Design of Experimentation for Formulation of Experimental Data Based Model for Bamboo Sliver Cutting Operation Using HPFM

S. K. Undirwade[1], Dr. M.P. Singh[2], Dr. C.N. Sakhale[3]

[1]Research Scholar & Asst. Professor, Mechanical Engg. Dept., Priyadarshini College of Engineering, Nagpur
[2]Professor & Principal, Priyadarshini College of Engineering, Nagpur: 440019, India
[3]Associate Professor, Mechanical Engg. Dept., Priyadarshini College of Engineering, Nagpur: 440019, India

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Abstract - *The design of experimental set up gives a direction towards planning of experimentation. This paper presents design of experimentation for formulation of an experimental data based model for sliver cutting from bamboo using human powered flywheel motor (HPFM) which describes the phenomenon under investigation more reliably, accurately and precisely. It is the integral part of engineering research and implementation of design of experiments (DoE) by systematically executing experimental plans and conducting actual test run. In this paper, the various steps of design of experimentation like dimensional analysis, identification of variables in human powered bamboo sliver cutting phenomenon, reduction of variables and* ***the formation of mathematical models' equations*** *are presented in detail. The evolution of bamboo sliver cutting using human power is a complex phenomenon. There are many factors affecting the performance of bamboo sliver cutting. In this paper the attempt is made to present the adopted design of experimentation in detail and to generate design data in the form of evolving experimental data based models for various dependant/ response variables of human powered bamboo sliver cutting by carrying out experimentation.*

Key Words: Experimentation, DoE, Dependent Variable, Independent Variable, Dimensional Analysis, Buckingham's pi theorem, Bamboo Sliver, HPFM, Sliver cutting.

1. INTRODUCTION

Design of Experimentation (DOE) is planning process in a research study to meet specific objectives. The proper planning of an experiment is very much important consideration in order to achieve the research objectives clearly and efficiently with the right type of data and appropriate sample size.

Adoption of basic laws of mechanics could be applied for correlation of various dependant and independent parameters of human powered bamboo sliver cutting in theoretical approach. A theoretical approach can be adopted in a case if known logic can be applied correlating the various dependent and independent parameters of the system. Though qualitatively, the relationship between dependant and independent variables could be known based on available literature data, the generalized quantitative relationship may not be known sometimes due to complexity of phenomenon.

The kinematics of transmission of rotational motion from the input shaft to output shaft in bamboo sliver cutting unit for the human powered flywheel motor is a complex phenomenon. Hence the formulation of quantitative relation based on logic is not possible in case of such a complex phenomenon. On account of no possibility of formulation of theoretical model i.e. logic based model, only alternative is left to formulate experimental data based model. This reasons cause to adopt an experimental approach to establish the experimental data based model. Hence it is proposed to formulate such model in this investigation. [1-5]

2. OPERATION OF BAMBOO SLIVER CUTTING BY HPFM

The operator drives the bicycle by pedalling the mechanism while clutch is in disengage position. The human power operated flywheel motor is energy source. This energy source energizes the process unit i.e. bamboo sliver cutting unit through clutch and transmission. The flywheel is accelerated and energized which stores some energy inside it. When the pedalling 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, two pairs of spring loaded rollers, sliver cutter, adjusting knobs etc. When the energy from flywheel is transferred to the sliver cutting unit by engaging the clutch, the split bamboo is fed through feeder. It enters the first pair of push-in rollers, then comes out of push-out roller pair and strikes the sliver cutter which is kept fixed and the sliver is cut. The sliver cutting immediately commences upon the clutch engagement it continues for 5 to 20 seconds until the flywheel comes to rest.

There is a provision of operating the system at the speeds by properly choosing the gear ratio of a torque amplification provided on the sliver cutting unit shaft. The figure 1 shows the schematic diagram of bamboo sliver cutting unit driven by human powered flywheel motor (HPFM). The figures 2 and 3 show the CAD Model of Actual Experimental Set Up and Actual Experimental Set Up respectively.

