounted on a pipe, and the needle nozzle is usually moved in a needle cone bend and a wear-free sheath.

Absolute speed can be calculated by equation*(Eisenring.M, 1994)* :

$$c_1 = k_c \sqrt{2.g.H_e}$$

Where :

c_1 = absolute jet speed (m/s) g = gravitational acceleration m/s^2
k_c= nozzle coefficient (0,96-0,98) He= Effective head (m)

4. Blade

Fig. 1 Planned Blade

Pelton turbine blades are mounted to the rotor with a positive connection. It is done by giving the form of dovetail on the bowl handle.

Optimal jet diameter can be calculated by the equation:

$$d = \sqrt{\frac{4.Q}{\pi.c_1}}$$

dimensions can be calculated by the following equations:

Bowl width: $b = (2,5 \sim 3,2)\,d)$ Bowl opening width: $a = 1,2 \cdot d$

Bowl height: $h = (2,1 \sim 2,7)\,d$

Where:

d = optimal jet diameter (m) c_1 = absolute jet speed (m/s)

Q = water discharge (m³/s) z = optimal number of blade

5. Shaft

The shaft is one of the most important parts of each machine. If the correction factor is fc, the plan power Pd (kW) as a benchmark is:

$Pd = fc \cdot P$

Table of the power correction factors that will Transmitted (fc).

Power transmitted	f_c
Average power needed	1,0 –2,0
Maximum power required	0,8-1,2
Normal power	1,0-1,5

If the twisting moment is called the plan moment, T (kg.mm), then the torsional moment of the plan is determined by the equation *(Sularso dan Suga, 1997)* :

$$P_d = \frac{\left(\frac{T}{1000}\right) \times \left(2.\pi \frac{n_1}{60}\right)}{102}$$

So that

$$T = 9,74.10^5 . \frac{P_d}{n_1}$$

So to calculate the shaft diameter can use the equation*(Sularsodan Suga, 1997)* :

$$d_p = \sqrt[3]{\frac{16 \times T}{\pi \cdot \bar{\tau}}} \text{Where} \bar{\tau} = \frac{\tau}{S_{f1} S_{f2}}$$

Angled corner

$$\theta = 584 \frac{T \cdot l}{G \cdot d_s^4}$$

l= Shaft length   G = Shear modulus

6. Bearing

To reduce friction loss, rolling bearings have been chosen in this plan that can withstand radial and axial forces. The choice of bearing is determined based on the axial force that occurs.

7. Electric Generator

Electric generator functions to convert mechanical energy to turn shaft into electrical energy. PLTMH uses a 3 phase alternating current generator.

8. Rapid Pipeline Calculation.

Head effective can calculation

$He = H - H_f$.

H = difference in height of water source with turbine

H_f = Head loss in the pipeline is fast

$$V = \frac{4 \cdot Q}{\pi \cdot d^2}$$

Where :

H_f= Total head loss in the rapid pipeline (m)   g = gravitational acceleration (m/s^2)

V = the speed of water in a rapid pipeline (m/s)

Q = Discharge of water in the rapid pipeline (m^3/s)

d = Inner daimeter in the rapid pipeline (m)

In pipe selection can be determined the estimated price of pipe roughness in the interior using the Moody diagram according to the pipe age plan.

From there, the price of k / d can be obtained so that using the Moody diagram the value f can be obtained.

$$H_f = f \cdot \frac{L}{d} \cdot \frac{V^2}{2g}$$

L= Horizontal distance from the source to the turbine house (m)

H_f = pressure losses on pipes and auxiliary materials

2.3 Design of Pelton Turbine

Pelton turbines are one type of water turbine which is suitable for watersheds that have a high head. Pelton turbines are one of the most efficient types of water turbines. The shape of the turbine blade consists of two symmetrical parts. Blades are formed so that the jet of water will hit the middle of the blade and the jet will turn both directions so that it can reverse the jet of water well and free the blade from the side forces so that kinetic energy is converted

into mechanical energy, *but in this design turbine, water is only directed to radiate to one side in order to develop water fountain to replace the function of the waterfall.* Because water is directed to one side, the shaft will experience an axial force (which is parallel to the shaft). The amount of axial force that occurs depends on the flow capacity of the water and the magnitude of the outflow angle of the blade:

