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Experimental investigation of processing time, number of slivers and resistive torque required for human powered bamboo sliver cutting operation

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Abstract: The human powered bamboo sliver cutting involves various variables affecting the responses of the dependent variables which make this operation complex. The independent variables like length and width of bamboo split, thickness of bamboo split, distance between Roller centre to Cutter tip, Modulus of Elasticity of bamboo, Modulus of Elasticity of Cutter, cutting angle of Cutter, Flywheel energy, angular speed of flywheel, time required to speed up the flywheel, gear ratio etc. are affecting the performance of bamboo sliver cutting operation driven by human powered flywheel motor (HPFM) which affects the responses of dependent variables like processing time, number of slivers and Resistive torque. In this paper an attempt has been made to formulate an experimental data based models for sliver cutting from bamboo using HPFM. The sensitivity analysis, optimization and the reliability of these models and the ANN simulation of the behavioral data were established. Finally, the analysis of mathematical, experimental and ANN simulation was compared for responses of processing time, number of slivers and resistive torque.

Key words: Experimentation, bamboo sliver, HPFM, sliver cutting, optimization, reliability, sensitivity, ANN.

INTRODUCTION

Slivers are thin, narrow sections of bamboos used for weaving a wide range of products. On a small scale they may be used for handicraft items and objects of daily use. On a large scale, one of the most useful products that can be woven into are the mats used to produce bamboo mat board. Slivering unit is a mechanical devise to produce slivers on a large scale for weaving. As an enterprise in itself, woven bamboo product has great potential due to its high demand in many countries, and the potential for export is also increasing. Bamboo cornpares favorably well with other building materials like steel, concrete and timber over energy requirements during construction, strength and stiffness per unit area of material, ease and safety of use (Janssen, 1981). The mechanical properties are correlated with specific gravity. Bamboo possesses excellent mechanical properties. These depend mainly on the fiber content and therefore vary considerably within the culm and between species (Liese, 2004). India has the richest bamboo resources next to China with almost 50% of the species distributed in north-eastern region. Bamboos occupy about 9.57 million

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hectares of forest area, which constitute about 12.8% of total land area under forests (Vermah and Bahadur, 1980).

Many researchers (Modak, 1992) covered various operations through human powered flywheel motor (HPFM) but no research work has been carried out on bamboo cutting operation by using human power. Researchers who had worked in the field of HPFM for any operation have not considered the total resistive torque of that operation. They have worked for only average resistive torque of the operation. Hence it is needed to study the effect of total resistive torque on the operation by formulating the models for this factor. The available bamboo slivering machines are hand operated, due to which there were restriction on power consumption and energy utilization for these machines and therefore, limitations on length of slivers to be produced. Most of these machines were able to produce the slivers of length 1.0 to 1.5 feet. The bamboo sliver cutting machine driven by human powered flywheel motor was fabricated by making initially the design calculations and power estimation. The machine was fabricated and tested for all successful test runs and obtained good results..

CONSTRUCTION AND WORKING OF MACHINE

Figure 1 shows the schematic arrangement of bamboo sliver cutting unit driven by HPFM. Human powered Bamboo Slivering machine mainly consists of following parts:

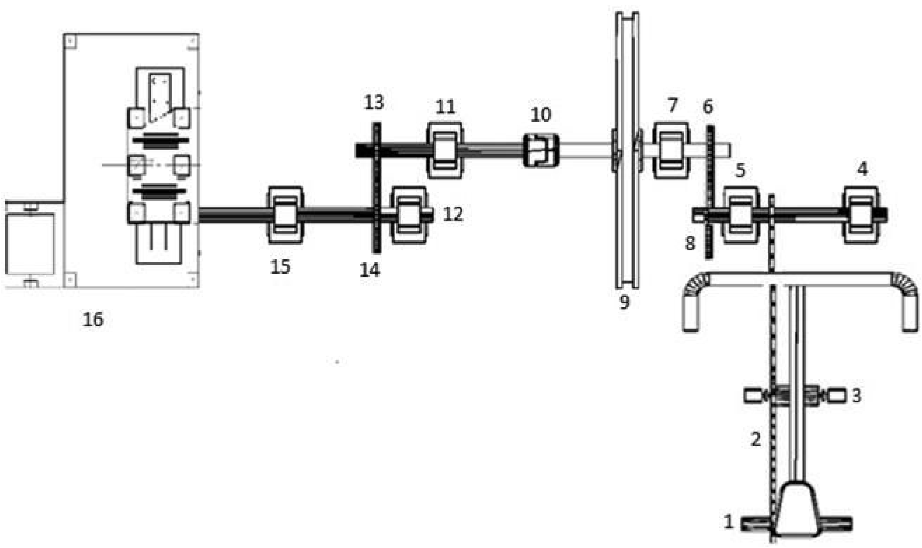

Figure 1: Schematic arrangement of bamboo sliver cutting unit by HPFM

1 - Chain Sprocket, 2 - Chain, 3 - Pedal, 4 & 5 - Bearing for bicycle, 6 - Gear I, 7 - Bearing for Fly wheel 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.

Energy unit: Energy unit consists of bicycle-drive mechanism with speed increase gearing, appropriate clutch transmission and a flywheel.

