EXPERIMENTAL & DIMENSIONAL ANALYSIS APPROACH FOR DESIGN OF HUMAN POWERED BAMBOO SLIVER CUTTING MACHINE

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Abstract

This paper presents the experimental approach towards formulation of an approximate generalized experimental data based model for cutting the slivers from bamboo energized by human powered flywheel motor (HPFM). Developing countries like India are facing problems of power shortage due to rapid industrialization coupled with limitations on additional power generation and non-availability of power in the interior area. In this context the sources of energy is human power operated systems which are considered to be one of the form of non-conventional energy sources. In this aspect, this paper aims at developing dimensional analysis approach along with test points and test envelopes for different variables involved in the design of bamboo sliver cutting machine using HPFM..

Index Terms: *Bamboo, Bamboo Slivers, Processing Machine, Flywheel, HPFM.*

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1. INTRODUCTION

Bamboo is especially been integral part of the cultural, social and economic traditions of many societies. Main characteristic features, which make bamboo as a potential building material, are its high tensile strength and very good weight to strength ratio. It can withstand up to 3656 Kg/cm^2 of pressure. The strength-weight ratio of bamboo also supports its use as a highly resilient material against forces created by high velocity winds and earthquakes. Above all bamboo is renewable raw material resource from agro-forestry and if properly treated and industrially processed, components made by bamboo can have a reasonable life of 30 to 40 years. Construction techniques using bamboo as main material have been found very suitable for earthquake resistant housing. [1]

The sliver cutting operations includes feeding of split bamboo through the push-in rollers which will come out and pass through push-out rollers and will strike the sliver cutter which cuts the internal knot from the split bamboo in the first pass. After internal knot cutting, the slivers are cut in the next passes by positioning the cutter in downward direction with the help of adjusting knobs. The machine consists of human powered flywheel motor as an energy source. The HPFM comprises of subsystems like human powered process unit, appropriate clutch and transmission and a process unit. Energy unit consists of bicycle-drive mechanism with speed increasing gearing, appropriate clutch transmission and a flywheel. The operator pumps energy to the flywheel at a convenient input power level. After enough energy is stored, pedaling is stopped and the energy in the flywheel is made available to the process unit by engaging the clutch. The brick making machine using HPFM is successfully in operation which gives need of HPFM, establishments of experimental generalized data based models and generation of design data for torsionally flexible clutches [2, 3]. The human energized chaff cutter is designed and fabricated in the Ph. D. research by principle of HPFM [4].

2. AIMS, OBJECTIVES & SCOPE

The traditional methods of making slivers by the rural people are taking much more time than that of making articles from them which are shown in figure 1.Therefore proposed machine is very useful in rural areas since bamboo articles have very high demand in rural market. Hence they can start their own business of making bamboo articles by purchasing this machine. As it is operated by human powered flywheel, it does not require electric power.

