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Design of experimentation and application of methodology of engineering experimentation for investigation of processing torque, energy and time required in bamboo processing operations

C. N. Sakhale[1], J. P. Modak[2], P. M. Bapat[3] and M. P. Singh[2]
[1]*Mechanical Engineering Department, Priyadarshini College of Engineering, CRPF Campus, MIDC Hingna Road, Digdoh Hills, Nagpur, India*
[2]*Priyadarshini College of Engineering, Nagpur, India*
[3]*Cummins College of Engineering for Women, Nagpur, India*

Abstract: The evolution of bamboo machining properties using processing cutters is a complex phenomenon. There are many factors (like geometric variables of machine and bamboo, variation in angular speed, processing torque and variation in current) affecting the performance of bamboo processing machine. In this paper an attempt is made to present the design of experimental approach in detail for gathering information to generate mathematical model for bamboo processing operations. Subsequently, sensitivity analysis, reliability and optimization of these models are established. Lastly, the ANN simulation of the behavioral data of the system is also established. In this, paper calculations for formulation of mathematical model only for stick making operation is explained in details. This paper reports on design and development of machine with specialty of multiple operations of bamboo processing incorporated in a single machine. It also includes designing of measuring devices for measurement of current drawn, processing torque, energy, and time required for each processing operations using specially designed electronic kit.

Keywords: Bamboo processing torque, opto-coupler, optimization, sensitivity analysis, Artificial Neural Network.

INTRODUCTION

Initial treatment to raw bamboo before ready for actual work is called bamboo processing which includes cross-cutting, splitting, external and internal knot removing, two side planner, four side planner, long sliver making through horizontal slicing, bamboo sticks making and sundering (Janssen, 1981, 2001; Janssen and Vaessen, 1997). At present, individual machines (Prashant Bamboo Machine, Wood Masters

* To whom correspondence should be addressed; E-mail: chsakhale@ gmail.com, ch_sakhale@rediffmail.com

(India) Machines, and VEDHA) are available for bamboo processing. But, operating of these machines for individual operations consumes time, material and also power requirement due to which cost of the operation carried out is very high. Also, to carry out these four operations require four different machines which again is a costly proposition. Thus, it was decided to develop a single machine, which can carried out all four operations, machine to be benefited from cost point of view and time.

In the year 2000, an International Symposium titled "International Training Workshop On Sustainable Bamboo Management and Processing Techniques for Small – Size Bamboo Enterprises" took place in Hangzhou, Zhejiang, China, organized by Ministry of Science and Technology of China which shows that although several types of bamboo processing devices have been developed, the proposed machine in this investigation has not reported in the literature (Liu, 2000). Similarly, the Proceedings of 7th World Bamboo Congress which took place in New Delhi (INDIA) in February 2004, Gnanaharan and Mosteiro (1997) and report of Oberai (2005) shows that no attempt so far towards design and development of this type of machine is done. Hence, development of the proposed machine is justified as an original future contribution. Obviously, when several operations can take place in one machine, it is bound to be commercially viable.

Hence, it was decided to design and fabricate the machine, which eliminated the disadvantages offered by the existing processing machines. For the fabrication of the machine RPS (Research Promotion Scheme) grant of Rs. 5.00 Lakhs was received from AICTE, New Delhi (India). Initially power estimation and design calculations were made (Basu *et al.*, 1993; Basu and Pal, 1990; ASTME, 1959; CMTI, 1988). The machine was fabricated and tested for all successful test runs and obtained good results.

For measurement and estimation of processing torque, energy and time required for bamboo processing operations, it is necessary to construct specially designed setup for measurements. So, measuring instruments were designed and fabricated according to expected output envisaged. The instruments measure speed, torque and current drawn from main supply. Energy meter and stop watch measure processing energy and time respectively. Subsequently, experimentation plan was formed, experimental setup is designed, experimentation is performed, and mathematical models were formed and interpreted.

Construction details of bamboo processing machine

Figure 1 and 2 provide the details of construction and power flow of machine respectively. Power is transmitted through a motor of 3 HP (3 phase induction motor) at 1440 rpm which is located at the base of the machine with double grove pulley. The power is transmitted to the cutter and planner shaft through the belt drive with velocity ratio of 1:5. From the same motor, pulley power is transmitted to sliver cutter shaft 1