Process unit: Process unit (Sakhale *et al*., 2010) is the bamboo sliver cutting unit which is coupled to the energy unit. It consists of the two pairs of the rollers where one pair is coupled to the output shaft of energy unit, spring loaded adjusting knobs, chain drive, belt drive and a cutter. The belt drive is used to transmit the motion from first roller pair to another roller pair and the chain drive along with gears help to transmit the motion from lower roller of second pair to the upper roller so that the split bamboo can easily strike the cutter which is stationary and kept exactly in front of the second roller pair. The various views of the process unit *i.e.* bamboo sliver cutting unit and its CAD model are shown in Figure 2.

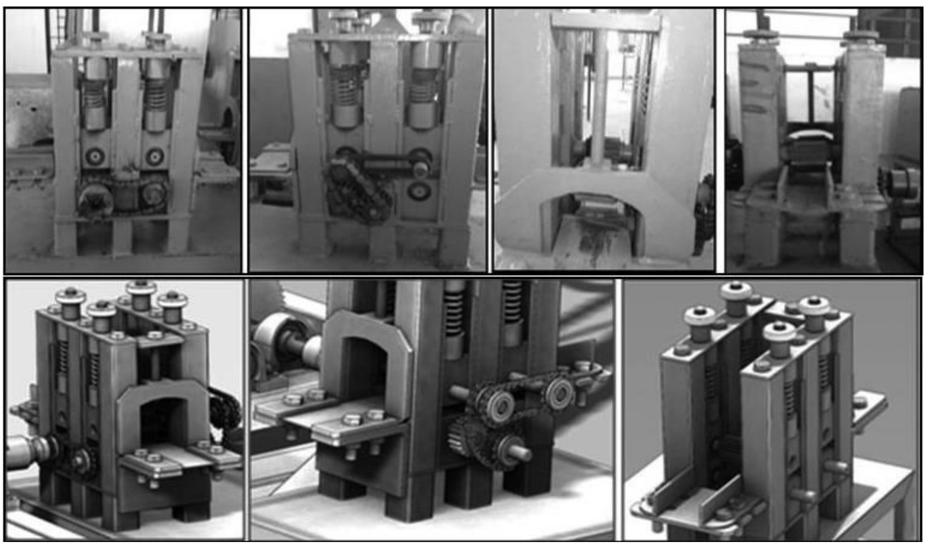

Figure 2: Various views of the bamboo sliver cutting unit and its CAD model

Freely chosen pedaling rate would increase with the increase in inertial crank load (Hansena *et al*., 2002). The operator drives the bicycle by pedaling the mechanism while clutch is in disengage position. The HPFM is energy source. Thin rim flywheel is best to store energy and second position is taken by the flywheel rim with the web. Disc type flywheel is worst to store energy and its energy stored to flywheel-weight ratio is very low (Haichang and Jiang, 2007). The HPFM as 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 the stored energy in the flywheel is transferred to the process unit input shaft.

The process unit is the 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.

DESIGN OF EXPERIMENTATION

The classical plan of experimentation (Hilbert, 1968) is used to carry out the experimentation.

Experimental set up:

The experimental set up is shown in Fig. 3. During the experimentation, the speed and the time of flywheel to speed up before engagement of the clutch, speed of process unit after engagement of clutch, time of process unit after engagement of clutch, resistive torque, processing time, number of slivers etc. are recorded. Fig. 4 shows electronic kit for speed measurement with software.

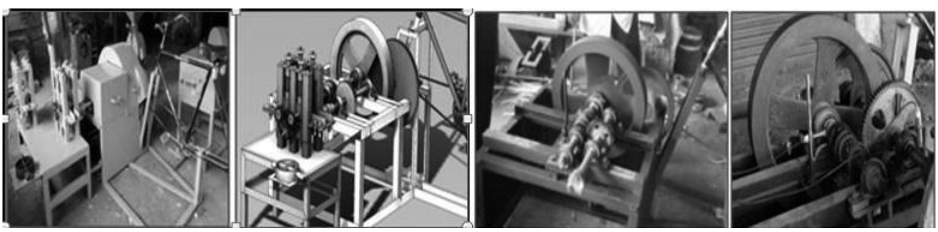

Figure 3: Experimental setup

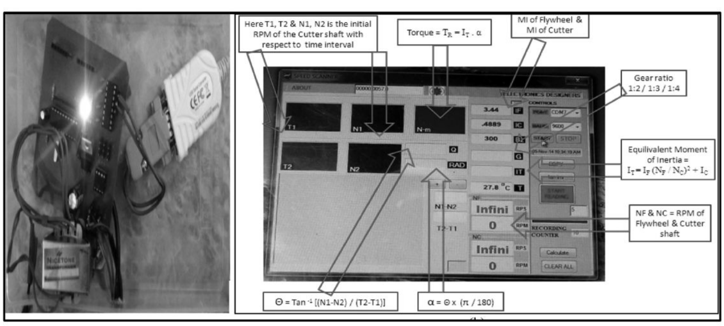

Figure 4: Electronic Kit for speed measurement with software

Experimental approach:

The kinematics of transmission of rotational motion from the input shaft to the output shaft in bamboo sliver cutting operation by HPFM is a complex phenomenon. Hence, the formulation of quantitative relation based on logic is not possible. On account of no possibility of formulation of theoretical model, *i.e.*, logic based model, the only alternative left was to formulate experimental data based model. Hilbert (1968) has suggested a methodology of experimentation to formulate the experimental data based models for prediction of behavior of such complex phenomenon. The same approach was adopted in the present research which is explained below:

Identification of variables in phenomenon:

The various dependent variables and independent variables involved in the phenomenon of the human powered sliver cutting are described in Table 1. By applying Buckingham's Π- Theorem method of Dimensional Analysis, the dimensional equations for all the three response variables *i.e.*, processing time, number of slivers and resistive torque are found as given below:

