Design of Bamboo Splitting Machine Using Chain Drive

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ABSTRACT

In the rural community, bamboo splitting activities were done by using traditional tools called sickle that exposed the operators to harmful damages. This study was deal with the utilization of modern technology related to the field of forest tree processing machinery, particularly a bamboo splitting machine. The project was to design and analyze of bamboo splitting machines used for the construction of small houses, traditional house equipment, and fences in the rural and urban areas of Ethiopia. Different data collection techniques (tools) were used, to understand the current problems of bamboo splitting activities and the need for this machine. The design feature was considering the geometrical components, operating power identification and determination, and stress, forces, and deformation analysis of each part. Pro-Engineer software was used for part details and assembly drawing. Materials were selected based on availability, cost, functionality, and durability. The splitter machine was functioning intermittent feeding through a chain drive comprising a motor, a tool rest, a cutter-head, and blades or cutting die, whereby a guide rail is arranged on the side of the tailstock. According to the new design and development, the bamboo splitting machine can perform splitting bamboo culm up to 2.5 m in length and 120 mm in diameter with different strap sizes. The new machine is better efficient than the existing one that avoids tediousness, reduces operation time and avoids the irregular surface of bamboo.

Keywords: Bamboo, Splitting Machine, Traditional house, Fence, Timber.

1. INTRODUCTION

The local manufacturing industry exploits industrial products and indigenous processing of natural resources like timber for many development activities. Timber is a natural resource harvested to meet society's demand for different purposes [1], [2]. Bamboo is a naturally occurring composite material that grows abundantly in most tropical countries. It is considered a composite material because it consists of cellulose fibers embedded in a lignin matrix [3]. Cellulose fibers are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction [4]. The way bamboo grows and its wide distribution throughout the world makes it an important natural resource and it has properties of fast growth and rejuvenation after cutting, which means it can provide a harvestable yield every 2-3 years once maturity is reached. Ethiopia has the greatest bamboo resources in Africa representing a significant proportion of Africa's total bamboo resources. Ethiopia has more than 1 million hectares of bamboo which is 67% of African bamboo resources and more than 7% of the world's total area covered by bamboo is found in Ethiopia. Ethiopia has two bamboo species namely, Yushania alpine(highland bamboo) and Oxytenantheriaabyssinica lowland bamboo [5]-[7]. However, unlike other countries, the development and utilization of bamboo in Ethiopia is fundamentally rudimentary, and its socio-economic and ecological potentials are not yet realized [8].

Fig. 1(a) Ethiopian highland bamboo (Y. alpine, Amhara, Awi-zone, injibara)

Fig.1(b) Highland bamboo (Yushania alpine) in awuro

Bamboo is becoming increasingly important in the world since: (i) it is a superior wood substitute; (ii) it is cheap, efficient, and fast-growing; (iii) high potential for environmental protection and it has wide ecological adaptation [5].

Bamboo products currently have very enormous demand. It can be used at all levels of industrial activity from small craft-based industries to modern highly integrated plants [9]. Some handicraft products are shown in Figure 2 below.

Fig. 2 Some handmade products of bamboo

This article is mainly focused on convenient or expediential processing of bamboo culm for the intended application and looks for the socio-economic contribution of bamboo splitter machines across the major bamboo-growing zone in Ethiopia.

2. MATERIALS AND METHODS

The selection of proper material, for engineering purposes, is one of the most difficult challenges for the designer. The best material is one that serves the desired objective at the minimum cost. Some factors should be considered while selecting the material such as local availability of the materials, Suitability of the materials for the working conditions in service, good machinability and having good heat treatment properties, having appropriate strength for the intended task, and the cost of the materials. Meanwhile, Numerous factors to be considered while in the designing stage of the bamboo splitter machine as points of design consideration such as establishing the mechanisms for the cutter (splitting) and movement of tailstock, design specifications and assumptions including vibration, determining and allocating the space provided for the system, selection of motor that can provide the required power and speed, Safety of profession, speed of cutter, maximum column height, etc.