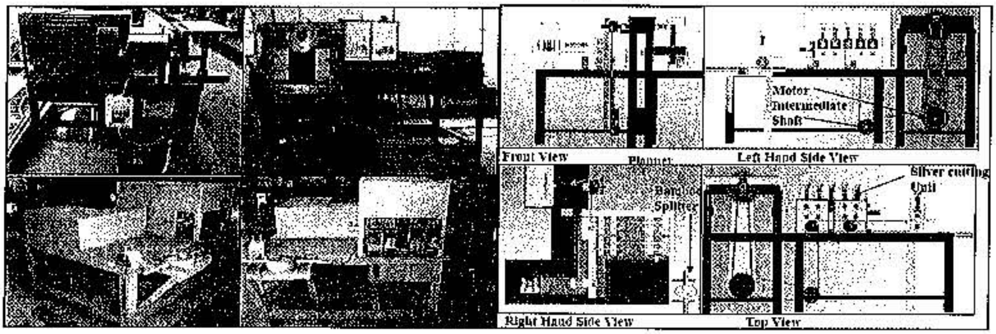


Figure 1. Fabricated and CAD Model of a Comprehensive Bamboo Processing Machine

which is rotating at 432 rpm through intermediate shaft. Sliver cutter 1 drives another sliver cutter shaft 2 which rotates at the same speed. These two shafts drive upper two shafts located exactly above it through spur gear. These four shafts drive pull in and push out rollers through knuckle joints. From sliver cutting shaft 2 power is given to stick making shaft, which drives the gear train assembly. This gear train drives steel stick making roller through knuckle and pipe power transmitting drive sets. The steel roller is fitted in the housing, which is supported by foundation frame. Between the steel rollers sharp blades are fitted for distance adjustment and stick cutting during stick making operation. The feeder is fitted at pushing end of roller pair of sliver cutting unit. Sliver cutter is fitted between top and bottom of pulling out roller pair. Internal knot cutter is fitted between intermediate push and pull out rollers. Splitter is fitted at back end of machine.

The cross cutter and planner are used for cross cutting and external knot removing. For cross cutting, bamboo is fed in radial direction and for planner operation it is fed in the axial direction. For splitting bamboo is kept axially over the center of splitter and hammered vertically in the downward direction. The split bamboo is fed through the feeder located between top and bottom pair of push in arbor type roller. The push in and push out arbor type rollers are used for the purpose of rolling split bamboo. Internal knot cutter removes internal knot and sliver cutter makes slices of split bamboo. For stick making slivers are passed between stick making roller blades.

Experimental setup

The experimental setup is shown in Figure 3. In bamboo processing, the objective of the experimenter is to gather information through experimentation for formulation of mathematical model for bamboo processing operations. During cutting operation for the measurement resistance torque, torque without load (*i.e.*, load torque) and torque with load (*i.e.*, driving torque) are measured using slotted opto-coupler (Chieze Ibeneche, 2008). Energy and time are measured using energy meter and stopwatch respectively. For the measurement of current drawn, speed and torque specially designed circuit is used (Figures 3, 4).