Table 1: Various dependant and independent variables

S.N.	Variables	Unit	MLT	Nature
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/s^2	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	Eb = Modulus of Elasticity of Bamboo	N/mm^2	$ML^{-1}T^{-2}$	Independent
16	Ec = Modulus of Elasticity of Cutter	N/mm^2	$ML^{-1}T^{-2}$	Independent
17	Φc = Cutting Angle of Cutter	Degree	-	Independent

$$t_P\sqrt{\frac{g}{L_b}} = f_1\left\{\left(\frac{E_f}{L_b^3E_b}\right)\left(\omega_f\sqrt{\frac{L_b}{g}}\right)\left(t_f\sqrt{\frac{g}{L_b}}\right)(G)\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)\left(\frac{E_c}{E_b}\right)(\varphi_c)\right\} \quad (1)$$

$$n = f_2\left\{\left(\frac{E_f}{L_b^3E_b}\right)\left(\omega_f\sqrt{\frac{L_b}{g}}\right)\left(t_f\sqrt{\frac{g}{L_b}}\right)(G)\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)\left(\frac{E_c}{E_b}\right)(\varphi_c)\right\} \quad (2)$$

$$T_r = f_3\left\{\left(\frac{E_f}{L_b^3E_b}\right)\left(\omega_f\sqrt{\frac{L_b}{g}}\right)\left(t_f\sqrt{\frac{g}{L_b}}\right)(G)\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)\left(\frac{E_c}{E_b}\right)(\varphi_c)\right\} \quad (3)$$

Brief experimental procedure:

During experimentation, the bamboo split were made of three varying lengths i.e., 1.5 ft, 2.0 ft and 2.5 ft and of different diameter ranges, i.e., 30 - 40 mm, 40 - 50 mm and 50 - 60 mm having different widths and thickness were processed in the machine at four different speeds, i.e., 300, 400, 500 and 600 rpm and at three different gear ratios 1/2, 1/3, and 1/4. Different varieties of bamboo were used during experimentation for monitoring the actual feasibility of the machine. During experimentation processing time, resistive torque, no. of slivers, time of flywheel to speed up etc. were measured using specially designed electronic kit. Table 2 shows the Experimental Plan and sample observations for bamboo sliver cutting operation by HPFM.

Table 2: Experimental Plan and sample observations for Bamboo Sliver Cutting Operation by HPFM

S.N.	Dimeter Range of Bamboo (D_b) mm	Gear Ratio (G)	Length of bamboo split (L_b)ft	Length of bamboo split (L_b)mm	Speed (N) rpm	Width of bamboo split (W_b) mm	Thickness of bamboo split (t_b) mm	Time of flywheel to speed up (ω_f) sec	Processing Time (t_p) sec	No. of sliver 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	41.87	50	4
3	30-40	0.5	1.5	457.5	500	28.9	5.2	52.33	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	41.87	55	3
7	30-40	0.5	2	610	500	25.1	6.6	52.33	60	4
8	30-40	0.5	2	610	600	24.8	7.2	62.8	60	5
9	30-40	0.5	2.5	762.5	300	31.4	8.1	31.4	45	2
10	30-40	0.5	2.5	762.5	400	31	8.4	41.87	60	2

MODEL FORMULATION

The models were formulated for all the three response variables by recording and studying the effect of all the independent variables.

Model for π_{D1} (i.e. Processing Time, t_p)

$$\boldsymbol{t_P} = \mathbf{5.15\,X10^{-10}}\sqrt{\frac{L_b}{g}}\left\{\begin{array}{c}\left(\frac{E_f}{L_b^3E_b}\right)^{0.2889}\left(\omega_f\sqrt{\frac{L_b}{g}}\right)^{0.1564}\left(t_f\sqrt{\frac{g}{L_b}}\right)^{-0.1769}\\ (\boldsymbol{G})^{-0.3499}\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)^{0.0371}\left(\frac{E_c}{E_b}\right)^{-3.1676}(\varphi_c)^{-30.5644}\end{array}\right\} \quad (4)$$

Model for π_{D2} (i.e. Number of Slivers, n)

$$\boldsymbol{n} = \mathbf{174.1406}\left\{\begin{array}{c}\left(\frac{E_f}{L_b^3E_b}\right)^{0.5082}\left(\omega_f\sqrt{\frac{L_b}{g}}\right)^{-0.3148}\left(t_f\sqrt{\frac{g}{L_b}}\right)^{-0.1208}\\ (\boldsymbol{G})^{-0.5089}\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)^{-0.1823}\left(\frac{E_c}{E_b}\right)^{1.3087}(\varphi_c)^{-1.4871}\end{array}\right\} \quad (5)$$

Model for π_{D3} (i.e. Average Resistive Torque, Tr-avg)

$$\boldsymbol{T_r} = \mathbf{1.08}\boldsymbol{E} + \mathbf{10}(L_b^3E_b)\left\{\begin{array}{c}\left(\frac{E_f}{L_b^3E_b}\right)^{0.7824}\left(\omega_f\sqrt{\frac{L_b}{g}}\right)^{-1.0005}\left(t_f\sqrt{\frac{g}{L_b}}\right)^{-0.351}\\ (\boldsymbol{G})^{-1.4423}\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)^{0.0889}\left(\frac{E_c}{E_b}\right)^{4.289}(\varphi_c)^{23.515}\end{array}\right\} \quad (6)$$