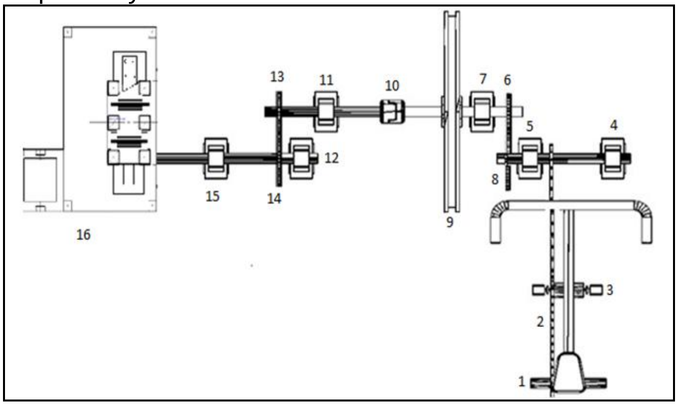

Fig - 1 Schematic arrangement of bamboo sliver cutting unit by HPFM

1 - Chain Sprocket, 2 - Chain, 3 - Pedal, 4 & 5 - Bearing for bicycle, 6 - Gear I, 7 - Bearing Flywheel Shaft, 8 - Gear – II, 9 – Flywheel, 10 – Clutch, 11 - Bearing for flywheel shaft, 12 - Bearing for Process Unit Shaft, 13 - Gear – III, 14 - Gear – IV, 15 - Bearing for Process Unit Shaft, 16 - Process Unit

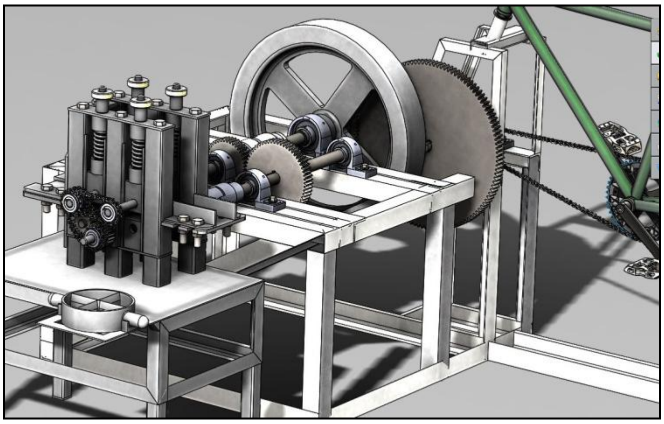

Fig - 2 CAD Model of Actual Experimental Set Up

Fig - 3 Actual Experimental Set Up

3. DESIGN OF EXPERIMENT

Design of experiment involves following steps:

- Based on the known qualitative physical characteristics of the phenomenon, identifying the independent and dependant variables which affect the phenomenon and establishing the dimensional equations for human powered bamboo sliver cutting is of prime importance. The experimentation becomes time consuming, tedious and costly if system involves large number of independent variables. So with the help of dimensional analysis one can reduce the number of variables and hence these reduced number of dimensional equations are the targeted form of mathematical models.
- Test planning consists of deciding test envelope, test sequence and plan of experimentation for the set of deduced dimensional equations.

It is necessary to evolve the physical design of experimental set up in setting up the test points, adjusting the test sequence, execution of proposed experimental plan, noting down the responses and provision for necessary instrumentation for deducing the relation of dependent pi terms of the dimensional equation in terms of independent pi terms. Experimental set up is designed in such a way that it can accommodate the ranges of independent and dependant variables within the proposed test envelope of experimental plan. After noting down the responses and obtained dimensional relations of dependant pi terms of dimensional equations, the exact mathematical model can be formed within the specified test envelope. [6-10]

4. DIMENSIONAL ANALYSIS

Dimensional analysis is an extremely useful mathematical technique used in reduction of variables by forming non-dimensional groups of the variables which are called as pi (π) terms. Deducing the dimensional equation for a phenomenon reduces number of independent variables pi terms in the experiment. The exact mathematical form of this dimensional equation is the targeted model. Thus this method of dimensional analysis provides a systematic experimental planning and permits the presentation of results in more useful and concise format.[1]

4.1 Identification of Variables

Depending upon the working operation of the bamboo sliver cutting phenomenon by HPFM, the various dependent or response variables, independent variables and extraneous variables affecting the phenomenon are identified and the data purification is carried out to remove the extraneous variables to avoid their unwanted effect on the phenomenon. Table 1 shows various dependent and independent variables involved in the phenomenon with their symbols, units, dimensions, nomenclature and nature.