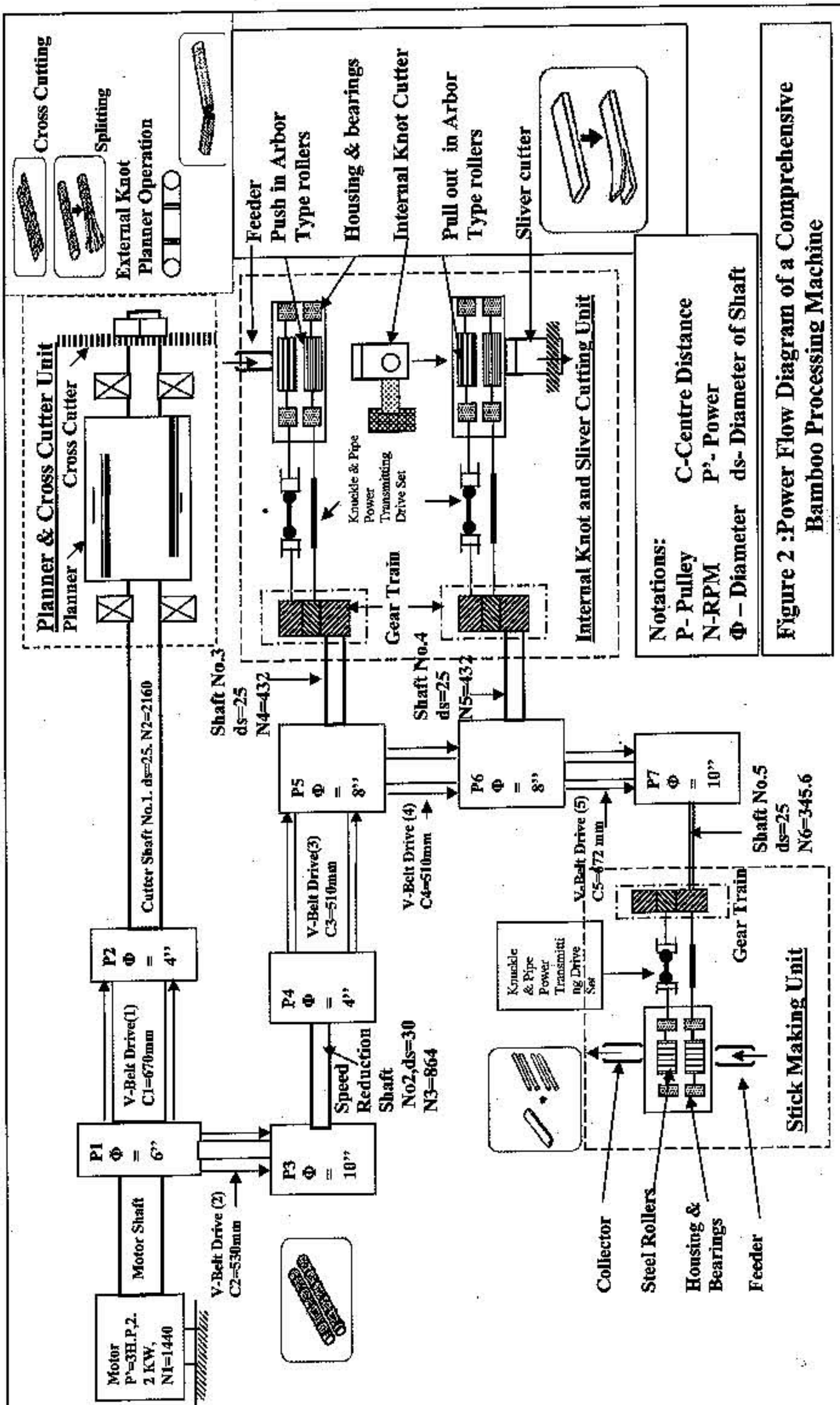


Figure 2 :Power Flow Diagram of a Comprehensive Bamboo Processing Machine

Figure 3. Experimental setup showing Slotted opto-coupler fitted below the cutter shaft and thin plate welded to shafts,circuit, circuit fitted to machine and output given to personal computer

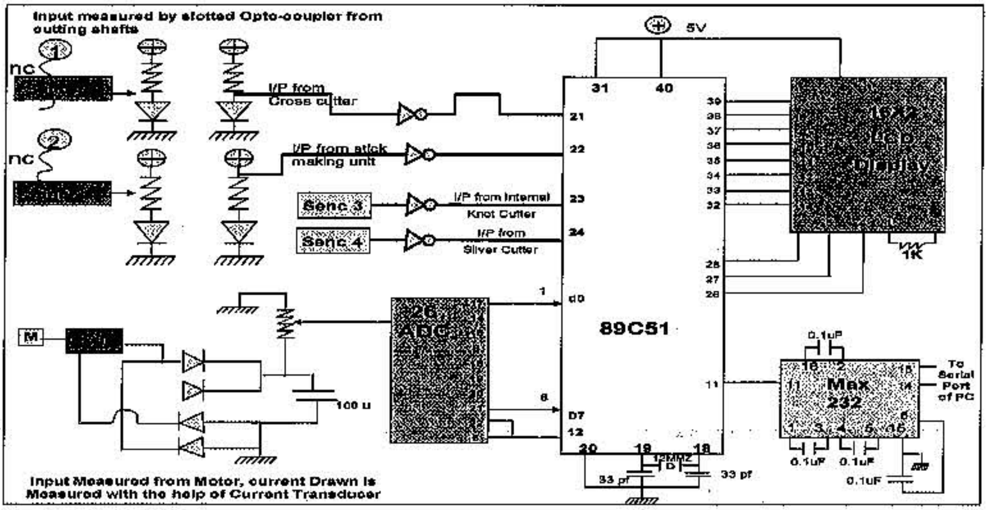


Figure 4. Circuit diagram of electronic kit

Design of experimentation

A number of experiments were conducted to study the effects of various machining parameters on bamboo processing operations. These studies were undertaken to investigate the effects of various sizes of bamboo, speed of cutting, geometry and material of cutters and other machine parameters on torque, energy and time required for processing operations. During experimentation various verities and sizes of bamboo samples were processed at three different speeds. The response of cutting phenomenon processing torque, energy and time were measured experimentally. In cross cutting operation along with different sizes of bamboo and cutting speed (1440, 1800, 2160 rpm), three cutters of different diameter, number of teeth and thickness were also used during experimentation. For external knot removal, bamboo of different knot thickness were selected and processed at three different speeds1440, 1800, 2160 rpm. In internal knot cutting, sliver cutting and stick making operations, 21 samples of different sizes were taken and processed at three different speeds (for Internal knot removing: 288, 360 and 432 rpm and for stick cutting 235,290 and 345 rpm). The formulation of mathematical model for stick cutting operation is given below.

Experimental approach (Quantitative)

A theoretical approach can be adopted for a phenomenon if a known logic can be applied for correlating the various dependent and independent parameters of the system. Though qualitatively, the relationships between the dependent and independent parameters are known based on the available literature, the generalized quantitative relationships are often not known. Whatever quantitative relationships are known those are pertaining to a specific machining data and specific task. The machining data for processing bamboo is not available for designers of industries engaged in the manufacturing of bamboo processing machines. On account of no possibility of formulation of theoretical model (logic based) one is left with the only alternative of formulating experimental data based model. Hence, it is proposed to formulate such a model in the present investigation. The approach adopted for formulating generalized experimental model suggested by Hilbert Schenck Jr (1961) was adopted in this investigation. The same is detailed below stepwise.