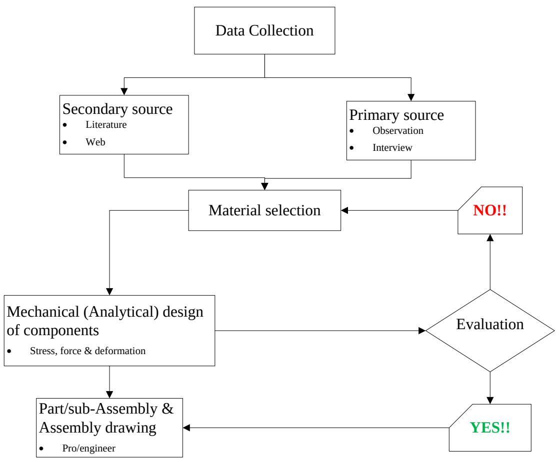

Fig.3 Design process's flow chart for bamboo splitting machine

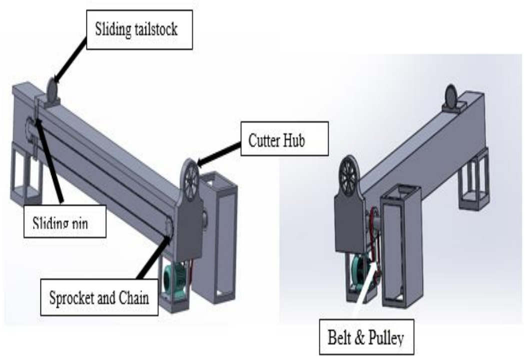

Fig.4 3D-Modeling for bamboo splitter machine

3. DESIGN ANALYSIS

3.1 Selection Input of Power Source

An electrical motor is used to convert electrical power to mechanical power for providing rotational movement. The working speed of the cutting tool would be 0.2 m/s so; we select the power motor in the following step [14]. Maximum stress developed on bamboo (σ max) =23.80Mpa [10],[11].

The cross-sectional area of bamboo can be calculated as:

$$\text{Area } (A) = \frac{\pi(D^2-d^2)}{4} = 2976 \text{ mm}^2 = 0.002976 \text{ m}^2$$

Where 'D' is the maximum outer diameter = 120 mm and 'd' is the maximum inner diameter of bamboo and it will = 103 mm.

From the maximum stress equation, the working (pushing) force can be calculated as:

$$F = \sigma \text{ x } A = 70.83 \text{ kN}$$

The minimum capacity of the motor would be determined by:

$$P = F \text{ x } V = 14.16 \text{ KW} \cong 14 \text{ kW}$$

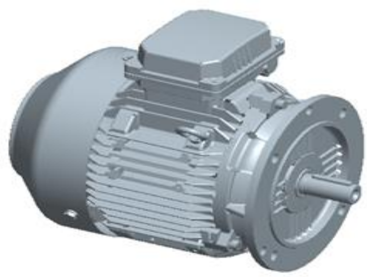

Fig.5 Three-phase AC motor of capacity 208-230V

Table 1. Design parameter of AC motor

Power Source	Motor Power	Input Speed	Speed of Cutting Tool
AC Motor	14kW	1400 RPM	0.2 m/s

3.2 Shaft Design

Shaft design consists primarily of the determination of the correct shaft diameter that will ensure satisfactory rigidity and enough strength when the shaft is subjected to a certain load during the transmitting of motion under operating and loading conditions. The selected material used for power transmission shafts was carbon steel SAE 1040 with the ultimate tensile strength of 621 MPa, yield strength of 414 MPa, Modulus of elasticity of 270 MPa, and density of 7680 Kg/m^3. It gives the highest overall satisfaction with high carbon content and can harden by heat treatment.