Table -1: Various dependant and independent variables with symbols, units, dimensions, nomenclature and nature

SN	Variables	Unit	MLT	Nature (Dependant/ Independent)
1	t_p = Processing Time	Second	T	Dependant
2	n = No. of Slivers	--	$M^0L^0T^0$	Dependant
3	Tr = Resistive Torque	N-mm	ML^2T^{-2}	Dependant
4	E_f= Flywheel Energy	N-mm	ML^2T^{-2}	Independent
5	ω_f = Angular speed of flywheel	Rad/sec	T^{-1}	Independent
6	t_f = Time required to speed up the flywheel	Second	T	Independent
7	G = Gear Ratio	--	$M^0L^0T^0$	Independent
8	g = Acceleration due to Gravity	mm/s²	LT^{-2}	Independent
9	L_b= Length of Bamboo split	mm	L	Independent
10	W_b= Width of Bamboo split	mm	L	Independent
11	t_b = Thickness of Bamboo split	mm	L	Independent
12	C_H = Horizontal Center Distance between Roller Pairs	mm	L	Independent
13	C_V = Vertical center distance between roller pairs	mm	L	Independent
14	L_{rc}= Distance between Roller Center to Cutter Tip	mm	L	Independent
15	E_b = Modulus of Elasticity of Bamboo	N/mm²	$ML^{-1}T^{-2}$	Independent
16	E_c = Modulus of Elasticity of Cutter	N/mm²	$ML^{-1}T^{-2}$	Independent
17	Φ_c = Cutting Angle of Cutter	Degree	-	Independent

It is seen from table 1 that there are total seventeen variables which affects the phenomenon of bamboo sliver cutting by human powered flywheel motor (HPFM). The fundamental physical dimensions to express all these seventeen variables are only three i.e. Mass (M), Length (L) and Time (T). Out of these total seventeen variables the first three variables are the dependant/ response variables and the later fourteen variables are independent variables.

4.2 Formation of Pi (Π) Terms (Application of Buckingham's Π- Theorem)

The Buckingham's Π- Theorem method is used to form the pi (π) terms for all dependant/response and independent variables affecting the phenomenon of human powered bamboo sliver cutting.

4.2.1 Formation of pi (π) terms for independent variables:

The process of dimensional analysis is followed step by step as explained below:

The processing time, $t_p$is function of Flywheel Energy (E_f), Angular speed of flywheel (ω_f), Time required to speed up the flywheel (t_f), Gear Ratio (G), Acceleration due to Gravity (g), Length of Bamboo split (L_b), Width of Bamboo split (W_b), Thickness of Bamboo split (t_b), Horizontal Center Distance between Roller Pairs (C_H), Vertical center distance between roller pairs (C_V), Distance between Roller Center to Cutter Tip (L_{rc}), Modulus of Elasticity of Bamboo (E_b), Modulus of Elasticity of Cutter (E_c), and Cutting Angle of Cutter (Φ_c) .

$t_p = f(E_f, \omega_f, t_f, G, g, L_b, W_b, t_b, C_H, C_V, L_{rc}, E_b, E_c, \Phi_c)$

Or, $f_1(t_p, E_f, \omega_f, t_f, G, g, L_b, W_b, t_b, C_H, C_V, L_{rc}, E_b, E_c, \Phi_c) = 0$

g, L_b , $E_b$are considered as the repeating variables (i.e. m = 3)

Total no. of independent variables = n = 14

No. of Π terms = n – m = 14 - 3 = 11

$\Pi_{D1} = f_1(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}, \Pi_{11}) = 0$

First Π term:

$\Pi_1 = (g)^{a_1}(L_b)^{b_1}(E_b)^{c_1}E_f,$

$(M)^0(L)^0(T)^0 = (LT^{-2})^{a_1}(L)^{b_1}(ML^{-1}T^{-2})^{c_1}(ML^2T^{-2})$

The values of a_1, b_1 and c_1 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+1 c_1 = -1	L→0 =a_1+ b_1 –c_1+2 (From eq. of T, subst. a_1 = 0) 0=0+ b_1 – (-1)+2 , Hence b_1 = -3	T→ 0 = - 2a_1 – 2c_1 -2 0 = - 2a_1 – 2(-1)-2, Hence a_1 = 0 Subst. in eq of L to get value of b_1