1) Identification of independent, dependent and extraneous variables. 2) Reduction of independent variables adopting dimensional analysis. 3) Test planning comprising of determination of test envelope, test points, test sequence and experimentation plan. 4) Physical design of an experimental setup. 5) Execution of experimentation.6) Purification of experimentation data.7) Formulation of the model 8) Model optimization 9) Reliability of the model.10) Artificial Neural Network (ANN) simulation of the experimental data.

The first five steps mentioned above constitute design of experimentation. Sixth step is as per rules of statistics. The seventh step constitutes model formulation whereas eighth and ninth steps are respectively optimization and reliability of model. The last step is ANN simulation of model explained by Modak and Bapat (1994) and Moghe, (1999).

Identification of variables

The variables influencing the phenomenon for stick cutting are speed, cutter roller dimensions, volume of bamboo material to be processed, elasticity of material of cutter blade bamboo and power. The dependent or the response variables in this case are: 1) processing torque, 2) processing energy and 3) processing time, which are presented in details in Table 1.

Test planning

This comprises of deciding test envelope, test points, test sequence and experimentation plan for deduced set of dimensional equations presented in Table 1.

Model formulation

It is necessary to correlate quantitatively various independent and dependent terms

Table 1. Testa envelope, test points for stick making operation

Pi term	Equation	Test envelope	Test points	Independent variables with its own range				
Π_1	Volume of Bamboo: $\left(\frac{\omega^6}{g^3}\times V_b\right)$ $V_b = W_b x\ t_b x\ L_b$	(1.411637 to 73.77361)	1.41,2.29,2.31, 2.89, 3.1, 3.11,	W_b, mm	t_b, mm	L_b, mm	Vb= ,mm³	w (rpm)
			3.5 7,3.81,4.4,	20	1.5	170	5100	235
			4.47, 4.54,4.96,	22	1.5	300	9900	290
			5.69,6.11, 6.77,	20	2	300	12000	345
			6.82, 7.85,8.22,	20	2.1	300	12600	g =
			8.25,8.67,9.47,	21	2	300	12600	9810mm
			9.78,10.46,11.21,	21.5	1.5	400	12900	/sec²
			12.01,13.4,13.75,	23	2	300	13800	Constant
			13.89,13.95,14.45,	21	1.8	400	15120	
			15.53,15.72,	22	2	400	17600	
			15.78,16.2,16.81,	24	2	400	19200	
			19.44,20.34,22.43,	24	1.8	450	19440	
			23.31,23.93,	26	1.5	500	19500	
			28.26,29.67,	27	2.5	300	20250	
			30.38,32.5,35.61,	21	2.5	400	21000	
			37.01,41.45,	26.7	1.6	550	23496	
			45.2,45.79,45.93,	26	2	500	26000	
			47.69,49.46,	25	3.5	300	26250	
			55.34,61.2,	22	2.5	500	27500	
			61.83,64.77,	20	3	500	30000	
			70.66,73.1,73.77	22.5	2.3	600	31050	
				29	2.7	400	31320	
Π_2	Cutter & roller Distance & Dimension: $\left(\frac{\omega^5}{g^4}\times L\times L_{rc}\times D_r\times W_r\right)$	(16.33986 to 352.5804)	16.33986, 87.87987, 352.5804	L / L_{rc}	Dr	Wr	ω (rpm)	g,mm /sec²
							235	9810
							290	
				20 / 25	50	45	345	
Π_3	Elasticity of materials: $\left(\frac{Eb}{Ec}\right)$	$9.71\text{x}10^{-02}$ Constant	$9.71\text{x}10^{-02}$	E_b=20000 N/mm²			E_c=206000 N/mm²	
Π_4	Power: $\left(\frac{\omega^5\times P}{g\times Ec}\right)$	(0.000102 to 0.000696)	0.000102, 0.000292, 0.000696	ω (rpm)		g, mm/sec²		P, Kw
				235				2.2
				290				
				345		9810		

involved in this complex phenomenon. This correlation is nothing but a mathematical model. The model can be tested as a design tool. The mathematical model for stick making operation is shown below.

For stick making operation

Mathematical model (Π_{11}) for Processing torque (T_p) :

$$T_p = 3.30293 \times 10^{23} \times \left(\frac{g^3 \times Ec}{\omega^6}\right)\left[\left(\frac{\omega^6}{g^3} \times V_b\right)^{0.1494} \times \left(\frac{\omega^8}{g^4} \times L \times L_{rc} \times D_r \times W_r\right)^{-2.0411} \times \left(\frac{Eb}{Ec}\right)^{10.8584} \times \left(\frac{\omega^5 \times P}{g \times Ec}\right)^{4.0462}\right] \quad \text{.......... (1)}$$