Model for π_{D3} (i.e. Total Resistive Torque, Tr-total)

$$\boldsymbol{T_r} = \mathbf{7.68\,X10^{10}}(L_b^3E_b)\left\{\begin{array}{c}\left(\frac{E_f}{L_b^3E_b}\right)^{0.7188}\left(\omega_f\sqrt{\frac{L_b}{g}}\right)^{-1.2769}\left(t_f\sqrt{\frac{g}{L_b}}\right)^{0.0101}\\ (\boldsymbol{G})^{-1.3708}\left(\frac{W_bt_bC_HC_VL_{rc}}{L_b^5}\right)^{0.0265}\left(\frac{E_c}{E_b}\right)^{-7.5718}(\varphi_c)^{6.7265}\end{array}\right\} \quad (7)$$

In this investigation, a total 108 sets of observations were noted and for these 108 sets of observations, 1380 observations for the total torque were recorded. Thus, during the study of average torque of 108 sets of observations, a total torque of 1380 observations were performed separately and the results compared.

SENSITIVITY ANALYSIS

Sensitivity of the model is the total percentage change in dependant pi terms by induction of unit percentage change in an independent pi term, the influence of various indices of independent pi terms reflects in sensitivity of the model output. The sensitivity analysis for all response variables was done which is shown in Fig. 5 and explained below.

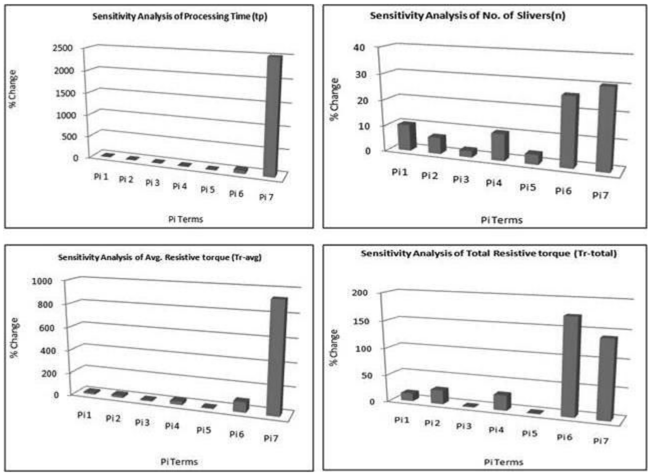

Figure 5: Bar chart showing sensitivity of models for Π_{D1} (Processing Time), Π_{D2} (No. of Slivers), Π_{D3} (Tr-avg) and Π_{D3} (Tr-total)

Processing Time (Π_{D1}): The graph shows that Π_7 is most sensitive whereas Π_5 is least sensitive. Π_5 is collectively representing the geometrical parameters of machine whereas the term Π_7 represents cutting angle of cutter which has highest influence. From the graph, following observations are made.

Pi Terms	% Change
Pi 5 (Π_5)	0.744351
Pi 2 (Π_2)	3.136153
Pi 3 (Π_3)	3.553208
Pi 1 (Π_1)	5.789777
Pi 4 (Π_4)	7.035269
Pi 6 (Π_6)	65.67714
Pi 7 (Π_7)	2498.085

Number of Slivers (Π_{D2}): The graph shows that Π_7 is most sensitive whereas Π_3 is least sensitive. Π_3 is collectively representing time required to speed up the flywheel whereas the term Π_7 represents cutting angle of cutter which has highest influence. From the graph, following observations are made.

Pi Terms	% Change
Pi 3 (Π_3)	2.425633
Pi 5 (Π_5)	3.661784
Pi 2 (Π_2)	6.328167
Pi 1 (Π_1)	10.17648
Pi 4 (Π_4)	10.24273
Pi 6 (Π_6)	26.16467
Pi 7 (Π_7)	30.17726

Average Resistive Torque (Tr-avg, Π_{D3}): The graph shows that pi term Π_7 is most sensitive whereas pi term Π_5 is least sensitive. The pi term Π_5 is collectively representing machines geometrical parameters whereas the term Π_7 represents cutting angle of cutter has highest influence. From the graph, following observations are made.

Pi Terms	% Change
Pi 5 (Π_5)	1.783189
Pi 3 (Π_3)	7.057435
Pi 1 (Π_1)	15.65493
Pi 2 (Π_2)	20.21221
Pi 4 (Π_4)	29.25513
Pi 6 (Π_6)	86.85653
Pi 7 (Π_7)	932.0839

Total Resistive Torque (Tr-total, Π_{D3}): The graph shows that pi term Π_6 is most sensitive whereas pi term Π_3 is least sensitive. The pi term Π_3 is collectively representing time required to speed up the flywheel whereas the term Π_6 represents elasticity of material has highest influence. From the graph, following observations are made.

Pi Terms	% Change
Pi 3 (Π_3)	0.202667
Pi 5 (Π_5)	0.531707
Pi 1 (Π_1)	14.38466
Pi 2 (Π_2)	25.8592
Pi 4 (Π_4)	27.78549
Pi 7 (Π_7)	140.6296
Pi 6 (Π_6)	173.464

OPTIMIZATION OF THE MODELS

The mathematical models have been developed for the phenomenon. The ultimate objective of this work is not merely developing the models but to find out the best set of independent variables, which will result in maximization/minimization of the objective functions. The limiting values of three response variables viz. processing time, number of slivers and resistive torque are found as shown in Table 3. The mathematical models are optimized and thus following equations for response variables are obtained.

Table 3: Limiting Values of Response Variables.