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

$\Pi_1 = (g)^0(L_b)^{-3}(E_b)^{-1}E_f,$

$$\pi_1 = \frac{E_f}{L_b^3 E_b}$$

Second Π term:

$\Pi_2 = (g)^{a_2}(L_b)^{b_2}(E_b)^{c_2}\omega_f,$

$(M)^0(L)^0(T)^0 = (LT^{-2})^{a_2}(L)^{b_2}(ML^{-1}T^{-2})^{c_2}T^{-1}$

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_2	L→0 =a_2+ b_2 –c_2 0 =a_2+ b_2 –0 (From eq. of T, subst. a_2 = -1/2) 0=-1/2+ b_2 – 0, Hence b_2 = 1/2	T→ 0 = - 2a_2 – 2c_2 -1 0 = - 2a_2 – 0 -1, Hence a_2 = -1/2 Subst. in eq of L to get value of b_2

Substituting the values of a_2, b_2 and c_2 in the eq. of Π_2 term, we have:

$\Pi_2 = (g)^{-1/2} (L_b)^{1/2} (E_b)^0 \omega_f$,

$$\pi_2 = \omega_f \sqrt{\frac{L_b}{g}}$$

In the similar way the all remaining pi (π) terms for independent variables are calculated by dimensional analysis and are listed in the following table 2. The table 2 shows total eleven pi terms for independent variables:

Table -2: Pi terms for independent variables

pi terms	pi terms equations
π_1	$\pi_1 = \frac{E_f}{L_b^3 E_b}$
π_2	$\pi_2 = \omega_f \sqrt{\frac{L_b}{g}}$
π_3	$\pi_3 = t_f \sqrt{\frac{g}{L_b}}$
π_4	$\pi_4 = G$
π_5	$\pi_5 = \frac{W_b}{L_b}$
π_6	$\pi_6 = \frac{t_b}{L_b}$
π_7	$\pi_7 = \frac{C_H}{L_b}$
π_8	$\pi_8 = \frac{C_V}{L_b}$
π_9	$\pi_9 = \frac{L_{rc}}{L_b}$
π_{10}	$\pi_{10} = \frac{E_c}{E_b}$
π_{11}	$\pi_{11} = \Phi_c$

4.2.2 Formation of pi (π) terms for dependent variables:

In the similar way, the dimensional analysis for dependent variables is performed by applying again Buckingham's Π-Theorem.

$\Pi_{D1} = (g)^{a_{D1}} (L_b)^{b_{D1}} (E_b)^{c_{D1}} t_p$

$(M)^0 (L)^0 (T)^0 = (LT^{-2})^{a_{D1}} (L)^{b_{D1}} (ML^{-1}T^{-2})^{c_{D1}} (T)$

The values of a $_{D1}$, b $_{D1}$ and c $_{D1}$ 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_{D1}	L→0 =a_{D1}+ b_{D1}– c_{D1} 0 =1/2+ b_{D1}-0 (From eq. of T, subst. a_{D1} = 0) Hence b_{D1} = -1/2	T→ 0 = - 2a_{D1} – 2c_{D1}+1 0 = - 2a $_{D1}$+0 +1, Hence a_{D1} = 1/2 Subst. in eq of L to get value of b_{D1}

$\Pi_{D1} = (g)^{a_{D1}} (L_b)^{b_{D1}} (E_b)^{c_{D1}} t_p$

$\Pi_{D1} = (g)^{1/2} (L_b)^{-1/2} (E_b)^0 t_p$

$$\pi_{D1} = t_P \sqrt{\frac{g}{L_b}}$$

In the similar way the all remaining pi (π) terms for dependent variables are calculated by dimensional analysis and are listed in the following table 3. The table 3 shows total three pi terms for dependent variables:

Table -3: Pi terms for dependent variables

pi terms	pi terms equations
π_{D1}	$\pi_{D1} = t_P \sqrt{\frac{g}{L_b}}$
π_{D2}	$\pi_{D2} = n$
π_{D3}	$\pi_{D3} = \frac{T_r}{L_b^3 E_b}$