$$Trust = \mathbf{P} = \mathbf{\dot{m}} \times \mathbf{V}$$

$\mathbf{\dot{m}}$ = *flow capacity (kg/det)*   V = *flow speed (m/det)*
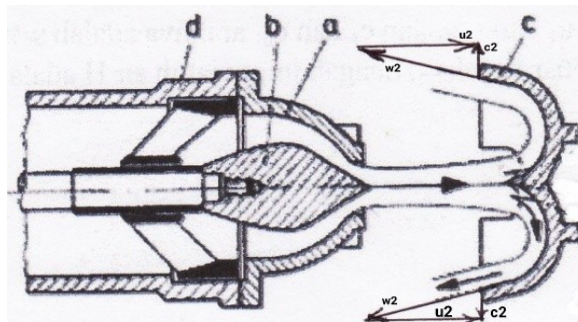

Figure 2. Common blade shapes (Fritz Dietzel 1980)
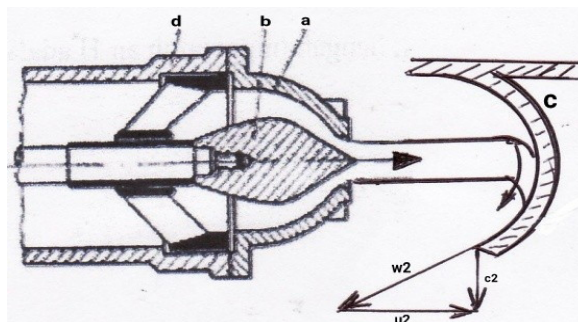

Figure 3. The planned form of Blade

*Description from the picture:

  a = nozzle   c = blade
  b = nozzle needle   d = pipeline

*For Speed Triangle Description:

  c_2 = called absolute speed, because the surrounding area is still stationary, except the vessel through which the flow moves with speed u

  w =   called relative speed, because it deals with the inside of the moving vessel

  u =   called the tangential speed of the turbine wheel

    To get good efficiency, in the Pelton turbine there must be a relationship between the traveling speed (u_1), and the exit speed (c_1). To analyze the flow through the motion of a curved propeller it is necessary to draw a velocity triangle.

    In planning Pelton turbines there are several things that must be considered, including the specific speed equation:

$$n_q = \frac{n\sqrt{Q}}{H^{\frac{3}{4}}}$$

Where:

  n_q = Specific Speed (rpm)   Pt = Turbine Power (HP)

n   = Rotation from turbine (rpm)   H = Water Drop Height (m)

For water discharge, i.e.:

$$Q = \frac{volume\ of\ water}{time}$$

Where:

Q   = Water discharge (m^3/s)

V   = volume of water (m^3)

t   = time (detik)

Where do we assume to the value of β_2 withsee the speed triangle produces a formula:

$$v_2 = u_2 - w_2 \cos \beta_2$$

Where :

   V_{u2}=tangential speed (m/s) W_2 = relative speed (m/s)
   U_2 = around speed (m/s) $\cos \beta_2$= outler corner blade (^{o})

Then to power the turbine using equations:

$$P_T = \rho . g . h . Q . \eta_T$$

Where :

   P_T = Turbine power   g = gravity (m/det^2)
   Q = water discharge (m^3/s)   h = falling height / head (m)
   η_T= Turbine efficiency   ρ = Density of water = 1000 kg/m^3

$$u = \frac{\pi . D . n}{60}$$

Where:

   u = around speedfrom turbine(m/s)   n = rotation from turbine (rpm)
   D = Turbine diameter (m)

Height of water source (H)

The water source height (H) can be measured using a tool (theodolite)

3. Research Methods

3.1   Data design

   From the results of surveys in the field, the following data are obtained:

1. Based on the measurements made by the author (measurements carried out in the dry season), the following results were obtained:

- Flow Speed Data (V) = 0,6 m/s
- Area of a River Cross (A) = 1,5 m^2

2. High waterfall H = 22m

   So the total water discharge that can be used in planning this Pelton microhidro turbine is at H = 22 m with Q = 0.07 m^3 / s (the determination of Q is an agreement with The village apparatus).
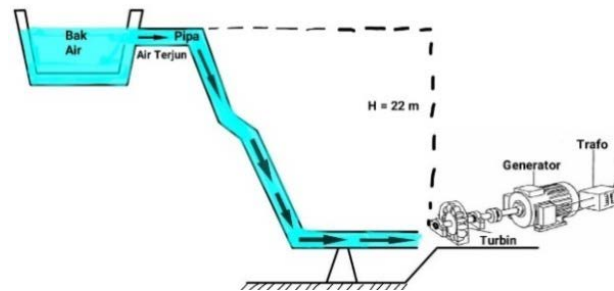
Figure 4. Design Scheme

3.2 Calculation of Head Loss in Rapid Pipes.

In rapid pipeline calculations, the discharge used to rotate the turbine is determined at 0.07 m³/s. The length of the pipe is obtained by measuring the field as follows:

Straight pipe   : 48 m

Rapid pipeline material was chosen from PVC, with a nominal diameter of 160 mm, the friction factor was searched using Moody's diagram:

Get value f = 0,018.

In the pipeline, the supporting materials are used as follows: :
1. Elbow 90°2 pieces,
2. Gate Valve 2 pieces
3. Reducer 2 pieces
4. Tee 1 pieces

If all auxiliary materials are considered the same as a straight pipe of 2 m each, then the equivalent length of all auxiliary materials is equal to 14 m, so the total length of the pipe is fast becoming 48 m + 14 m = 62 m.

The speed of water in the pipe is rapid:

$$V = \frac{4.Q}{\pi.d^2} = \frac{4 \times 0,07 \frac{m^3}{s}}{3,14 \times (0,016m)^2} = 3,98 \text{ m/s}$$

Then the head loss on the pipe is fast:

$$H_f = f . \frac{L}{d} . \frac{V^2}{2g}$$

$$H_f = 0,018 . \frac{62m}{0,16} . \frac{(3,5m)^2}{2 \times 9,81 \frac{m}{det^2}} = 4,0 \text{ m.}$$

Then the total head on the turbine: He = 22 m- 4 m = 18 m.

Estimated power generated by the turbine:

$$P_T = \rho . g . h . Q . \eta_T$$

If turbine efficiency = 60 %,

So :

$$P_T = 1000 \frac{kg}{m^3} \times 9,81 \frac{m}{s^2} \times 18m \times 0,07 \frac{m^3}{s} \times 0,6$$

P_T = 7,0 kW.

Water speed out the nozzle (c) :

$$c_1 = k_c \sqrt{2 . g . H_e}$$

Taken $k_c = 0,97$, so:

$$c_1 = 0,97 \times \sqrt{2 \times 9,81 \frac{m}{s^2} 18m}$$

$$c_1 = 18,5 \text{ m/sec}$$

Nozzle diameter:

In order to obtain a balance in turbine construction, 2 nozzles are used, so that the Q for one nozzle is 0, 04 m³/sec

$$A = \frac{Q}{V} = \frac{0,035 \frac{m^3}{sec}}{18,5 \frac{m}{sec}} = 0,002174 m^2$$

$$d = \frac{4 \times 0,002174 m^2}{3,14} = 0,05m$$

Nozzle hole diameter (d) = 50 mm.

Speed around the pelton wheel (u_1)

$$u_1 = k_u (2.g.H_e)^{\frac{1}{2}} \quad \text{m/s}$$

$$u_1 = 0,48\sqrt{2 \times 9,81 \times 18,5}$$

$$= 9,1 \text{ m/det.}$$

Stab circle diameter (Dt)

$$D_t = \frac{60 \times u_1 \times i}{\pi \times n_G} = \frac{60 \times 9,1 \frac{m}{s} \times 2}{3,14 \times 1450} = 0,25 \, m = 250 \, mm.$$

Outside diameter (D_L)

$$D_L = D_t + 1,2h = 250 \, mm + 1,2.80mm = 346 \, mm.$$

Shaft Calculation

Because the turbine uses 2 pieces of nozzle, so the wheel is relatively stable, so that the shaft can be calculated to only with stand twisting loads.

$$T = W_p \times \sigma_g$$

Power planned (Pd) taken 1,2.

