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Design of Micro Hydro Power Plant in Girimulyo Village

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ABSTRACT

The purpose of this research is to design a micro-hydro power plant in Girimulyo Village, Ngargoyoso District as an alternative solution to replace the need for fossil fuels, the team tries to take advantage of field observations and calculations using the GPS (Global Positioning System) application with a water discharge Q = 0.2 m^3/s. and waterfall height H = 16.5 m. Based on the existing water level and flow, the turbine used is the Pelton turbine. From the calculation of the effective head of 15.81 m. With the discharge of water used to rotate the Pelton turbine, a test was carried out and a power of 20,162 kW was obtained. From this power, it can be calculated that the shaft diameter is 38 mm. To facilitate the setting of rotation between the generator and the Pelton turbine rotation, a flat belt type transmission belt is used with a width of 300 mm and a thickness of 9 mm while the maximum tension of the belt is 39 kg with a tangent angle between the pulley and the belt of 7.18^0.

Keywords: Micro Hydro, Power Plant, Pelton Turbine

INTRODUCTION

Girimulyo village, Ngargoyoso sub-district, there is a river that has the potential for micro-hydro power generation [1]. On the river, there is a dam where the flow of water from upstream to the dam is used for rafting tourism facilities so that the use of micro hydropower plants is in the flow after the dam [2].

Micro hydro is a small-scale hydroelectric power plant with a capacity limit of 5 kW-1 MW per unit. The basic requirements for a small-scale hydroelectric power plant are the presence of flowing water and a height difference. Micro-hydro turbines for rivers and irrigation channels can already be produced in Indonesia [3].

The design of a micro-hydro power plant in the village of Girimulya has the aim of generating electricity as well as a water tourism destination as well as educating the public about the use of water energy [4]. So that the village of Girimulyo has more varied tourism.

Based on the surveys and observations made, the flow of water from the river can be utilized by directing water to a reservoir with a channel width of 1,2 meters, a water thickness of 22 centimeters, flow rate Q = 0,385 m^3/s. From the measurements, it was also found that the waterfall falls H = 16,5 m[5]. Based on the height and flow of water that falls into the main dimensions of the Pelton Micro Hydro type water turbine as a propulsion power plant, it has been planned [6]. The results of the calculation for the effective head = 15,81 meters, with water flow Q = 0.385 m^3/sec, the power generated is 20,162 kW [7]. In designing the turbine, the water is only directed to one side, so the shaft will experience an axial force that is parallel to the shaft. Then the shaft will be connected or installed with the runner by using a peg as a lock[8]. The rotation on the shaft will be transmitted through a belt to the pulley on the generator to continue the rotation produced by the turbine [9]. The planning and design of a power plant in Girimulyo village, Karanganyar district is based on research with surveys and direct observations in Girimulyo village, Central Java [10][11].

RESEARCH METHOD

The design stage of making a micro-hydro power plant using a Pelton turbine can be seen in Figure 1.

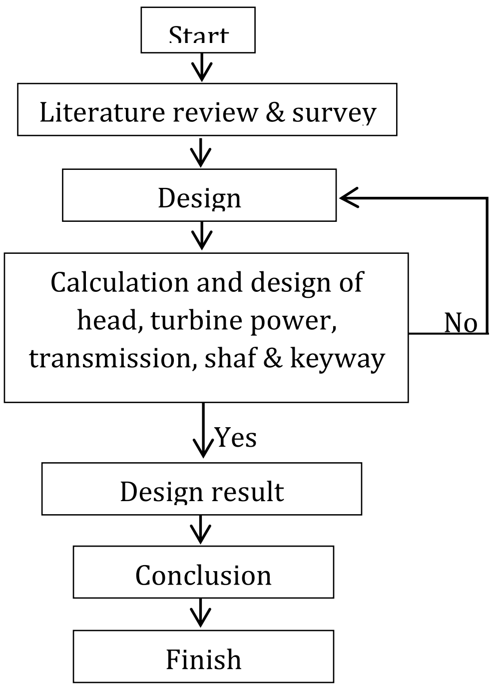

Figure 1. Research flowchart

Retrieval of discharge data along with flow height or head to determine the potential power generated by the river is by direct measurement on the river accompanied by the local village [12]. From the measurements, the river water level h = 0,22 meters, and the river width is 1,2 meters [13]. The difference in the height of the waterfall is obtained using the Global Positioning System application and the data for the difference in altitude is 16,5 meters [14].