Table 2. Property of shaft material

Material Type	Yield Strength (MPa)	Modulus of Elasticity (MPa)	Density (Kg/M^3)	Ultimate Tensile Strength (MPa)
SAE 1040	414	270	7680	621

The shaft is exposed to bending stress due to tensioning effect by the chain and sprocket and also it is subjected to torsional stress during the rotating of the feeder chain. Therefore the minimum diameter of the shaft would be determined by using the maximum shear stress theory. The maximum shear stress theory is used to determine the minimum diameter of the shaft and calculated as [12]:

$$\text{Allowable shear stress} = \frac{\text{yeald strength of strengthed material}}{\text{factor of safty}} = \frac{414}{4}$$

$$= 103.5 \text{ N/mm2} = 103.5 \times 10^6 \text{ N/m}^2$$

$$D = \sqrt[3]{\frac{16}{\pi * \tau}\left(\sqrt{M^2 + T^2}\right)}$$

Where, D is the minimum diameter of the shaft, M is the bending moment, τ is shear stress and T is the torsional moment (torque). Since the shaft is subjected to both twisting and bending moments, torque will be calculated as

$$T = \frac{60 * p}{2\pi N} = 32{,}000 \text{ N} - \text{mm}$$

$$= 32 \times 10^6 \text{ N-m}$$

Where, P is input power from the motor (4400 N) and N is the speed of the motor (1400 rpm)

From the bending moment calculation, the maximum bending moment is M = 736 x 103 N-mm

= 75.808 N-m

$\tau_{Allowable}$ (with keyway) = 0.57 x 103.5

=51.75 N/mm^2

And, $$D = \sqrt[3]{\frac{16}{\pi * 51.75}\left(\sqrt{736000^2 + 32000^2}\right)}$$

= 41.70 mm = 0.0471 m

However, the shaft is affected by shock and fatigue load so consider fatigue and shock factor (km= 1.7) and kt = 1.6. Then using maximum shear stress criteria, the diameter of the shaft can be calculated using the equivalent bending moment criteria equation[13]:

$$M_e = \frac{1}{2}(Km * M + \sqrt{+(Km * M)^2 + (Kt * T)^2}$$

= 1251723.5 N-mm

= 1251.7235 N-m

The allowable tensile stress (σ) can be determined by using:

$$\sigma = \frac{\text{Tensile strength of selected material}}{\text{Factor of safety}}$$

Taking factor of safety is 3.

$$\sigma = \frac{\text{Tensile strength of selected material}}{\text{Factor of safety}}$$

$$= 207 \text{ MPa}$$

The equivalent bending moment also can be calculated by the equation:

$$M_e = \frac{\pi}{32} * \delta * D^3$$

Therefore, D = 39.49 mm ≅ 40 mm = 0.04 m

Note: from the above two cases, it should select the shear stress failure criteria. Therefore the minimum design diameter of the shaft is 41.70 mm however there is no standard shaft with this design value so the next minimum standard shaft diameter would be taken as the minimum diameter of shaft d = 50 mm.

Since, the selected material is SAE 1040 having a modulus of rigidity, (G) equals 79.3 Gpa. Therefore, twist angle (θ) is determined as:

$$\theta = \frac{TL}{GJ}$$

Where, J = polar moment of inertia of the cross-sectional area about the axis of rotation and it is calculated as

$$J = \frac{\pi * d^4}{32} = 613.281 \times 103 \text{ mm}^2 = 0.0631 \text{ m}^2$$

L is the length of shaft = 600 mm, the twist angle (θ) is : $\theta = \frac{TL}{GJ} = 0.003^0$

$\theta = 0.003^0$, since the twist angle is less than one degree, the design of the shaft is safe from being twisted.

3.3 Design of Pulley

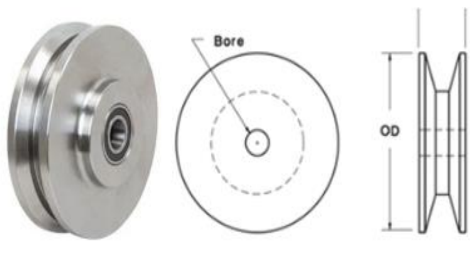

Fig.6 Taper-lock V-belt pulleys

The pulleys are used to transmit power from one shaft to another through flat belts, V-belts, or ropes. The pulleys are made of good materials that should have good friction and wear resistance characteristics.