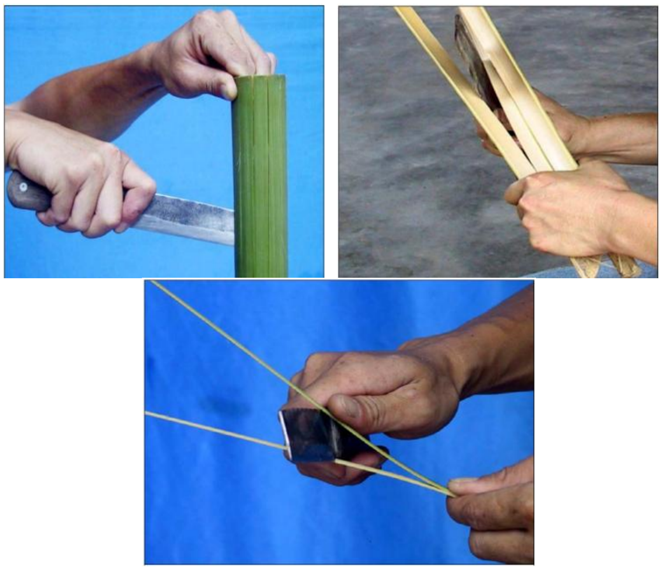

Fig- 1: Traditional Methods of making slivers from bamboo

The unit operating by means of electricity has limited applications in the rural area. In remote and interior places where there is no facility of electricity as well as in urban areas, while in the duration of load shading or during electrical power-off timings, this type of human power operated unit will have very extensive utility. Therefore this human powered machine is having extensive utility in such areas. The work of formulating experimental model using HPFM for cranking arrangement of cycle rickshaw is done [5] and the comprehensive bamboo processing machine is developed working on electric motor [6]. This work is especially for sliver cutting not by electricity but using HPFM. It is obvious that one will have to decide what should be the minimum processing torque and cutting force required and energy to be supplied to the system for getting appropriate sizes of processed bamboo in minimum time. By knowing this, one can establish bamboo machining properties. This would be possible if one can have a quantitative relationship amongst various dependent and independent variables of the system. This relationship would be known as the mathematical model of this bamboo sliver cutting operation. It is well known that such a model for the bamboo processing cannot be formulated applying logic. The only option with which one is left is to formulate an experimental data based model. Hence in this investigation, it is decided to formulate such experimental data based model. In this approach all the independent variable are varied over a widest possible range, a response data is collected and an analytical relationship are established. Once such a relationship is established then the technique of optimization will be applied to deduce the values of independent variables at which the necessary responses will be minimized or maximized. Hence in this research, it is decided to make conformity about functional feasibility and economic viability of human powered unit for internal knot removing and bamboo sliver making. [7]

3. WORKING OF THE UNIT

The operator drives the bicycle by pedaling the mechanism while clutch is in disengage position. The human power operated flywheel motor is energy source. This energy source energizes the process unit through clutch and transmission. The flywheel is accelerated and energized which stores some energy inside it. When the pedaling is stopped, clutch is engaged and stored energy in the flywheel is transferred to the process unit input shaft by means of clutch. The process unit is sliver cutting unit which comprises of feeder, four pairs of spring loaded rollers, sliver cutter, adjusting knobs, helical spur gear train, foundation frame and knuckle and pipe joint. Figure 2 depicts Schematic arrangement of human powered sliver cutting unit.

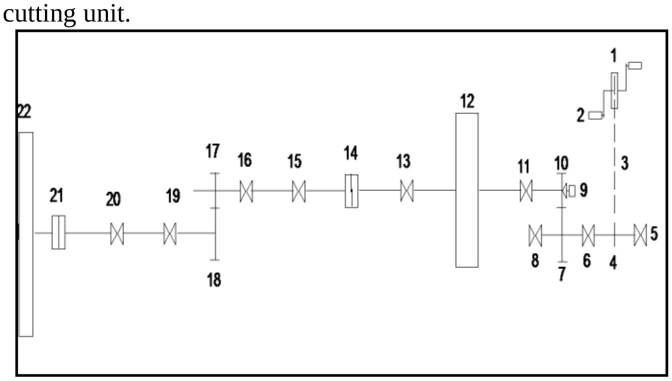

Fig-2: Schematic arrangement of human powered sliver cutting unit

1-Chain Sprocket, 2- Pedal, 3- Chain, 4- Freewheel, 5 & 6- Bearing for bicycle, 7- Gear I, 8- Bearing, 9- Tachogenerator for flywheel shaft, 10- Pinion I, 11- Bearing for flywheel shaft, 12- Flywheel, 13- Bearing for flywheel, 14- Two jaw Clutch, 15 & 16- Bearing of intermidiate shaft, 17- Pinion II, 18- Gear-II, 19 & 20- Bearing for process unit shaft, 21- Coupling, 22-Process Unit.