4.3 Reduction of Variables

To reduce the coplexity and to obtain the simplicity in the behaviour of the phenomenon, the pi terms of independent variables are reduced by reduction of variables method as suggested by Schenk Jr. The pi terms related to the independent variables like width of bamboo split(W_b), thickness of bamboo split (t_b), Horizontal Centre Distance between Roller Pairs (C_H), vertical Centre Distance between Roller Pairs (C_V), and Distance between Roller Centre to Cutter Tip (L_{rc}) are reduced to form a single new pi term. The following table 4 shows the new pi terms of independent variables in reduced form. Thus the total eleven pi terms of independent variables are reduced to seven new pi terms as shown table 4.

Table -3: New Pi terms in reduced form for independent variables

pi terms	pi terms equations	Description
π_1	$\pi_1 = \frac{E_f}{L_b^3 E_b}$	The term related to energy of flywheel
π_2	$\pi_2 = \omega_f \sqrt{\frac{L_b}{g}}$	The term related to angular speed of flywheel
π_3	$\pi_3 = t_f \sqrt{\frac{g}{L_b}}$	The term related to time required to speed up the flywheel
π_4	$\pi_4 = G$	The term related to gear ratio
π_5	$\pi_5 = \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)$	Machine's geometrical parameters
π_6	$\pi_6 = \frac{E_c}{E_b}$	The term related to elasticity of materials
π_7	$\pi_7 = \varphi_c$	The term related to cutting angle of cutter

4.4 Dimensional Equation for Response Variables

For Processing Time (t_p):

The dependent variable/response variable, processing time (t_p) can be expressed in terms of all the fourteen independent variables as shown below:

$t_p = f_1 (E_f, \omega_f, t_f, G, g, L_b, W_b, t_b, C_H, C_V, L_{rc}, E_b, E_c, \Phi_c)$

or

$f_1 (t_p, E_f, \omega_f, t_f, G, g, L_b, W_b, t_b, C_H, C_V, L_{rc}, E_b, E_c, \Phi_c)$

or

$\Pi_{D1} = f_1(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6, \Pi_7, \Pi_8, \Pi_9, \Pi_{10}, \Pi_{11})$

$$\pi_{D1} = f_1 \left\{ \left(\frac{E_f}{L_b^3 E_b}\right) \left(\omega_f \sqrt{\frac{L_b}{g}}\right) \left(t_f \sqrt{\frac{g}{L_b}}\right) (G) \left(\frac{W_b}{L_b}\right) \left(\frac{t_b}{L_b}\right) \left(\frac{C_H}{L_b}\right) \left(\frac{C_V}{L_b}\right) \left(\frac{L_{rc}}{L_b}\right) \left(\frac{E_c}{E_b}\right) (\varphi_c) \right\}$$

$$t_p \sqrt{\frac{g}{L_b}} = f_1 \left\{ \left(\frac{E_f}{L_b^3 E_b}\right) \left(\omega_f \sqrt{\frac{L_b}{g}}\right) \left(t_f \sqrt{\frac{g}{L_b}}\right) (G) \left(\frac{W_b}{L_b}\right) \left(\frac{t_b}{L_b}\right) \left(\frac{C_H}{L_b}\right) \left(\frac{C_V}{L_b}\right) \left(\frac{L_{rc}}{L_b}\right) \left(\frac{E_c}{E_b}\right) (\varphi_c) \right\}$$

$$t_p \sqrt{\frac{g}{L_b}} = f_1 \left\{ \left(\frac{E_f}{L_b^3 E_b}\right) \left(\omega_f \sqrt{\frac{L_b}{g}}\right) \left(t_f \sqrt{\frac{g}{L_b}}\right) (G) \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right) \left(\frac{E_c}{E_b}\right) (\varphi_c) \right\}$$

Similarly for number of slivers (n) and resistive torque (T_r), the dimensional equations are found as follows:

$$n = f_2 \left\{ \left(\frac{E_f}{L_b^3 E_b}\right) \left(\omega_f \sqrt{\frac{L_b}{g}}\right) \left(t_f \sqrt{\frac{g}{L_b}}\right) (G) \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right) \left(\frac{E_c}{E_b}\right) (\varphi_c) \right\}$$

$$T_r = f_3 \left\{ \left(\frac{E_f}{L_b^3 E_b}\right) \left(\omega_f \sqrt{\frac{L_b}{g}}\right) \left(t_f \sqrt{\frac{g}{L_b}}\right) (G) \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right) \left(\frac{E_c}{E_b}\right) (\varphi_c) \right\}$$

The equations (1), (2) and (3) are the mathematical equations for three response variables (viz. processing time t_p, number of slivers n and resistive torque T_r) of bamboo sliver cutting phenomenon operated by human powered flywheel motor (HPFM) which are used for formation of mathematical models of these variables for sliver cutting phenomenon.