The design of this Micro hydro Power Plant, it is necessary to install a generator that utilizes flow through channels and reservoirs [15]. The initial data obtained in the field measurements for the design are shown in table 1. The initial data, some supporting materials for the design can be seen in table 2.

Table 1. Survey preliminary data

Initial Data	Number
River width	1,2 m
River water level	0,22 m
Tube lenght	4 m
Tube width	4 m
Tube height	3 m
Debit	0,20 m^3/s
Head	16,5 m

Table 2. Auxiliary materials

Auxiliary materials	Number
Elbow 90°	1 pcs
Elbow 45°	2 pcs
Gate valve	1 pcs
Reducer	2 pcs
Tee	1 pcs
Straight pipe	63 m

RESULT AND DISCUSSION

The initial data obtained and the specified auxiliary materials, the design of the MHP can be carried out as follows:

Turbin Power Design

To find out the turbine power can be obtained by following the formula $P_{turbine} = \rho \times g \times H_{total} \times Q \times \eta_T$ [16] and the turbine efficiency is known as 50-80 %, so that the selected turbine efficiency is 65%[17]. The selected pipe material is PVC with a diameter of 160 mm, and the friction factor is based on the moody diagram f = 0,015 [18]. The discharge used based on calculations in the field is 0,20 m³/sec[19]. So the diameter of the pipe is $D = \sqrt{\frac{4 \times Q}{\pi}} = \sqrt{\frac{4 \times 0{,}2}{3{,}14}} = 0{,}5$ m [20]. By obtaining diameter of the pipe, it can be calculated the head loss in the rapid pipe $H_{fp} = f \times \frac{L}{d} \times \frac{V^2}{2 \times g} = 0{,}015 \times \frac{63\ m}{0{,}5\ m} \times \frac{(2\ m/s)^2}{2 \times 9{,}81\ m/s^2} = 0{,}3$ m [21]. The head loss on the valve is $H_{fv} = k \times \frac{V^2}{2 \times g} \times 1\ pcs = 0{,}05$ m. The head loss at the 90^0 elbow is $H_{fe1} = k \times \frac{V^2}{2 \times g} \times 1\ pcs = 0{,}18$ m, and head loss at elbow 45^0 is $H_{fe2} = k \times \frac{V^2}{2 \times g} \times 2\ pcs = 0{,}16$ m. So the total head is $(H_{tot}) = H - (H_{fp} + H_{fv} + H_{fe1} + H_{fe2}) = 15{,}81$ m. With the total head obtained, the turbine power is $P_{turbin} = \rho \times g \times H_{total} \times Q \times \eta_T = 20{,}16$ kW.

Nozzle Design

A nozzle is a tool used to increase the speed of water out of the nozzle[15]. The velocity of the water leaving the nozzle is $V_N = \sqrt{2 \times g \times H_{Tot}} = 17{,}61$ m/s [22], while the tangential velocity of the nozzle is $\frac{V_T - V_n}{2} = 8{,}80$ m/s [23]. In the nozzle inlet area, the designed area is $A_1 = \frac{\pi}{4} \times d^2 = 0{,}196\ m^2$, while the nozzle outlet area is $V_1 \times A_1 = V_2 \times A_2$ or $A_2 = (V_1 \times A_1)/V_2 = 0{,}022\ m^2$. So that the nozzle area is $A = \frac{\pi}{4} \times {d_2}^2 = 0{,}111\ m^2$, where the number of nozzles planned is 2 with a nozzle diameter ${d_2}^2 = (4 \times A)/\pi = 118$ mm.