When the input shaft is rotated by means of energy transferred by the flywheel with the help of clutch, the pulley keyed to the input shaft starts to rotate due to which the rollers are driven by knuckle and pipe joint through helical spur gear train which is keyed to shaft. The shafts of the rollers are supported in brass bush bearings which are fixed in spring loaded housing to accommodate any size of split bamboo. The split bamboo is fed and guided through the feeder which is fixed before pull-in arbor type rollers at the front end of process unit i.e. sliver cutting unit. When the split bamboo is fed through the feeder and pull-in rollers of sliver cutting unit, it passes through rotating pull-in rollers and due to the force given by pull-in rollers, that split bamboo passes through the rotating push-out rollers and when this split bamboo comes out of push-out rollers, it strikes to sliver cutter which is fitted just after push-out rollers due to which the internal knot is removed in the first pass of split bamboo. By positioning the cutter in downward direction, the sliver is cut from split bamboo. The thickness of sliver is adjusted by adjusting the position of sliver by moving the sliver cutter up and down by means of studs fixed to the cutter frame. For continuous contact between the split bamboo and sliver cutter, spring tensions of the springs fitted over the bearing housing is adjusted by tightening and loosening the adjusting knobs. This helps in adjusting any size of split bamboo. The line diagram of proposed process unit is shown in above figure 3.

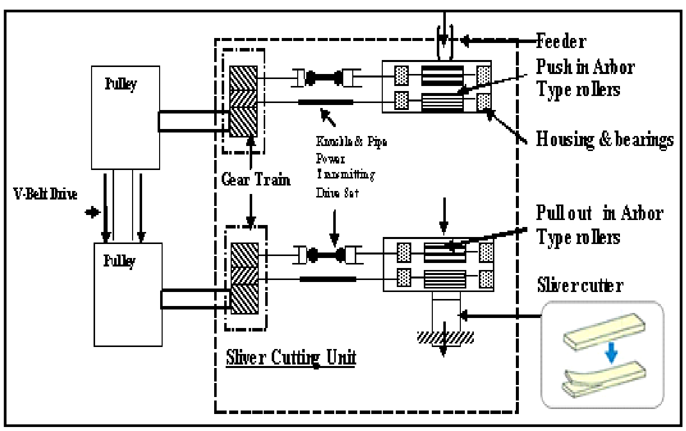

Fig-3: Line Diagram of the proposed process unit.

4. VARIABLES IDENTIFICATION

The process of sliver cutting constitutes following dependent or the response variables:
(1) Instantaneous Torque,
(2) Angular velocity of process unit and
(3) Processing Time.
The various dependant and independent variables involved in the process of making the bamboo slivers from the proposed machine are identified as depicted in following table:

S.N.	Variables	Unit	MLT	Dependant/ Independent
1	T = Instantaneous Torque	N-m	ML^2T^{-2}	Dependant
2	t_p = Processing Time	Second	T	Dependant
3	ω = Angular Velocity of Process Unit	Rad/s	T^{-1}	Dependant
4	V_b = Volume of Bamboo	m^3	L^3	Independent
5	t_b = Thickness of Bamboo	m	L	Independent
6	W_b = Width of Bamboo	m	L	Independent
7	L = Distance of Cutter from Bearing	m	L	Independent
8	C_V = Vertical center distance between roller pairs	m	L	Independent
9	C_H = Horizontal Center Distance between Roller Pairs	m	L	Independent
10	L_{rc}= Distance between Roller Center to Cutter Tip	m	L	Independent
11	g = Acceleration due to Gravity	m/s^2	LT^{-2}	Independent
12	E_b = Modulus of Elasticity of Bamboo	N/m^2	$ML^{-1}T^{-2}$	Independent
13	E_c = Modulus of Elasticity of Cutter	N/m^2	$ML^{-1}T^{-2}$	Independent
14	N_{tt}/N_{tb} = Ratio of No. of teeth on top roller to bottom roller, (R)	-	-	Independent
15	Φ_c = Cutting Angle of Cutter	Degree	-	Independent
16	ω_f = Angular velocity of flywheel	Rad/sec	T^{-1}	Independent
17	W_c = Width of cutter	m	L	Independent
18	t_c = Thickness of cutter	m	L	Independent