Mathematical model (Π_{12}) for Energy (E):

$$E = 37940.23355 \times \left(\frac{g^3 \times Ec}{\omega^6}\right)\left[\left(\frac{\omega^6}{g^3} \times V_b\right)^{0.7834} \times \left(\frac{\omega^8}{g^4} \times L \times L_{rc} \times D_r \times W_r\right)^{-0.2359} \times \left(\frac{Eb}{Ec}\right)^{4.1213} \times \left(\frac{\omega^5 \times P}{g \times Ec}\right)^{0.6354}\right] \quad \text{..........(2)}$$

Mathematical model (Π_{13}) for Processing time (t_p):

$$t_p = 55.71857489 \times \left(\frac{1}{\omega}\right)\left[\left(\frac{\omega^6}{g^3} \times V_b\right)^{0.112} \times \left(\frac{\omega^8}{g^4} \times L \times L_{rc} \times D_r \times W_r\right)^{-0.1698} \times \left(\frac{Eb}{Ec}\right)^{-0.9458} \times \left(\frac{\omega^5 \times P}{g \times Ec}\right)^{0.352}\right] \quad \text{..........(3)}$$

Sensitivity analysis

Sensitivity is defined as the average values of the change in the dependent À term due to the introduced change of ± 10 per cent in each independent À term. The total per cent change in output for ±10 per cent change in input is shown in Table 2.

Estimation of limiting values of response variables

The ultimate objective of this work is not merely developing the models but to find

Table 2. Sensitivity analysis of response variables

Sensitivity analysis				Limiting values of response variables			
Pi terms	Torque: Π_{11}	Energy: Π_{12}	Time: Π_{13}	Response Variables maximum & min. value	Torque: Π_{11}	Energy: Π_{12}	Time: Π_{13}
Pi 1-% Change	2.99	15.67	2.24	Maximum	1429234.684	0.04222	1.330582
Pi 2-% Change	41.67	4.73	3.4121		N-mm	Kw-hr	Seconds
Pi 3-% Change	249.63	83.33	19.09	Minimum	0.6338	0.0002723	0.2579
Pi 4-% Change	81.76	12.71	7.05		N-mm	Kw-hr	Seconds

out best set of dependant variables, which will result in maximization/minimization of the response variables. In this section attempt was made to find out the limiting values of three response variables *viz.* processing torque, energy and time of five processing operations. To achieve this, limiting values of independent pi terms *viz.* $\pi1, \pi2, \pi3, \pi4$ are substituted in the respective models. In the process of maximization, maximum value of independent À term is substituted in the model if the index of the term was positive and minimum value is substituted if the index of the term was negative. In the process of minimization, minimum value of independent π term is substituted in the model if the index of the term was positive and maximum value is substituted if the index of the term was negative. The limiting values of these response variables are presented below:

$$T_{p\,max} = 3.30293 \times 10^{23} \times (403652140)[(73.77361)^{0.1494} \times (16.33986)^{-2.0411}$$

$$\times (0.097087)^{10.8584} \times (0.000696)^{4.0462}] = 1429234.684 \text{ N-mm}$$

$$T_{p\,min} = 3.30293 \times 10^{23} \times (403652140)[1.411637)^{0.1494} \times (352.5804)^{-2.0411}$$

$$\times (0.097087)^{10.8584} \times (0.000102)^{4.0462}] = 0.633893134 \text{ N-mm}$$

$$E_{max} = 37940.23355 \times (4.04 \times 10^{8})[(73.77361)^{0.7834} \times (16.33986,)^{-0.2359}$$

$$\times (0.097087)^{4.1213} \times (0.000696)^{0.6354}] = 152025498 = 0.04222931 \text{ Kw-hr}$$

$$E_{min} = 37940.23355 \times (4.04 \times 10^{8})[(1.411637)^{0.7834} \times (352.5804)^{-0.2359}$$

$$\times (0.097087)^{4.1213} \times (0.000102)^{0.6354}] = 980469.924 = 0.00027235 \text{ Kw-hr}$$

$$t_{p\,max} = 55.71857489 \times (0.03374768)\ [(73.77361)^{0.112} \times (16.33986)^{-0.1698}$$

$$\times (0.097087)^{-0.9458} \times (0.000696)^{0.352}] = 1.330582218 \text{ Sec.}$$

$$t_{p\,min} = 55.71857489 \times (0.03374768)\ [(1.411637)^{0.112} \times (352.5804)^{-0.1698}$$

$$\times (0.097087)^{-0.9458} \times (0.000102)^{0.352}] = 0.257993489 \text{ Sec.}$$

4.7 Reliability of Model: The reliability is given by,

Reliability = (1-mean error) ....(4)

Mean error = Σfi*xi/Σfi ....(5)

In Equation 5, fi is the frequency of occurrence and xi is the % of error.