5. TEST POINTS, TEST ENVELOPE & TEST SEQUENCE

Test Envelope: Deciding the end points or limits comprises the test envelope and it is obvious and best way to select or fix the test points. All such test points are covered in the test envelope. So it is obvious to ascertain the complete range over which the entire experimentation is carried out.

Test Points: The spacing of the test points within the test envelop is selected not for getting a 'symmetrical' or a 'pleasing' curve but to have every part of our experimental curve map the same precision as every other part. The conceptual proper spacing of test points is replaced by permissible spacing of test points.

Test Sequence: In classical or sequential plan, the variables are varied from one extremity to the other in a sequential manner, in the random plan those are varied in random fashion. The classical plan or sequential plan is essentially opted for irreversible experiments or where there is no scope for randomization. The majority of engineering experiments use partial randomized plan and hence it is used for testing the phenomenon. [1, 12-16]

The table 5 shows test envelope, test points for Sliver cutting operation by HPFM.

Table -5: Test envelope, test points for bamboo sliver cutting operation by HPFM

Pi Terms	Equation	Test Envelop	Test Point
Π_1=Energy of Flywheel	$\left(\frac{E_f}{L_b^3 E_b}\right)$	1.91E-10 to 3.54E-09	1.91E-10, 3.4E-10, .74E-10, 5.31E-10, 6.64E-10, .65E-10, 8.85E-10, 1.04E-09, .49E-09 1.57E-09, .46E-09,3.54E-09
Π_2= Angular Speed of Flywheel	$\left(\omega_f \sqrt{\frac{L_b}{g}}\right)$	6.780952 to 17.50834	6.780952, 7.829969, 8.754172, 9.04127, 10.43996, 11.30159, 13.04995, 13.5619, 14.59029, 15.65994, 17.50834
Π_3= Time required to speed up the flywheel	$\left(t_f \sqrt{\frac{g}{L_b}}\right)$	71.73723 to 277.8371	71.7372254, 80.20465626, 89.67153175,100.2558203, 107.6058381, 115.7654497, 120.3069844, 125.5401445, 138.9185396, 140.3581484, 143.4744508, 160.4093125, 161.4087572, 162.0716296, 179.3430635, 180.4604766, 185.2247195, 197.2773699, 200.5116406, 208.3778095, 215.2116762, 220.5628047, 231.5308994, 233.1459826, 240.6139688, 254.6839893, 260.6651328, 277.8370793
Π_4=Gear Ratio	G	0.25 to 0.5	0.25, 0.33, 0.50
Π_5=Machines geometrical Paramers	$\left(\frac{W_b . t_b . C_H . C_V . L_{rc}}{L_b^5}\right)$	3.2E-07 to 8.76E-06	3.19713E-07, 3.20794E-07, 3.27331E-07, 3.29694E-07, 3.38367E-07, 3.43773E-07, 3.62025E-07, 3.75852E-07, 3.77109E-07, 3.89679E-07, 3.93576E-07, 4.02391E-07, 4.02652E-07, 4.07844E-07, 4.10483E-07, 4.27642E-07, 4.65478E-07, 4.70733E-07, 4.79683E-07, 4.82121E-07, 4.83077E-07, 4.85893E-07, 4.89437E-07, 4.90242E-07, 4.917E-07, 4.97331E-07, 5.05917E-07, 5.27425E-07, 5.49912E-07, 5.75998E-07, 6.10907E-07, 6.35497E-07, 6.37914E-07, 6.579E-07, 6.61736E-07, 6.84983E-07, 6.95494E-07, 7.16401E-07, 1.22181E-06, 1.22531E-06, 1.22565E-06, 1.24153E-06, 1.26371E-06, 1.27291E-06, 1.29263E-06, 1.29374E-06, 1.31196E-06, 1.34649E-06, 1.3977E-06, 1.49944E-06, 1.50542E-06, 1.536E-06, 1.5762E-06, 1.60336E-06, 1.60984E-06, 1.62235E-06, 1.63075E-06, 1.9043E-06, 1.95441E-06, 1.97219E-06, 2.05464E-06, 2.14206E-06, 2.16877E-06, 2.23084E-06, 2.24054E-06, 2.29146E-06, 2.36825E-06, 2.37051E-06, 2.39088E-06, 2.42935E-06, 2.43323E-06, 2.45554E-06, 2.45894E-06, 2.51034E-06, 2.54025E-06, 2.67054E-06, 2.91949E-06, 4.84965E-06, 5.17478E-06, 5.79372E-06, 6.22017E-06, 8.15712E-06, 8.42159E-06, 8.47849E-06, 8.48689E-06, 8.61363E-06, 8.66342E-06, 8.75557E-06,
Π_6= Elasticity of Materials	$\left(\frac{E_c}{E_b}\right)$	10.3 to 10.3	10.3
Π_7=Cutting Angle	Φ_c	0.261667 to 0.261667	0.261667