Tab1: Variables related to bamboo sliver cutting operation

5. DIMENSIONAL ANALYSIS

The Buckingham's Π- Theorem is used for the dimensional analysis of proposed machine after identifying the dependant and independent variables. The process of dimensional analysis is followed step by step as explained below:

The instantaneous torque, T is function of V_b, L_{rc}, L, C_H, C_V, g, E_b, E_c, R(= N_{tt} / N_{tb}), Φ_c, ω_f and W_c. Thus instantaneous torque, T is dependent variable and others are independent variables.

$$T = f(V_b, L_{rc}, L, C_H, C_V, g, E_b, E_c, R, \Phi_c\, \omega_f, W_c, t_c)$$

$$\text{Or, } f_1(T, V_b, L_{rc}, L, C_H, C_V, g, E_b, E_c, R, \Phi_c, \omega_f, W_c, t_c) = 0$$

Where R= Ratio of N_{tt} / N_{tb}

V_b, g, E_c are considered as the repeating variables (i.e. m = 3)

Total no. of variables = n = 11 and No. of Π terms = n – m = 13 - 3 = 10

$$f_1(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}) = 0$$

Writing the equations in terms of Π terms, therefore,

$\Pi_1 = (V_b)^{a}{}_1 (g)^{b}{}_1 (E_c)^{c}{}_1 L_{rc}$, $\Pi_2 = (V_b)^{a}{}_2 (g)^{b}{}_2 (E_c)^{c}{}_2 L$, $\Pi_3 = (V_b)^{a}{}_3 (g)^{b}{}_3 (E_c)^{c}{}_3 C_H$,

Similarly up to $\Pi_{10} = (V_b)^{a}{}_{10} (g)^{b}{}_{10} (E_c)^{c}{}_{10} t_c$

First Π term:

$\Pi_1 = (V_b)^{a}{}_1 (g)^{b}{}_1 (E_c)^{c}{}_1 L_{rc}$

$(M)^0(L)^0(T)^0 = (L^3)^{a}{}_1 (LT^{-2})^{b}{}_1 (ML^{-1}T^{-2})^{c}{}_1 (L)$

The values of a_2, b_2 and c_2 are computed by equating the powers of M, L & T on both sides as given below:

For 'M'	For 'L'	For 'T'
M→0 = c_1 **c_1 = 0**	L→0 =$3a_1 + b_1 - c_1 + 1$ $3a_1 + b_1 + 1 = 0$, (From eq. of T, subst. **$b_1 = 0$)** $3a_1 + 0 + 1 = 0$, Hence **$a_1 = -1/3$**	T→ 0 = - $2b_1 - 2c_1$ 0 = - $2b_1$ – 0, Hence **$b_1 = 0$** **Subst. in eq of L to get value of a_1**

Substituting the values of a_1, b_1 and c_1 in the eq. of Π_1 term, we have:

$\Pi_1 = (V_b)^{-1/3} (g)^0 (Ec)^0 L_{rc}$

$\Pi_1 = (V_b)^{-1/3} (g)^0 (Ec)^0 L_{rc}$

$$\Pi_1 = \frac{Lrc}{V_b^{1/3}} \quad \text{Eq. (1)}$$

Similarly other independant pi terms are determined as follows:

Second Π term: $\Pi_2 = \dfrac{L}{V_b^{1/3}}$ Eq. (2)

Third Π term: $\Pi_3 = \dfrac{C_H}{V_b^{1/3}}$ Eq. (3)

Fourth Π term: $\Pi_4 = \dfrac{C_V}{V_b^{1/3}}$ Eq. (4)

Fifth Π term: $\Pi_5 = \dfrac{E_b}{E_c}$ Eq. (5)

Sixth Π term: $\Pi_6 = \dfrac{N_{tt}}{N_{tb}}$ Eq. (6)

Seventh Π term: $\Pi_7 = \Phi c$ Eq. (7)