Any material or surfaces that have below 40-48 HRC will wear as the belt or rope moves across it. So the materials used for the pulley should be in the range of the stated hardness value. However, it is very hard to be the machine in a conventional machining system and will not be cost-effective. The best solution is to choose low-carbon steel and heat treat the pulley up to the required value [14].

To determine the pulley parameters the following initial values:

Input power = 4kW

Diameter of smaller pulley (D_1) = 75 mm= 0.075 m

Speed smaller pulley (N_1) = 1400 RPM

Then, Diameter of larger pulley (D_2)

And, Speed of larger pulleys (N_2) can be determined and is shown below.

Assuming the output speed should not exceed 350 rpm. Therefore the speed reduction of 1:4, Velocity ratio: 1:4

To find the speed and diameter of the larger pulley as follow;

$$V_R = \frac{N1}{N2} = \frac{D2}{D1}$$

$$N_2 = \frac{N1}{VR} = \frac{1400}{4} = 350 \text{ RPM}$$

$$\frac{N1}{N2} = \frac{D2}{D1};$$

$$D2 = \frac{1400 \text{ X } 75}{350} = 300 \text{ mm} = 0.3 \text{ m}$$

The peripheral speed of the pulley is given by;

$$V_1 = \frac{\pi D1 \text{ X } N1}{60} = \frac{\pi \text{ X } 0.075 \text{ X } 1400}{60} = 5.5 \text{ m/s}$$

$$V_2 = \frac{\pi D2 \text{ X } N2}{60} = \frac{\pi \text{ X } 0.3 \text{ X } 350}{60} = 5.5 \text{ m/s}$$

Where, V_1 and V_2 are the peripheral speed of the driving (smaller) and driven (larger) pulley respectively.

The center distance of the two pulleys is between D_2 and $2(D_2 + D_1)$, $300 < X < 750$. Let's take the center distance of the two pulleys C = 600 mm.

The angle of contact of pulleys is determined as follows:

$$\text{Sin } \alpha = \frac{D2-D1}{2C} = \frac{300-75}{2(600)} = 0.1875;$$

Therefore, $\alpha = 10.8^o$

(a)Angle of contact for smaller pulley is calculated as

$$\theta_1 = 180^0 - 2\alpha$$
$$= 180 - 2(10.8) = 158.8^o$$

(b)Angle of contact for larger pulley is calculated as

$$\theta_2 = 360^o - \theta_1$$
$$= 360^o - 158.8^0 = 201.2^0$$

(c)Width of pulley:

Width (face thickness) of the pulley (B) is taken as 1.25 times the face with of the belt.

B = 1.25V (face thickness of belt)

Where, face thickness of belt (b) = 22 mm = 0.022 m

Therefore, B = 1.25(22) = 27.5 mm = 0.0275 m

(d) Diameter of Hub:

The diameter of hub (d_h) can be calculated as:

$d_h = 1.5d + 25$ mm,

where, d is diameter of shaft.

Therefore, d_h = 1.5(50) + 25 = 100 mm = 0.1 m

3.4 Design of Cutter (Splitting Die)

Cutter blade or splitting die is one of the most important and essential elements for the bamboo splitting machine that makes a crack and propagate the loge. The number of blades would be designed as per the required shape and thickness of stripe. The splitting die exposed for bending force and fatigue stress due to pushing and rubbing with the bamboo loge. Therefore the selection of proper materials that can serves for the desired objective is depending on those failure criteria and it allows heat treatment process. Hence the material for the cutter blade is Steel (Normalized) with AISI 1080 with yield strength 345mpasteel is selected. The blades have a triangular sharp edge at the cutting edge and it was made with the dimension of (60×40×3) mm [15].