The total reliability for the parallel system is calculated by relation:

$$\text{System Reliability (Rp)} = 1 - \prod_{i=1}^{n}(1-R_i) \ ..... (6)$$

Therefore, reliability of the system for this case is given by

System Reliability (Rp) =1-[(1-RiE)*(1-RiTp)*(1-Ritp)]. ..... (7)

In Equation 7 Rp is the total reliability of parallel system RiE is the reliability of processing energy, RiTp is the reliability of processing torque, and Ritp is the reliability of processing torque. Since, observations were taken simultaneously during experimentation. Therefore, the total reliability of stick cutting models is =1-[(1-0.92873)(1- 0.43873)(1- 0.552698)= 0.982107 =98.21072 per cent.

Model optimization

The objective functions for processing torque, energy and time required for processing of bamboo need to be minimized. The models have a non-linear form hence, it is to be converted into a linear form for optimization purpose (Singiresu, 2002; Rao 1984). This can be achieved by taking the log of both the sides of the model. The linear programming technique is applied which is detailed as below for stick cutting operation. Taking log of both the sides of the Equation 1, we get

$$\text{Log}(\eta_{11})=\log(3.30293 \text{ x } 10^{23})+\log\left(\frac{g^3\times Ec}{\omega^6}\right)+0.1494 \text{ x } \log \text{ x}\left(\frac{\omega^6}{g^3}\times V_b\right)-$$

$$2.0411\text{x}\log\left(\frac{\omega^8}{g^4}\times L\times L_{rc}\times D_r\times W_r\right)+10.8584 \text{ x } \log\left(\frac{Eb}{Ec}\right) 4.0462 \text{ x } \log\left(\frac{\omega^5\times P}{g\times Ec}\right)$$

$Z = K+ K_1+ a \text{ x } X_1+ b \text{ x } X_2+ c \text{ x } X_3+d \text{ x } X_4$..... (8) and

$Z = \log(3.30293 \text{ x } 10^{23})+\log(403652140) + 0.1494 \text{ x}$

$\log (\eta_1) + 2.0411\log (\eta_2) +10.8584 \log (\eta_3) +4.0462 \log (\eta_4)$

Z (Torque: $_{11}$ min) =23.5189 +8.606007+ 0.1494 x X_1-2.0411 x X_2+10.8584 x X_3 +4.0462x X_4 –(9)

Similarly,

Z (Energy: $_{12}$ min) = 4.5791 + 8.065539 +0.7834 x X_1-0.2359x X_2+4.1213 x X_3 +0.6354 x X_4—(10)

Z (Time: $_{13}$ min) = 1.746 -1.47176 + 0.112 x X_1-0.1698 x X_2 -0.9458 x X_3+0.352 x X_4————(11)

Subject to the following constraints

1 x X_1+ 0 x X_2 + 0 x X_3 + 0 x X_4 d•1.867901

1 x X_1+ 0 x X_2 + 0 x X_3 + 0 x X_4 e•0.149723

0 x X_1+ 1 x X_2 + 0 x X_3 + 0 x X_4 d•2.547258

0 x X_1+ 1 x X_2 + 0 x X_3 + 0 x X_4 e•1.213248

0 x X_1+ 0 x X_2 + 1 x X_3 + 0 x X_4 d•-1.01284

0 x X_1+ 0 x X_2 + 1 x X_3 + 0 x X_4 e•-1.01284

0 x X_1+ 0 x X_2 + 0 x X_3 + 1 x X_4 d•-3.15721

0 x X_1+ 0 x X_2 + 0 x X_3 + 1 x X_4 e•-3.99097——(12)

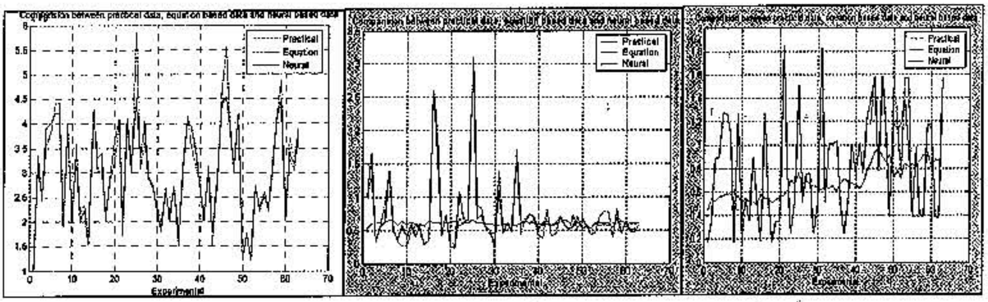
On solving the above set of equations by using MS solver we get values of X_1, X2, X3, X4 and Z. Thus $_{11\ min}$ = Antilog of Z and corresponding to this value of the $_{11min}$ the values of the independent terms are obtained by taking the antilog of X_1,X_2,X_3,X_4 and Z. Similar procedure is adopted to optimize the models for $_{12min}$ and $_{13min}$ and the optimized values of $_{11\ min,\ 12\ min}$ and $_{13\ min}$ are tabulated in the following Table 3.