Eighth Π term: $\Pi_8 = \dfrac{\omega_f \times (V_b^{1/6})}{\sqrt{g}}$ Eq. (8)

Ninth Π term: $\Pi_9 = \dfrac{W_c}{V_b^{1/3}}$ Eq. (9)

Tenth Π term: $\Pi_{10} = \dfrac{t_c}{V_b^{1/3}}$ Eq. (10)

Now dimensional analysis for dependant variables T, ω, t_p are performed as follows:

$\Pi_{01} = (V_b)^{a}{}_{01} (g)^{b}{}_{01} (Ec)^{c}{}_{01}\, T$

$(M)^0(L)^0(T)^0 = (L^3)^{a}{}_{01} (LT^{-2})^{b}{}_{01} (ML^{-1}T^{-2})^{c}{}_{01} (ML^2T^{-2})$

The values of a_{01}, b_{01} and c_{01} are computed by equating the powers of M, L & T on both sides as given below:

For 'M'	For 'L'	For 'T'
M→0 = c_{01} + 1 **c_{01} = -1**	L→0 =$3a_{01} + b_{01} - c_{01} + 2$ $3a_{01} + b_{01} + 1 + 2 = 0$ $3a_{01} + b_{01} = -3$, $3a_{01} + 0 = -3$, Hence **a_{01} = - 1**	T→ 0 = - $2b_{01} - 2c_{01} - 2$ 0 = - $2b_{01}$ + 2 – 2, Hence **b_{01} = 0** **Subst. in eq of L to get the value of a_{01}**

$\Pi_{01} = (V_b)^{-1} (g)^0 (Ec)^{-1}\, T$

$$\Pi_{01} = \frac{T}{(V_b)(E_c)} \quad \text{Eq. (11)}$$

Similarly other dependant pi terms are determined as follows:

$$\Pi_{02} = \frac{\omega \times (V_b^{1/6})}{\sqrt{g}} \quad \text{Eq. (12)}$$

$$\Pi_{03} = \frac{\sqrt{g} \times (t_p)}{V_b^{1/6}} \quad \text{Eq. (13)}$$

We know, T =f (V_b, L_{rc}, L, C_H, C_V, g, E_b, E_c, N_{tt}, N_{tb}, Φ_c, ω_f, W_c, t_c)

$$\Pi_{01} = f\left[\left(\frac{Lrc}{V_b^{1/3}}\right), \left(\frac{L}{V_b^{1/3}}\right), \left(\frac{C_H}{V_b^{1/3}}\right), \left(\frac{C_V}{V_b^{1/3}}\right), \left(\frac{E_b}{E_C}\right), \left(\frac{N_{tt}}{N_{tb}}\right), (\Phi c), \frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}}, \frac{W_c}{V_b^{1/3}}, \frac{t_c}{V_b^{1/3}} \right]$$

$$\frac{T}{(V_b)(E_c)} = f\left[\left(\frac{Lrc}{V_b^{1/3}}\right), \left(\frac{L}{V_b^{1/3}}\right), \left(\frac{C_H}{V_b^{1/3}}\right), \left(\frac{C_V}{V_b^{1/3}}\right), \left(\frac{E_b}{E_C}\right), \left(\frac{N_{tt}}{N_{tb}}\right), (\Phi c), \frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}}, \frac{W_c}{V_b^{1/3}}, \frac{t_c}{V_b^{1/3}} \right]$$

$$\frac{T}{(V_b)(E_c)} = f\left[\left(\frac{(L_{rc} \times L \times C_H \times C_V \times W_c \times t_c)}{V_b^{1/729}}\right), \left(\frac{E_b}{E_C}\right), \left(\frac{N_{tt}}{N_{tb}}\right), (\Phi c), \frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}} \right] \qquad \text{Eq. (14)}$$