Response Variable	Limiting Values	
	Maximum	Minimum
Processing time, tp	138.7953256 Sec.	28.12198254 Sec.
Number of slivers, n	11.78047463	0.897559452
Resistive Torque, Tr	240913.4427 N-mm	7550.050918 N-mm

Z (Processing Time: Π_{D1} min) = -9.28781+ -0.60548+ 0.2889X1 +0.1564X2 -0.1769X3 -0.3499X4 +0.0371X5 3.1676X6 -30.5644X7

Z (No. of slivers: Π_{D2} max) = 2.2409+0.5082 X1 - 0.3148 X2 -0.1208 X3 -0.5089 X4 -0.1823 X5+1.3087 X6- 1.4871 X7

Z (Resistive torque-avg: Π_{D3} min) = 10.0317+ 12.70817) + 0.7824 X1 -1.0005 X2 -0.351 X3 - 1.4423 X4 + 0.0889 X5 + 4.289 X6 + 23.515 X7

Z (Resistive torque-total: Π_{D3} min) =10.8855+12.70817) + 0.7188 X1- 1.2769 X2+0.0101 X3 -1.3708 X4 +0.0265 X5- 7.5718 X6 +6.7265 X7

Subjected to the following constraints

$1 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \leqslant -8.45076$

$1 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \geqslant -9.71836$

$0 \times X1 + 1 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \leqslant 1.243245$

$0 \times X1 + 1 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \geqslant 0.831291$

$0 \times X1 + 0 \times X2 + 1 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \leqslant 2.44379$

$0 \times X1 + 0 \times X2 + 1 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \geqslant 1.855745$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 1 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \leqslant -0.30103$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 1 \times X4 + 0 \times X5 + 0 \times X6 + 0 \times X7 \geqslant -0.60206$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 1 \times X5 + 0 \times X6 + 0 \times X7 \leqslant -5.05772$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 1 \times X5 + 0 \times X6 + 0 \times X7 \geqslant -6.49524$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 1 \times X6 + 0 \times X7 \leqslant 1.012837$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 1 \times X6 + 0 \times X7 \geqslant 1.01283$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 1 \times X7 \leqslant -0.58225$

$0 \times X1 + 0 \times X2 + 0 \times X3 + 0 \times X4 + 0 \times X5 + 0 \times X6 + 1 \times X7 \geqslant -0.58225$

On solving the above problem by using MS solver we got values of X1, X2, X3, X4, X5, X6, X7 and Z. Thus Π_{D1} min = Antilog of Z and corresponding to this value of the Π_{D1}min the values of the independent pi terms were obtained by taking the antilog of X1, X2, X3, X4, X5, X6, X7 and Z. Similar procedure was adopted to optimize the models for Π_{D2}max and Π_{D3}min and the optimized values of Π_{D1}min, Π_{D2}max and Π_{D3}min are tabulated in the Table 4.

Table 4: Optimized values of response variables

	Processing Time: Π_{D1} min		No. of slivers: Π_{D2} max		Resistive torque-average: Π_{D3} min		Resistive torque-total: Π_{D3} min	
	Log values of π terms	Antilog of π terms	Log values of π terms	Antilog of π terms	Log values of π terms	Antilog of π terms	Log values of π terms	Antilog of π terms
Z	1.449	28.121	1.142	13.873	3.543	3497.43	-9.013	9.69E-10
X_1	-9.718	1.912	-8.450	3.5E-09	-9.718	1.91E-10	-9.718	1.91E-10
X_2	0.831	6.780	0.831	6.780	1.243	17.508	1.243	17.508
X_3	2.443	277.837	1.855	71.737	2.443	277.837	1.855	71.737
X_4	-0.301	0.5	-0.602	0.25	-0.301	0.5	-0.301	0.5
X_5	-6.495	3.19E-07	-6.495	3.1E-07	-6.495	3.19E-07	-6.495	3.19E-07
X_6	1.012	10.3	1.012	10.3	1.012	10.3	1.012	10.3
X_7	-0.582	0.261	-0.582	0.261	-0.582	0.261	-0.582	0.261

RELIABILITY OF THE MODELS

The Reliability of the model can be established by using the following relation.

Reliability (%) = 100 – percentage mean error

$$\text{Reliability } (\%) = 100 - \frac{\Sigma(x_i \times f_i)}{\Sigma f_i} \times 100$$

$$\text{Where Mean error} = \frac{\Sigma(x_i \times f_i)}{\Sigma f_i}$$

And x_i is percentage (%) error and f_i is frequency of occurrence of the error.

Let, $R_{i(\pi D1)}$ is the reliability of model representing processing time (Π_{D1}), $R_{i(\pi D2)}$ is the reliability of model representing number of slivers (Π_{D2}) and $R_{i(\pi D3)}$ is the reliability of model representing resistive torque (Π_{D3}). The reliability of the models representing all the three dependent/response variables were calculated using above relationship and found as given below:

$R_{i(\pi D1)}$= 85.04629 %

$R_{i(\pi D2)}$= 89.06481 %

$R_{i(\pi D3)}$resistive torque- average = 92.57031 %

$R_{i(\pi D3)}$resistive torque- total = 84.448551 %

Reliability of the system (Rp) for this case is given by,

$$\boldsymbol{R_P} = \mathbf{1} - \prod_{i=1}^{n} (\mathbf{1} - \boldsymbol{R_i})$$

$$\boldsymbol{R_P} = 1 - [(1 - \text{Ritp}) * (1 - \text{Rin}) * (1 - \text{RiTr})]$$

Where, Rp is the total reliability of parallel system, Ritp is the reliability of processing time (Π_{D1}), Rin is the reliability of number of slivers (Π_{D2}), and RiTr is the reliability of resistive torque (Π_{D3}). Since, observations were taken simultaneously during experimentation.