The table 6 shows the sample observations for bamboo sliver cutting operation by human powered flywheel motor (HPFM)

Table -6: Experimental Plan and observations for Bamboo Sliver Cutting Operation by HPFM

S. N.	Dimeter Range of Bamboo (D_b)	Gear Ratio (G)	Length of bamboo split (L_b)ft	Length of bamboo split (L_b)mm	Speed (N)	Width of bamboo split (W_b)	Thickness of bamboo split (t_b)	Time of flywheel to speed up (ω_f)	Processing Time (t_p)	n
1	30-40	0.5	1.5	457.5	300	28.7	5.3	31.4	40	3
2	30-40	0.5	1.5	457.5	400	29.3	5.3	41.86666667	50	4
3	30-40	0.5	1.5	457.5	500	28.9	5.2	52.33333333	50	5
4	30-40	0.5	1.5	457.5	600	29.1	5.4	62.8	65	6
5	30-40	0.5	2	610	300	24.1	6.9	31.4	40	2
6	30-40	0.5	2	610	400	24.5	6.5	41.86666667	55	3
7	30-40	0.5	2	610	500	25.1	6.6	52.33333333	60	4
8	30-40	0.5	2	610	600	24.8	7.2	62.8	60	5

6. CONCLUSIONS

Though the bamboo sliver cutting by HPFM is complex phenomenon due to effect of various independent parameters over dependent parameters, due to the method of experimentation adopted in this work it made possible to achieve generalized quantitative relationship between the variables affecting the phenomenon.

Due to the method of DoE applied in this process, it became easier for proper planning of an experiment in order to achieve the research objectives clearly and efficiently with the right type of data and appropriate sample size.

As there is no possibility of formulation of theoretical model i.e. logic based model, only alternative is left to formulate experimental data based model. Adoption of an experimental approach to establish the experimental data based model in this investigation made it possible.

Through the formation of test points and test envelopes, it made possible to ascertain the complete range over which the entire experimentation is to be carried out and spacing the independent variables in a predetermined manner and most effectively helped to constitute efficient and compact experimental plan.

REFERENCES

[1] Hilbert Schenck Junior, Theory of Engineering Experimentation, McGraw Hill, New York.

[2] Modak J. P., "Human powered flywheel motor concept, design, dynamics and applications", Keynote lecture, 12th World Congress (17-20 June 2007), IFTOMM 2007, Besancon, France, (www.iftomm.org/iftomm/proceedings/proceedings .../A983)

[3] J. P. Modak& A. R. Bapat, " Manually driven flywheel motor operates wood turning process", Contemporary Ergonomics, Proceedings of International Ergonomics Society Annual Convention, 13-16 April 1993, Edinburgh, Scotland, pp 352-357.

[4] S. D. Moghe& J. P. Modak, "Design and development of Human Powered Machine for Manufacture of Lime-fly-ash-sand-bricks", Human Power, Technical Journal of the IHPVA Spring 1998, Vol. 13, No. 2, pp 3-7.