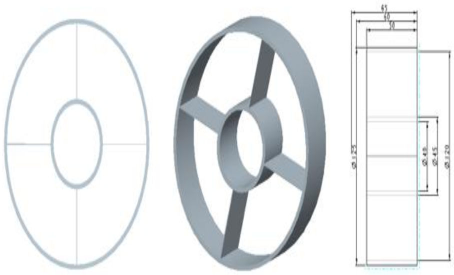

Fig.7 Four jaw cutting blade

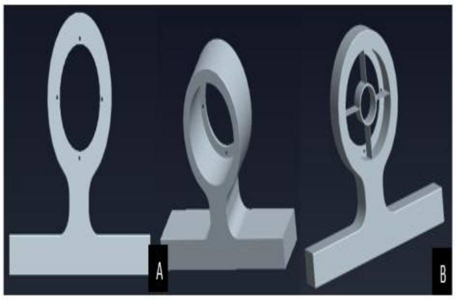

Fig.8(a) Cutter housing (hub) (b) sub-assembly for cutter hub with cutter blade (Die)

Splitting Force Calculations:

The splitting force is the maximum force in which the tailstock (pusher) is pressed into the splitting material (bamboo). Therefore it can be calculated as follows [16] :

- Maximum splitting strength of bamboo = 23.08 MPa
- Area of contact (A) = Blade contact length X blade thickness X number of blade
- The thickness of blade at the contact point is 1/3 of blade thickness, Bt = (1/3) x 3 = 1mm = 0.001 m
- For this particular design we have 4 blades.
- The maximum external diameter of bamboo is as assumption up to 120 mm and from the filed measurement (3 tests), it was an average value of 20 mm thickness. Hence d_2 = 80 mm. Now, blade contact length is BL = 40 mm

Area of contact (A) = 40 x 1 x 4

= 160 mm^2 = 0.00016 m^2

Therefore, required splitting force can be calculated as: F (Splitting force) = σ x A

= 23.08 N/mm^2 x 160 mm^2

= 3692.8 N = 3.6928 kN

3.5 Design of Belt

The belt is used to transmit power from the input shaft to the output shaft through pulleys which rotate at the given speed. The amount of power transmitted was depended upon many factors such as the velocity of the belt, the tension under which the belt is placed on the pulleys, the arc of contact between the belt and the smaller pulley, the conditions under which the belt is used are some of a few[13]. Light drives types of v-belt were used for bamboo splitter machine because it is used to transmit small powers with the belt speeds up to about 10 m/s, especially for agricultural machines and small machine tools. In most cases, belts are generally selected by the designer from the manufacturer's catalog however the following input data is required for the selection of belt:

(i)Power to be transmitted (ii) Transmission ratio (iii)Center distance

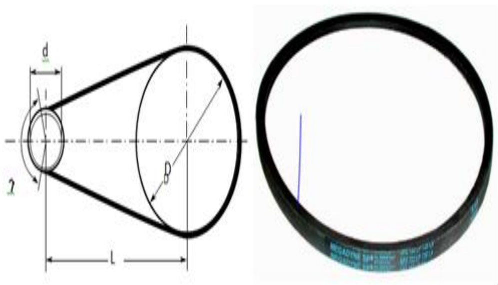

Fig.9 Taper lock V-belt

$$\mathrm{Lv, belt} = 2c + \frac{(D+d)^2}{2} + \frac{(D-d)^2}{4C}$$

$$\mathrm{Lv, belt} = 2(600) + \frac{(300+75)^2}{2} + \frac{(300-75)^2}{4(600)}$$

= 1.362 m

Where, L is the length of the belt, C center distance between two pulleys, D diameter of the larger pulley d is the diameter of the smaller pulley.

The Speed of the belt (V_b) can be determined as,

$$V_b = (1-s)V;\ \ (1-S)\frac{\pi D1\ X\ N1}{60}$$

Where, V is the speed of a smaller pulley, S represents the percentage of slippage which is 2% from standard.

$$V_b = (1-0.02)\frac{\pi\ x\ 0.075\ X\ 1400}{60} = 5.38\ \ m/s$$

Coefficient of friction (μ) of the pulley also calculated as follow;

$$\mu = 0.54 - \frac{42.6}{152.6+V}$$; where V is the speed of belt

Therefore, $\mu = 0.54 - \frac{42.6}{152.6+5.38} = 0.27$

From catalogue table, rubber material and C-type v-belt is selected with a thickness of (t) = 14 mm = 0.014 m and width (b) = 22 mm and groove angle 2β = 34^0.