Table 3. Optimized values of $\Pi_{11\ min}$, $\Pi_{12\ min}$ and $\Pi_{13\ min}$

	Torque: Π_{11} min		Energy: Π_{12} min		Time: Π_{13} 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
Z	-0.197983952	0.633389	5.991434276	980469.9	-0.588391254	0.257993
X_1	0.14972311	1.411637	0.14972311	1.411637	0.14972311	1.411637
X_2	2.547258198	352.5804	2.547258198	352.5804	2.547258198	352.5804
X_3	-1.012837225	0.097087	-1.012837225	0.097087	-1.012837225	0.097087
X_4	-3.99096916	0.000102	-3.99096916	0.000102	-3.99096916	0.000102

Computation of the predicted values by Artificial Neural Network (ANN)

In this research the objective is to formulate models for prognosis. In such complex phenomenon involving non-linear system it is also planned to develop Artificial Neural Network (ANN). The output of this network can be evaluated by comparing it with observed data and the data calculated from the mathematical models equations (1), (2) and (3). For development of ANN the investigator / researcher has to recognize the inherent patterns. Once this is accomplished training the network is mostly a fine-tuning process .The results of ANN are shown in Figure 5.



Stick making operation: Energy, Time and Torque

Figure 5. Comparison of results of experimental, mathematical model and ANN

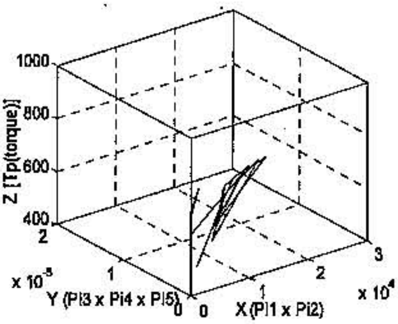
3-D / 2-D graph : It is possible to evaluate the behavior of any model through graphical presentation to justify how the real phenomena work on account of appropriate interaction of independent terms. For plotting 3D and 2D graphs for stick cutting operation combination of (Pi1 x Pi2) is taken on X-axis, combination of (Pi3 x Pi4) on Y-axis and response variable (*i.e.* Energy, Processing Torque and Time) on Z-axis (Modak, 2010). Figure 6 shows 3D and 2-D graphs for stick cutting operation.

RESULTS AND DISCUSSION

I] Analysis of the model for dependent pi term Π_{11}, Π_{12} and Π_{13}

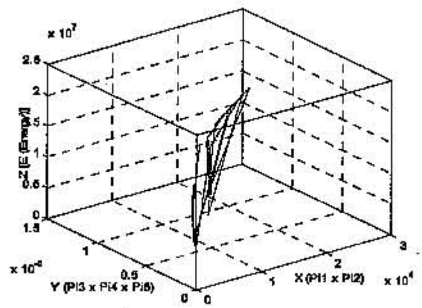
A) Energy:

3-D Graph: Processing torque required in Silver cutting operation



B) Torque:

3-D Graph: Energy required in Stick making operation



C) Time:

3-D Graph: Processing time required in Stick making operation

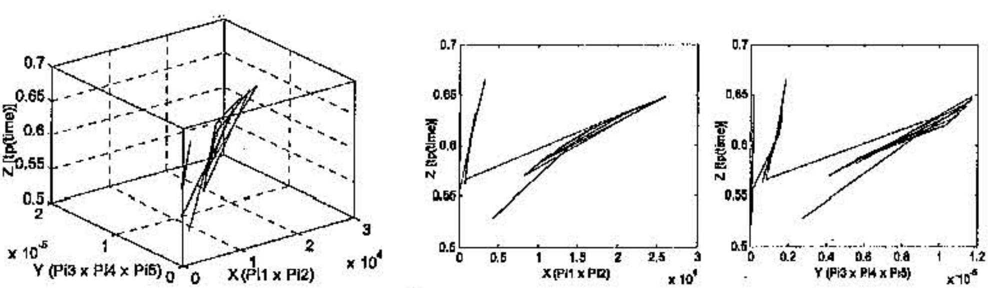


Figure 6. 3-D and 2-D Graphs for Pi term vs. response variables of Stick making operation

$$p_{11=}\left(\frac{\omega^6 \times Tp}{g^3 \times Ec}\right) = 3.30293 \text{ x } 10^{23} \text{ x } (p_1)^{0.1494}\,(p_2)^{-2.0411}\,(p_3)^{10.8584}\,(p_4)^{4.0462} \quad ..(9)$$

$$p_{12=}\left(\frac{\omega^6 \times E}{g^3 \times Ec}\right) = 37940.23355 \text{ x } (p_1)^{0.7834}\,(p_2)^{-0.2359}\,(p_3)^{4.1213}\,(p_4)^{0.6354} \quad ..(10)$$

$$p_{13=}(tp \times a) = 55.71857489 \text{ x } (p_1)^{0.112}\,(p_2)^{-0.1698}\,(p_3)^{-0.9458}\,(p_4)^{0.352} \quad ..(11)$$

It would be seen that the equation 9, 10 and 11 is a model of a pi term containing Processing Torque (Tp), Processing Energy (E) and Processing Time tp as a response variable. The following primary conclusion drawn appears to be justified from the above model.