Therefore, the total reliability of models for sliver cutting operation is

=1-[(1-0.850462)(1-0.890648)(1-0.9257031)= 0.9987817 = 99.8781%

System Reliability = 99.8781%.

RESULTS AND DISCUSSION

ANN Simulation: The models have been formulated mathematically as well as by using ANN. Values of three dependent pi terms computed by experimental observations, by mathematical model and by ANN are compared and all these values were complimentary to each other. The comparisons of values of dependent pi terms obtained by experimentation, mathematical models and by ANN for Processing time (t_p), Number of Slivers (n) and Resistive Torque (T_r) are shown in Figs. 6, 7 and 8, respectively.

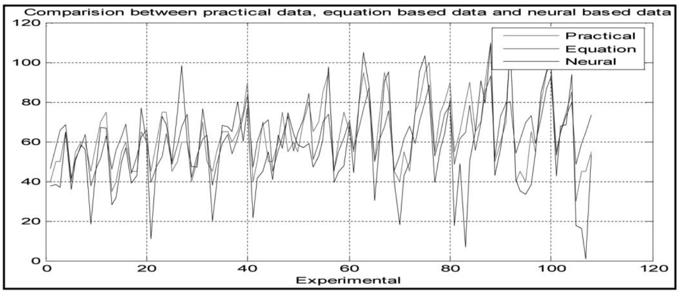

Figure 6: Comparison of actual and computed data by ANN for Processing Time-Π_{D1}

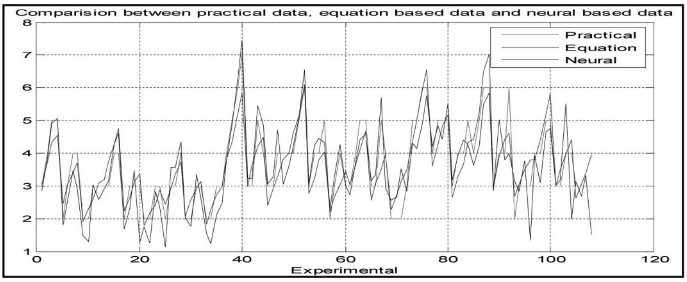

Figure 7: Comparison of actual and computed data by ANN for No. of slivers-Π_{D2}

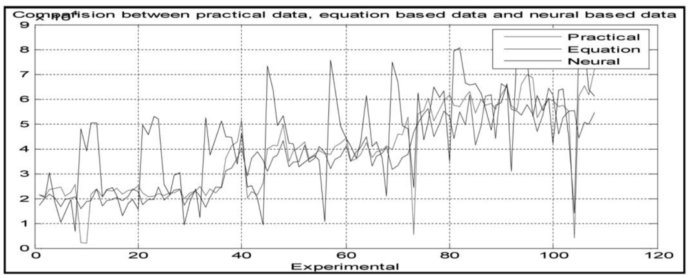

Figure 8: Comparison of actual and computed data by ANN for Resistive Torque-Π_{D3}

Graphical Representation of the Model: It is possible to evaluate the behaviour of any model through graphical presentation in order to justify how the real phenomena work on account of appropriate interaction of independent πterms. An attempt has been made for the human powered bamboo sliver cutting operation. Figs. 9, 10, 11 and 12 showed 3D graphs for processing time, number of slivers, resistive torque (average) & resistive torque (total), respectively.