3.6 Design of chain and Sprocket

Chain drive is recognized to be one of the most effective forms of power transmission in mechanical systems. It is generally suitable for transmission at a slower speed due to its multilateral action and interlocking impact [17].

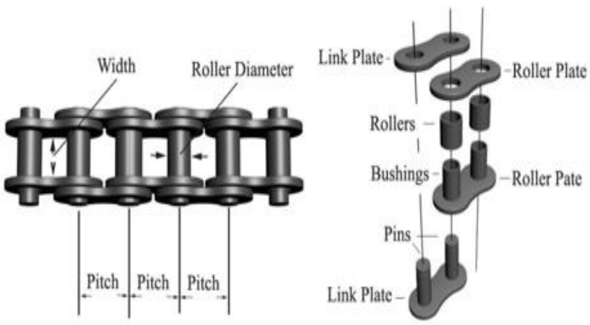

Fig.10 Roller chain link (Source:http://gearseds.com/documentation/deb%20holmes/2.5_Chain_drive_systems.pdf)

The chain system generally consists of a driver and driven sprocket and a long chain. The driver sprocket is directly mounted to the output shaft and the driven sprocket is connected to the driven shaft that has been linked with the tip of the tailstock via a connecting pin. high-grade gray cast iron is the most common and economical material for making sprockets. The following chain parameters are has being calculated during the designing of the roller chain.

3.7 Chain Pitch

The size of the chain is based on its pitch. The center distance between the consecutive two-link pin defines the pitch size.

The dimensions of roller chains and sprockets are governed by American National Standards Institute ANSI. According to ANSI, the dimension of chain components such as length, height, and width of chain parts is depend on chain pitch. The table 3 shows ANSI standard dimension for the # 630 chain.

Where, P = Pitch ; W=Width; ;

∅r = Roller Dia; LPT = Link Plate Thickness ;

Hp= Link Plate Height ;

The ratio between driver and driven sprocket is one-to-one, therefore the length of the chain can be calculated as[18]:

$$\text{Chain length (L)} = 2(\text{Center distance} + \text{arc contact of driven sprocket})$$

$$\text{Arc contact } (\theta) = \frac{\pi}{2} - 2\alpha,\quad 2\alpha = 0,$$

Therefore, arc of contact $(\theta) = \frac{\pi}{2}$

The total length of the chain (L) is:

$\text{Chain length (L)} = 2(2500\ \text{mm} + \frac{\pi}{2}) =$ 5003.14 mm

= 5.00314 m

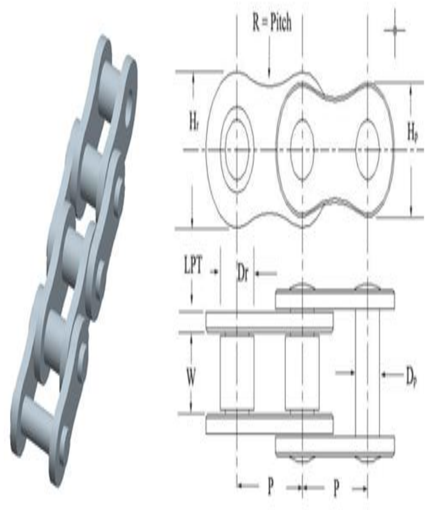

Fig.10 Chain link dimensions

(Source:http://gearseds.com/documentation/deb%20holmes/2.5_Chain_drive_systems.pdf)

Table 3. Standard dimension for chain number #630 (all dimensions are in mm)