1) The absolute index of π_3 is highest for Π_{11}, Π_{12} viz. 10.8584, 4.1213and π_4 is highest for Π_{13} (ie.0.352). The factor π_3, and π_4, is related to ratio of elasticity of material and power is the most influencing term in this model. The value of this index is positive indicating involvement of ratio of elasticity of material and power has strong impact on Π_{11}, Π_{12}, and Π_{13} respectively.

2) The absolute index of π_1, π_4 and π_1 is lowest index of Π_{11}, and Π_{13} respectively viz. 0.1494, 0.6354, and 0.112. The factor 'π_1 and π_4' is related to volume of bamboo sliver and power is the least influencing term in this model. Low value of absolute index indicates the factor Volume of bamboo sliver and power needs improvement.

3) The negative indices indicate there influence is inversely proportional. The negative indices of Π_{11}, Π_{12} are inversely varying with respect to π_3 and Π_{13} is inversely varying with respect to π_1.

4) The curve fitting constant K in this case equal to more than 1 for mode $\Pi 11$, $\Pi 12$ and $\Pi 13$. This represents the influence of all independent quantities is more which can not be measured collectively.

5) Sensitivity analysis of stick making operation indicates roller dimensions, is most sensitive and ratio of elasticity of material is least sensitive for model Π_{11} and hence needs strong improvement. Similarly volume of bamboo sliver and ratio of elasticity of material for model Π_{12} and Π_{13} are most sensitive and least sensitive respectively.

II) **Discussion of 3D and 2D graphs**: From 3D and 2D graphs it is observed that the phenomenon is complex because of variation in the dependent π terms are in a fluctuating form mainly due to continuous variation in the angular speed of the cutting shaft. This variation in the angular speed of cutting shaft is exponentially dropping. This in turn is due to nonlinearly varying load torque on the cutter shaft due to the process resistance and inertia resistances which are likely to be instantaneous speed dependent upon the variation in supply voltage, non-linear cross section of bamboo and quality of bamboo in 0.5 to 5 seconds. From Figure 6(A), it can be observed that there are 3 peaks in graph of Z *i.e.* processing torque vs. X. There must be in all 6 mechanisms which are responsible for giving these 3 peaks. Whereas in graph of Z *i.e.* processing torque vs. Y, there are 4 peaks. Hence there must be in all 8 mechanisms which are responsible for giving these 4 peaks. From Figure 6 (B), it can be observed that there are 3 peaks in graph of Z *i.e.* processing Energy vs. X. There must be in all 6 mechanisms which are responsible for giving these 3 peaks. Whereas in graph of Z *i.e.* processing Energy vs. Y, there are 8 peaks. Hence there must be in all 16 mechanisms which are responsible for giving these 8 peaks. Similarly from Figure 6 (C), it can be observed that there are 3 peaks in graph of Z *i.e.* processing time vs. X There must be in all 6 mechanisms which are responsible for giving these 3 peaks. Whereas in graph of Z *i.e.* processing time vs. Y, there are 9 peaks. Hence there must be in all 18 mechanisms which are responsible for giving these 9 peaks. This is based on reasoning given as regards deciding number of physical mechanisms prevalent in any complex phenomenon in a course work. (Modak, 2010)

CONCLUSIONS

In the present work all the details of proposed machine are found considering all design parameters. The present machine is robust in construction. It can be operated by three unskilled operators simultaneously. It has sufficient space on its bed. So, any size of bamboo can be easily processed on this machine. It has capability of 100 cuts per 8 hours shift. It can split bamboo of minimum diameter 50 mm to maximum diameter 150 mm. It saves power as well as money as compared with individual machines. This machine is very useful in rural areas because bamboo articles have very high demand in market in rural area. So, they can start their own business of making bamboo articles by purchasing this machine. Since all operations are done in a single machine, they need not require purchasing separate machineries for every operation.

The models have been formulated mathematically for the Indian conditions and bamboo species. The comparison of values of dependent term obtained from experimental data, mathematical model and ANN is shown in Table 4. From the values of per cent errors, it seems that the mathematical models can be successfully used for the computation of dependent terms for a given set of independent terms. Indian industries can use the data for calculation of cutting forces and power estimation for bamboo processing machines.

Table 4. Error estimation for stick making operation

Operation	Stick making operation		
Mean experimental	0.8176	0.0030	0.7000
Mean ANN	0.8176	0.0030	0.7031
Mean math. (model)	0.6842	0.0030	0.5999
MAEPF	0.0451	7.8252e-005	0.1014
MSEPF	0.0177	1.2508e-008	0.0206
Perf	3.9735	0.4290	0.65
% Error between model and ANN	19%	0%	6%
% Error between exp. and ANN	0%	0%	0.44%

Note: MAEPF : mean_absolute_error_performance_function
MSEPF :mean_squared_error_performance_function

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