$$T = 1,2 \times 9,74 \times 10^5 \frac{7,0 \, (kW)}{725} \, kg \, mm$$

$T = 12.091 \, kg \, mm.$

The shaft material used which is with shear stress 60 kg/mm², then the shear stress is permitted:

$$\bar{\tau} = \frac{\tau}{S_{f1} S_{f2}} \quad \text{, if} \quad S_{f1} = 6 \text{ and } S_{f2} = 2$$

$$\bar{\tau}_g = \frac{60 \frac{kg}{mm}}{6.2} = 5,0 \frac{kg}{mm^2}$$

$$d_p = \sqrt[3]{\frac{16 \times 12.091 \; kg \; mm}{3,14 \times 5 \frac{kg}{mm^2}}} = \sqrt[3]{12.322} = 23,9 \; mm$$

Because the shaft is reduced by the keyway, the shaft diameter is made 30 mm.
The twisting angle that occurs:

$$\theta = 584 \frac{T.l}{G.d_s^4}$$

L = 25 mm   ds = 30 mm
T = 12,091 kg mm $G = 8,3. \; 10^3 \; (kg/mm^2)$

$$\theta = 584 \frac{12,091 \; x \; 25}{8,3 x 10^3 x 30^4} = 0,065^o$$

Selection of Bearings
To reduce the power lost due to friction, the bearings used are rolling bearings.
From fig. 3.2, it can be seen that the water velocity out of the turbine is as follows:
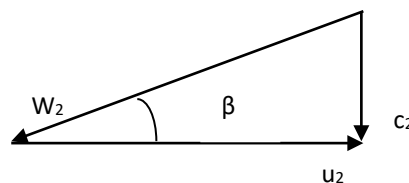

Figure 5. Velocity triangle

The greater the angle taken then the axial force that occurs will be greater and the speed of the water emitting out of the turbine will be even greater, but the power of the turbine will be smaller.

By taking an angle= 30°, so:

tan30° = c_2/u_2. c_2= 9, 25 m/sec. x 0, 577 = 5, 34 m/sec

Then the axial force acting on the shaft (trust) :

$P_A = \dot{m}. V$ = 70 kg/det. 5, 34 m/sec = 373 N
    = 38 kg.

Because the axial force acting is relatively small, the sliding bearing is chosen: 6006 ZZ.

4. Result and Discussion
4.1 Data Processing Results
   From the calculation results it is known that the Pelton turbine is suitable for designing Micro Hydro electric generator drive turbines because it works at low compressive height. This can be seen in the calculation data as follows:
a. Turbine
- The actual power produced by the turbine, P = 7,0 kW
- Actual jet speed, c_1= 18,5 m/s   - Number of bowls, z = 12 buah
- Stab circle diameter, D = 202 mm   - Jet diameter, d = 50 mm
- Blade (bowl) width, b = 177 mm   - Blade (bowl) height, h = 149 mm
- Outer diameter of runner, D_0 = 380,8 mm

b.Shaft

- Shaft diameter, d_s=25 mm   - Twisting Deflection, = 0,02
- Bearings used.
  The selected bearings are rolling bearings that can withstand axial forces.
- Same as shaft diameter, d_s=30 mm

4.2.   Discussion

In this plan, a water discharge is used to rotate the turbine as big as 0,07 m^3/s, with effective head 18,0 m, the power generated by the turbine is may be obtained 7,0 kW, where total efficiency is 60% based on the range of application of Pelton micro turbines.

5. Conclusions and Recommendations
5.1 Conclusion

Based on the result of research and calculations it can be concluded :

1.   A Pelton Micro Hydro type water turbine can be designed to be used as a driver for a power plant in the village of Cimanggu. Produced from Turbine design
   - The actual power produced by the turbine, P = 7,0 kW
   - Actual jet speed, c_1 = 15,03 m/s
   - Stab circle diameter, D = 202 mm
   - Jet diameter, d = 71 mm
   - Number of bowls, z = 19 buah
   - Bowl width, b = 177 mm
   - Bowl height, h = 149 mm
   - Outer diameter of runner, D_0 = 380,8 mm
2.   The construction of micro hydro turbines will be carried out in the village of Cimanggu.

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