Impeller Wheel Diameter

The impeller wheel functions to convert or convert the energy from the flow into rotation on the turbine shaft. The planned rotation is 750 Rpm, then the impeller wheel diameter uses the formula $V = \pi \times D \times n$ [24] then $D = V/(\pi \times n) = 448$ mm.

Transmission System Diameter

In the design of this Micro hydro Power Plant, the transmission used is an indirect transmission by increasing the rotation using pulleys. Calculating the size of the pulley can be seen in the following equation $\frac{N_1}{N_2} = i = \frac{D_p}{d_p} = \frac{1}{u}; u = \frac{1}{2}$ [9]. The diameter of the small pulley is determined to be 250 mm, and the diameter of the large pulley is $\frac{D_p}{d_p} = i =$ 500 mm, then turbine rotation N_2 is $N_2 = N_1 \times \frac{2}{1} = 1500$ rpm.

Flat Belt Calculation

In this design, the type of belt designed is a flat belt. By knowing the diameter of the small pulley and large pulley and the distance between the pulleys is determined to be 1000 mm, the length of the belt can be calculated based on the following equation $L = \pi(r_1 + r_2) + 2x + \frac{(r_1+r_2)^2}{x} = 3.224{,}37$ mm.

The contact angle of the small pulley is determined by the equation $\theta = (180 - 2\alpha)\frac{\pi}{180}$, and the tension on the tight side or the part of the belt under tension is 2 mPa. The skin density value is 980 kg/m^3 and the coefficient of friction between the belt and pulley is 0,35. The pulley angle is calculated according to the following equation $\sin\alpha = \frac{r1 - r2}{x} = 7{,}18$ while the angle of the small pulley is $\theta = (180 - 2\alpha)\frac{\pi}{180} = 2{,}8$ rad.

The speed of the flat belt or flat belt needs to be considered considering the safety factor that must be ensured, for the ideal speed is a speed that is still below or less than 10 meters per second, so the belt speed is calculated based on the equation $V = \frac{\pi \times d \times n}{60} = 9{,}81 \frac{m}{s}$ (declared safe).

A flat belt is a type of belt that has a large area when compared to other belt types, so the area of the flat belt is $a = b \times t = 2700\ mm^2$. While the maximum tension on the tight belt side or the tension on the tight side is $T = \sigma \times a = 5400$ N. the mass of the belt is $m = \text{area} \times \text{lenght} \times \text{density} = 8{,}52\ \text{kg/mm}^2$.

Calculation of centrifugal pull based on the mass of the flat belt that has previously been obtained, against the speed of the belt, then the centrifugal pull is $T_C = m \times V^2 = 793{,}89$ N. While the tension on the high belt side is $T_1 = T - T_C = 376{,}11$ N and the pull on the slack belt side can be calculated as follows $2{,}3 \log\left(\frac{T_1}{T_2}\right) = \mu \times \theta = 0{,}35 \times 2{,}8 = 0{,}98$ or $\log\left(\frac{T_1}{T_2}\right) = \frac{0{,}98}{2{,}3} = 0{,}426$ and the value of $\frac{T_1}{T_2}$ so the value of T_2 is $T_2 = \frac{T_1}{2{,}66} = 393{,}27$ N.

The power to be transmitted by the belt comes from the power generated by a turbine, so the belt can transmit power greater than the capacity of the power generated by a turbine. The power of the flat belt is $P = (T_1 - T_2) \times V = 22{,}688$ kiloWatts or 30,425 HP.

Shaft design

The shaft is used to transmit power and rotation, therefore the shaft must have a large enough strength, it is important to determine the material of the shaft. In this design the selected material is S40C carbon steel which has a tensile strength of $\sigma_B = 55\ \text{kg/mm}^2$ and a factor value of $S_{f1} = 6{,}0$; $S_{f2} = 2{,}0$ as well as with normal heat treatment. The correction factor used in planning is 1,2 so that the planned power will be greater than the power that has been obtained through previous calculations[25]. To determine the planning power based on the correction factor is $P_d = P \times f_{cl} = 20{,}162 \times 1{,}2 = 24{,}194$ kW or 32,44 HP.