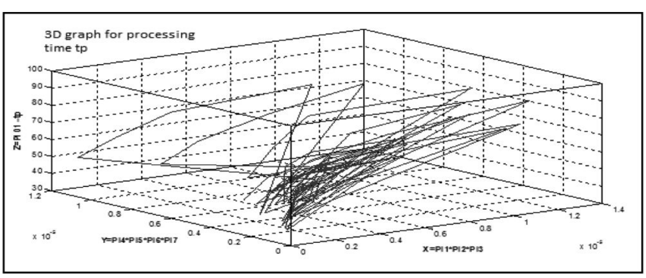

Figure 9: 3-D Graph of processing time vs. Pi terms

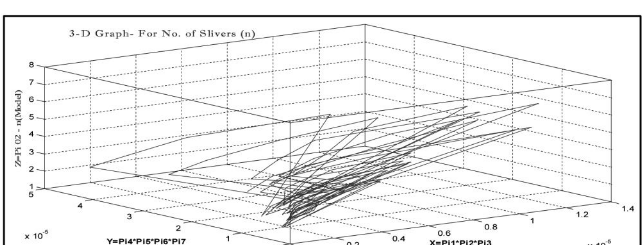

Figure 10: 3-D Graph of number of slivers vs. Pi terms

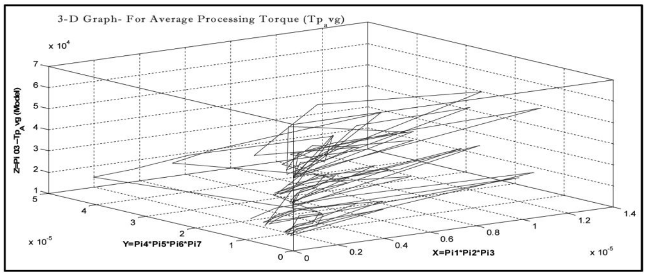

Figure 11: 3-D Graph of average resistive torque vs. Pi terms

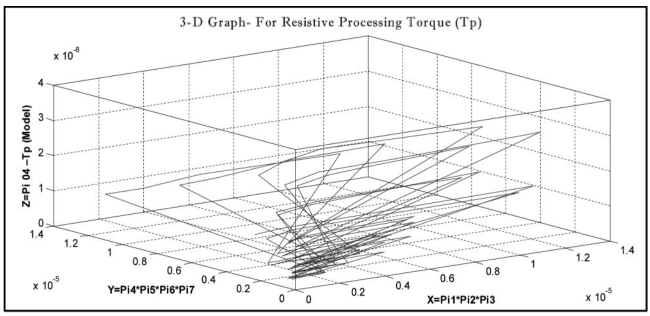

Figure 12: 3-D Graph of total resistive torque vs. Pi terms

From Fig. 9, it was observed that there were 11 peaks in graph of Z i.e. processing time vs. X. There must be in all 22 mechanisms which were responsible for giving these 11 peaks. From Fig. 10, it was observed that there were 11 peaks in graph of Z i.e. Number of slivers vs. X. There must be in all 22 mechanisms which were responsible for giving these 11 peaks. From Fig. 11, it was observed that there were 14 peaks in graph of Z i.e. average resistive torque vs. X, There must be in all 28 mechanisms are responsible for giving these 14 peaks. Similarly from Fig. 12, it was observed that there were 16 peaks in graph of Z i.e. average resistive torque vs. X There must be in all 32 mechanisms are responsible for giving these 16 peaks.

Analysis from indices of the models:

Analysis of the model for Processing Time.

The model for the Processing Time, π_{D1} is as under:

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

$$= 5.15\times10^{-10}(\pi_1)^{0.2889} (\pi_2)^{0.1564} (\pi_3)^{-0.1769} (\pi_4)^{-0.3499} (\pi_5)^{0.0371} (\pi_6)^{-3.1676} (\pi_7)^{-30.5644}$$

The following primary conclusions were drawn from the above model.

The absolute index of π_1 is highest viz.0.2889. The factor 'π_1 is related to energy of flywheel which is the most influencing term in this model. The value of this index is positive indicating involvement of energy of flywheel has strong impact on π_{D1} and π_{D1} is directly varying with respect to π_1.

The absolute index of π_5 is lowest viz. 0.0371. Thus π_5, the term related to geometrical parameters of the machine which is the least influencing term in this model. Low value of absolute index indicates that the factor, geometrical parameters of the machine needs improvement.

The influence of the other independent pi terms present in this model is π_2, having absolute index of 0.1564. The indices of π_3, π_4, π_6 and π_7 are negative viz. -0.1769,-0.3499, -3.1676 and -30.5644, respectively. The negative indices are indicating need for improvement. The negative indices indicating that π_{D1} varies inversely with respect to π_3, π_4, π_6 and π_7.

The constant in this model is 5.15×10^{-10}. This value being less than one, hence it has no significant effect in the value computed from the product of the various terms of the model.

Analysis of the model for No. of Slivers:

The model for No. of Slivers, π_{D2} is as under:

$$\pi_{D2} = n = 174.1406\,(\pi_1)^{0.5082}\,(\pi_2)^{-0.3148}\,(\pi_3)^{-0.1208}\,(\pi_4)^{-0.5089}\,(\pi_5)^{-0.1823}\,(\pi_6)^{1.3087}\,(\pi_7)^{-1.4871}$$

The following primary conclusions were drawn from the above model.

The absolute index of π_6 is highest viz.1.3087. The factor 'π_6 is related to ratio of elasticity of material is the most influencing term in this model. The value of this index is positive indicating involvement of ratio of elasticity of material has strong impact on π_{D2} and π_{D2} is directly varying with respect to π_6.

The absolute index of π_1 is lowest viz. 0.5082. Thus π_1, the term related to the energy of flywheel is the least influencing term in this model. Low value of absolute index indicates the factor, energy of flywheel needs improvement.

The indices of π_2, π_3 π_4 π_5 and π_7 are negative viz. -0.3148,-0.1208, -0.5089, -0.1823 and -1.4871, respectively. The negative indices are indicating need for improvement. The negative indices indicating that π_{D2} varies inversely with respect to π_3 and π_6.

The constant in this model is 174.1406. This value being greater than one, hence it has highly significant effect in the value computed from the product of the various terms of the model.

Analysis of the model for Resistive torque-average:

The model for Resistive Torque-average is as under

$$\pi_{D3} = \frac{T_r}{L_b^3 E_b}$$

$$= 1.08 \times 10^{10}\,(\pi_1)^{0.7824}\,(\pi_2)^{-1.0005}\,(\pi_3)^{-0.351}\,(\pi_4)^{-1.4423}\,(\pi_5)^{0.0889}\,(\pi_6)^{4.289}\,(\pi_7)^{23.515}$$

The following primary conclusions were drawn from the above model.

The absolute index of π_7 is highest viz.23.515. The factor 'π_7 is related to cutting angle of cutter is the most influencing term in this model. The value of this index is positive indicating involvement of cutting angle of cutter has strong impact on π_{D3} and π_{D3} is directly varying with respect to π_7.

The absolute index of π_5 is lowest viz. 0.0889. Thus π_5, the term related to geometrical parameters of machine is the least influencing term in this model. Low value of absolute index indicates the factor geometrical parameters of machine needs improvement.