Also similarly,

$$\frac{\omega \times (V_b^{1/6})}{\sqrt{g}} = f\left[\left(\frac{(L_{rc} \times L \times C_H \times C_V \times W_c \times t_c)}{V_b^{1/729}}\right), \left(\frac{E_b}{E_C}\right), \left(\frac{N_{tt}}{N_{tb}}\right), (\Phi c), \frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}} \right] \qquad \text{Eq. (15)}$$

And,

$$\frac{\sqrt{g} \times (t_p)}{V_b^{1/6}} = f\left[\left(\frac{(L_{rc} \times L \times C_H \times C_V \times W_c \times t_c)}{V_b^{1/729}}\right), \left(\frac{E_b}{E_C}\right), \left(\frac{N_{tt}}{N_{tb}}\right), (\Phi c), \frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}} \right] \qquad \text{Eq. (16)}$$

6. FORMATION OF TEST POINTS & TEST ENVELOPE

The test points and test envelopes are developed by executing the reduction of variables as shown below. The total 572 test points were found for first variable i.e. geometric variables of cutter (Π_1) by taking different combinations of L_{rc}, L, C_H, C_V, W_c, t_c and V_b. The terms L_{rc}, L, C_H were kept constant and C_V, W_c, t_c and V_b were varied for different values and by taking different combinations total 572 test points were found. The test envelope is as shown in following table 2.

Table 2: Π_1 = Geometric variables of cutter, $\frac{(L_{rc} \times L \times C_H \times C_V \times W_c \times t_c)}{V_b^{1/729}}$

Pi Term	Equation	Test points	Test envelope
Π_1	**(L_{rc} × L × C_H × C_V × W_c × t_c)/ $V_b^{1/729}$**	Total 572 test points	2627838045 to 5093598727

In the similar way the test points and test envelopes were found out for remaining variables i.e. Elasticity ratio between bamboo and cutter (E_b/E_c), Ratio top roller teeth to bottom roller teeth (N_{tt}/N_{tb}), Cutting angle of cutter (Φc) and Geometric variables associated with volume of bamboo and flywheel speed $(\omega_f \times V_b^{1/6})/g^{1/2}$.

Tab3:Π_2 = Elasticity ratio between bamboo and cutter, E_b / E_c

Pi Term	Equation	Independent variables with its own range: E_b	Independent variables with its own range: E_c	E_b / E_c	Test points	Test envelope
Π_2	E_b / E_c	20000	206000	0.097087379	0.096153846	0.096153846 to 0.097087379
		25000	260000	0.096153846	0.097087379	

Tab4:Π_3 = Ratio top roller teeth to bottom roller teeth, N_{tt} / N_{tb}

Pi Term	Equation	Independent variables with its own range: Φc	Test envelope	Test points
Π_4	Φc	15	15	15 to 20
		17	17	
		20	20	

Table- 6: Π_5 = Geometric variables associated with volume of bamboo and flywheel speed, $\frac{\omega_f \times (V_b^{1/6})}{\sqrt{g}}$

Pi Term	Equation	Test points	Test envelope
Π_5	$(\omega_f \times V_b^{1/6})/\sqrt{g}$	Total 63 test	1.290341834 to 4.844820498

7.CONCLUSIONS & FURTHER METHODOLOGY

Thus the dimensional equations are established in reduced or compact mode in order to make the complete experimentation process less time taking having generation of optimum data. The test points and test envelopes are found with combinations of constant and varied variables and it is found that the data of test points and test envelopes was sufficient for design of experimentation. The experimental data will be generated for formulation of the mathematical model. The experimental set up will be designed which will include the measurement of processing torque, processing time and angular velocity at outlet using specially designed electronic kit, stop watch and tachometer etc. The extensive experimental data will be generated through experimentations for which the test envelope, test points and plan of experimentation will be decided. The indices of mathematical model will be formulated using regression analysis. The analysis technique implemented for this work will comprise of sensitivity analysis, determination of limiting values, optimization, reliability and AI technique will be used to establish ANN model and to reduce error between experimental and mathematical data. Based on the results, conclusions and hypothesis will be made.

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