The torsional moment acting on the shaft causes a change in rotary motion which increases the speed or vice versa. The torsional moment on the shaft is $T = 9{,}74 \times 10^5 \times \frac{P_d}{n_2} = 15.709{,}97$ kg mm. The shear stress caused by the force acting on the surface of the object is $\tau_\alpha = \frac{\sigma_B}{S_{f1} \times S_{f2}} = \frac{55}{6 \times 2} = 4{,}58\ \frac{kg}{mm^2}$ or 0,0458 kg/cm^2 < of allowable stress (55 kg/mm^2) then declared safe[26]. In calculating the diameter of the shaft requires a correction factor with a torsional moment correction factor K_t = 1,5 and a bending factor C_b = 2, then the diameter of the shaft is $d_s = (\frac{5{,}1}{\tau_\alpha} \times K_t \times C_b \times T)^{\frac{1}{3}} = 37{,}43$ mm, so that the diameter of the shaft selected is 38 mm, the diameter at the bearing position is 42 mm with a fillet radius (42 – 38)/2 = 2 mm, and the keyway is 10 × 8 × 0,6 and the fillet is 0,4 (0,4>JIS). By obtaining the shear stress on the surface and the diameter of the shaft, the stress on the shaft is $\tau = \frac{5{,}1 \times T}{ds^3} = 1{,}71\ \frac{kg}{mm^2}$. To determine the size designed above has met the requirements, it is necessary to check the value where $\left(\frac{\tau_a \times S_{f2}}{a}\right) > \tau \times C_b \times K_t$ or 3,27 kg/mm^2 < 5.13 kg/mm^2 (calculation of shaft diameter is eligible)[23].

Keyway Design

Keyway as retaining elements in the form of pulleys, gear sprockets, shafts, and others. In this design the keyway used are S35C material which has a tensile strength of $\sigma_B = 52\ \text{kg/mm}^2$ with a safety factor of $\text{Sfk}_1 = 6$ and $\text{Sfk}_2 = 2{,}25$ so the shear stress in the keyway is $\tau_{ka} = \frac{\sigma_B}{\text{Sfk}_1 \times \text{Sfk}_2} = 3{,}85\ \text{kg/mm}^2$ [9]. Based on these calculations, the allowable shear stress is $\tau_{ka} = 3{,}85\ \text{kg/mm}^2$ < from the allowable stress $52\ \text{kg/mm}^2$ (then it is declared safe). By obtaining the allowable shear stress, the value of l_1 can be calculated by $\tau_k = \frac{F}{10 \times l_1} = \frac{826{,}84}{10 \times l_1} \leqq 3{,}85\ \frac{\text{kg}}{\text{mm}^2}$, then $l_1 \geqq 21{,}4$ mm where $\tau_{sa} = 3{,}85\text{kg/mm2}$.

On the shaft diameter between 30-38 mm nominal size of the key $b \times h = 10 \times 8$, the depth of the keyway on the shaft t_1 = 5 mm, the depth of the keyway on the nave t_2 = 3,3 mm, and the length of the key = 22,5 x d_s= 32,5 mm [27]. The tangential force acting on the keyway is $F = \frac{T}{d_s/2} = 826{,}84$ kg. The shear stress in the post is $\tau_k = \frac{F}{b \times l} = 3{,}32\ \frac{\text{kg}}{\text{mm}^2}$ < of allowable shear stress 3,85 kg/mm^2 (declared safe). The allowable stress on the post surface is 11 kg/mm^2, then l_2 is $P = \frac{F}{l \times (t_1 \text{ atau } t_2)}$ or $= \frac{826{,}84}{l_2 \times (3{,}3)} \leqq 11{,}0$ then $l_2 = \frac{826{,}84}{11 \times (3{,}3)} = 22{,}5$.

CONCLUSION

Based on the planning and discussion of the design process of the Micro-hydro Power Generation Unit in Girimulyo village, Karanganyar district, it is concluded that the water discharge is 0,2 m^3/second and the effective head that can be converted to energy is 15,81 meters, can generate power of 20,162 kW or 27 HP (horsepower), assuming 65% efficiency.

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