The sequence of influence of the other independent pi terms present in this model is π_6, and π_1 having absolute indices 4.289 and 0.7824, respectively. The index of π_2, π_3 and π_4 are negative viz. -1.0005, -0.351 and -1.4423, respectively. The negative indices are indicating need for improvement. The negative indices indicating that π_{D3} varies inversely with respect to π_2, π_3 and π_4.

The constant in this model is 1.08×10^{10}. This value being greater than one, hence it has a highly significant effect in the value computed from the product of the various terms of the model.

Analysis of the model for Resistive torque-total:

The model for the Resistive Torque-total is as under:

$$\pi_{D3} = \frac{T_r}{L_b^3 E_b}$$

$$=7.68\times10^{10}\,(\pi_1)^{0.7188}\,(\pi_2)^{-1.2769}\,(\pi_3)^{0.0101}(\pi_4)^{-1.3708}(\pi_5)^{0.0265}\,(\pi_6)^{-7.5718}(\pi_7)^{6.7265}$$

The following primary conclusions were drawn from the above model.

The absolute index of π_7 is highest viz.6.7265. The factor 'π_7 is related to cutting angle of cutter is the most influencing term in this model. The value of this index is positive indicating involvement of cutting angle of cutter has strong impact on π_{D3} and π_{D3} is directly varying with respect to π_7.

The absolute index of π_3 is lowest viz. 0.0101. Thus π_3, the term related to time required to speed up the flywheel is the least influencing term in this model. Low value of absolute index indicates the factor time required to speed up the flywheel needs improvement.

The sequence of influence of the other independent pi terms present in this model is π_1, and π_5 having absolute indices 0.7188 and 0.0265, respectively. The index of π_2, π_4 and π_6 are negative viz. -1.2769, -1.3708 and -7.5718, respectively. The negative indices are indicating need for improvement. The negative indices indicating that π_{D3} varies inversely with respect to π_2, π_4 and π_6.

The constant in this model is 7.68×10^{10}. This value being greater than one, hence it has a highly significant effect in the value computed from the product of the various terms of the model.

Analysis from sensitivity of the models:

For processing time, highest change takes place because of the pi term π_7, whereas the least change takes place due to the pi term π_5. Thus, π_7 is the most sensitive pi term and π_5 is the least sensitive pi term. The sequence of the various pi terms in the descending order of sensitivity is π_7, π_6, π_4, π_1, π_3, π_2 and π_5.

For no. of slivers, highest change occurred because of the pi term π_7, whereas the least change takes place due to the pi term π_3. Thus, π_7 is the most sensitive pi term and π_3 is the least sensitive pi term. The sequence of the various pi terms in the descending order of sensitivity is π_7, π_6, π_4, π_1, π_2, π_5 and π_3.

For average resistive torque, highest change occurred because of the pi term π_7, whereas the least change takes place due to the pi term π_5. Thus, π_7 is the most sensitive pi term and π_5 is the least sensitive pi term. The sequence of the various pi terms in the descending order of sensitivity is π_7, π_6, π_4, π_2, π_1, π_3 and π_5.

For total resistive torque, highest change was noticed because of the pi term π_6, whereas the least change takes place due to the pi term π_3. Thus, π_6 is the most sensitive pi term and π_3 is the least sensitive pi term. The sequence of the various pi terms in the descending order of sensitivity is π_6, π_7, π_4, π_2, π_1, π_5 and π_3.

CONCLUSIONS

The present machine is robust in construction. It can be operated by skilled/semiskilled/unskilled operators. Any size of bamboo can be easily processed on this machine.

Since the machine operation is by HPFM, it does not require electricity to work; hence this machine is very useful in the rural/interior/remote areas where electricity is lacking and problems of load shedding. As the time and work required in bamboo processing is saved because of this machine, people can spend more time on manufacturing varieties of good quality bamboo articles.

The trends for the behavior of the models demonstrated by graphical analysis, influence analysis and sensitivity analysis have been found complementary to each other. It was observed that the variation in the sliver cutting shaft was exponentially dropping. This may be due to linearly varying load torque on the process unit shaft exerted in the process resistance and inertia resistances which are likely to be instantaneous speed depend upon the variation in human energy, non-linear cross section of bamboo and quality of bamboo in 0.5 to 5 seconds.

The values of dependent term obtained from experimental data, mathematical model and ANN were compared. From the values of percent errors, it has been noted that the mathematical models can be successfully used for the computation of dependent terms for a given set of independent terms. With the help of present bamboo sliver cutting machine driven by HPFM, the sliver lengths of 1.5 feet, 2.0 feet and 2.5 feet can be produced successfully.

From sensitivity analysis of human powered bamboo sliver cutting operation, it was shown that–

For models of processing time and number of slivers, cutting angle of the cutter and elasticity of material is predominant over Machine geometrical parameters, Angular speed of flywheel, Time to speed up flywheel, Energy of flywheel, Gear ratio.

For model of average resistive torque, cutting angle of the cutter was the most influencing term whereas elasticity of material is second influencing term over the others like machine geometrical parameters, angular speed of flywheel, time to speed up flywheel, energy of flywheel, gear ratio. Whereas, in the case of total resistive torque, elasticity of material was the most influencing term and cutting angle of cutter is second influencing term over the others.

From reliability analysis of human powered bamboo sliver cutting operation, it was shown that the reliability of dependent variables processing time, number of slivers, resistive torque-average and resistive torque-total were found to be 85 %, 89 %, 92 % and 84 %, respectively.

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