Chain Type	Motor Power	Overall Width	Roller Dia.	Link Plate Thickness	Link Plate Height	Sprocket Thickness
#630	19.05	9.525	11.9	18.0975	15.621	8.7122

3.8 Calculating Sprocket Parameters

The sprocket Pitch Diameter can be calculated as follow [19],[20]: $PD = \frac{P}{\text{Sin}\frac{180}{N}}$

Where, P_D is Pitch Diameter, P is chain Pitch in mm and N is the number of teeth on the sprocket

$$PD = \frac{19.05}{\text{Sin}\frac{180}{30}} = \frac{19.05}{\text{Sin}(6)} = 68.2 \text{ mm}$$

3.8.1 Sprocket Ratio

The sprocket ratio is defined as the number of teeth on the driving sprocket divided by the number of teeth on the driven sprocket. However, in this case, the number of teeth on the driving sprocket is equal to the number of teeth on the driven sprocket [20].

$$\text{Sprocket ratio} = \frac{N1}{N2}, 1:1$$

3.8.2 Outside Sprocket Diameters (OD)

To accurately calculate the clearances for a given chain and sprocket drive, it is necessary to determine the outside diameters of the sprockets. This dimension can be approximated using the following formula [15]:

$$D = OP(0.6 + \text{Cot}(\frac{180}{N}))$$

$$= 19.05(0.6 + \text{Cot}(\frac{180}{30}) = 76.88 \text{ mm}$$

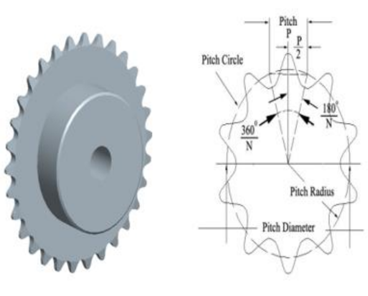

Fig.11 Machine able-bore sprockets for roller chain

4. DESIGN SUMMARY

Table 4. Specification of proposed splitting machine

S. No	Part	Design Parameter	Design Value
1	Motor	Motor type Motor power Input speed Working speed	AC Motor P = 4kW V_{input}= 1400 rpm $V_{working}$ = 0.2 m/s
2	Shaft	Minimum diameter Shaft length Twisting angle	D =0.05 m L = 6 m θ = 0.003°
3	Pulley	diameter of larger pulley Speed of larger pulley Groove depth Overall width Pitch diameter	D = 0.3m N_2 = 350 RPM G_d = 0.0175 m W = 0.045 m P_d = 0.28 m
4	belt	Belt length Belt thickness Belt width Speed of the belt Coefficient of friction (μ) of pulley	L = 1.362 m t= 0.014 m W = 0.022 m (V_b) = 5.38 m/s μ = 0.27
5	Chain	Chain type Chain length Pitch Width Roller dia. Link Plate Thickness Link Plate Height	Roller chain L = 500314 m P = 0.01905m W = 0.009525 m ∅r = 0.0119 m LPT=0.018075 m Hp = 0.015621 m
6	Sprocket	Number of Teeth Pitch diameter Outer diameter	T = 30 P_D = 0.0682 m D_o = 0.07688 m

The actual force is the force exerted by the 'motor and its assembly' on the bamboo. It will be the centrifugal force exerted by the motor shaft and can be calculated from the relation F_{cf} = mass x Velocity ^{2}/radius. And, all the force cannot be transferred onto bamboo. There will be a little unused force called friction. It can be considered as the future work.

5. CONCLUSION

The present work deals principally with the designing or theoretical aspects of bamboo log splitter machines that have a significant contribution to the development of wood industries work from manual and small craft-based activities to modern integrated plants. The endowment of the splitter is to eliminate harmful risks to the operator during the splitting of bamboo and give long surface time with a little maintenance (regrinding of cutter). The splitter machine is working with a simple mechanism**.** The machine is portable, cost and time effective, sustainable, feasible, enables reduced labor workers, is interesting ergonomically, and constructed from locally available materials. The designed splitter machine is the safest and most comfortable for a working environment with minimum vibration.

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