[5] Sohoni V. V. et al., "Manually Powered Manufacture of Keyed Bricks", Building Research and Information, Vol.25, No. 6, UK 1997, pp 354-364.

[6] J. P. Modak, "Design and Development of Manually Energized Process Machines Having Relevance to Village / Agriculture and other productive operations, Evolution of Manually Energized Smiths Hammer (Drop Forged Type)", Human Power- A Technical Journal of International Human Powered Vehicle Association (IHPVA), Spring 1992, Vol. 4, No. 2, pp 3-7.

[7] Modak, J. P. And Katpatal A.A., "Design of Manually Energized Centrifugal Drum Type Algae Formation Unit" Proceedings International AMSE Conference on System Analysis, Control and Design, Layon (France), Vol. 3, 4-6 July 1994, pp 227-232.

[8] Pattiwar J. T., Gupta S. K., Modak, J. P. "Formulation of An Approximate Generalized Experimental Model of Various types of Torsionally Flexible Clutches", Proceedings International Conference on Contribution of Cognition to Modelling (CCM-98). CluditeBenard Uni. of Layon, France, July 1998, pp 16-35.

[9] Zakiuddin Syed Kazi and Jayant P.Modak, "Design and Development of the Human Energized Chaff Cutter", New York Science Journal, 2010 ;Vol.3 No. (4): pp104-108.

[10] R. Deshmukh and V. V. Uddanwadikar, "Formulation of Generalized Experimental Model of a Dynamic Finger type Torsionally Flexible Clutch", Proceeding of International Conference on Contribution of Cognition to Modelling (CCM 98), Clued Bernard University of Layon, France, July 1998.

[11] S. B. Deshpande and S. Tarnekar, "Confirming Functional Feasibility and Economic Viability of Adoption of Manually Energized Flywheel Motor for Electricity Generation", Proceedings of International Conference on CAD/CAM Robotics Autonomous Factories- Indian Institute of Technology, New Delhi, Aug 11-14, 2003.

[12] "Bamboo Splitting and Slivering Unit", International Network for Bamboo and Rattan (INBAR), Transfer of Technology Model (TOTEM), Indian Plywood Industries Research Institute (IPIRTI), P.B.No.2273, Tumkur Road, Bangalore, India, pp 1-25.

[13] Bamboo Brochure, "Bamboo- A Material for Cost Effective and Disaster Resistant Housing" Building Materials and Technology Promotion Council (BMTPC), Ministry of Urban Development and Poverty Alleviation, Govt. Of India, pp 1-24.

[14] Cottage Industry Manual, "Bamboo MAT Weaving Techniques and Applications", Work of Mr.Yunhua, Edited & Revised by Dr. Victor Brias, UNIDO Consultant and Dr.Jinhe Fu (INBAR) under the supervision of UNIDO Project Manager, Mr.JuergenHierold, pp 1-29.

[15] Jules J. A. Janssen, "The Mechanical Properties of Bamboo", Technical University, Eindhouen, Post Pus. 513, 5600-Eindhoven. The Netherlands, INBAR Bamboo Report, pp 250-256.

[16] C. N. Sakhale et al, "Design of a Comprehensive Bamboo Processing Machine", PCEA-IFToMM International conference – PICA 2006, PCE&A, Nagpur, INDIA, July 11-14, 2006, pp 1-6.

BIOGRAPHIES

Prof. Siddharth K. Undirwade is Research Scholar and Assistant Professor at Mech. Engg. Deptt at Priyadarshini College of Engg. Nagpur. His specialization is in Mechanical Design. He has published 21 papers in National and International Journals. The present research work received the grant from AICTE under Research Promotion Scheme (RPS),

Dr. M. P. Singh is working as a Principal at Priyadarshini College of Engg., Nagpur. He is having 25 years of experience in teaching and research. His specialization is in Industrial Engg. He received 02 RPS grants from AICTE. He has published 60 papers in International Journals and Conferences.

Dr. Chandrashekhar N. Sakhale is working as a Associate at Priyadarshini College of Engg., Nagpur. He is having 15 years of experience in teaching, Industry and research. His specialization is in Mech. Design. He received 03 RPS grants from AICTE. He has published 65 papers in International Journals and Conferences.

