Influence of Operational Variables in Bicycle Driven Bamboo Slicing Phenomena by Methodology of Response Surface Approach

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Since global energy consumption rises, there seems to be a pressing need to create innovative technologies for saving energy and power production, especially those with lower ecological effects. There is indeed a current must to discover an alternate for renewable sources of energy to be used at any time from any location as well as being accessible to the entire public. Human energy is indeed a kind of alternative energy which has been employed to varying degrees throughout history. In this regard, this research consists of the design and construction of a pedal-driven bamboo slivering (sliver making) machine powered by a human-powered flywheel motor (HPFM). This article evaluates the overall impacts of several process factors upon the outputs of the human-powered bamboo slivering (sliver cutting) phenomenon, such as torque -resistive, sliver numbers and processing time. The 108 sets of experiments were carried out based on which experimental based models were formulated by using designed experiments and the influence of several independent (input)factors on response (output factors) variables were investigated in cutting the slivers of bamboo using an approach of response surface methodology.

Keywords: Bamboo sliver, HPFM, response surface methodology, energy, dependant variable, independent variable.

1 Introduction

The power of human and its energy was disregarded during periods of increasing utilization of fossil fuels. However, because of extremely high costs of fossil fuels and the severe pollution of environment caused by them, human power has resurfaced as a sustainable source of energy. There are serious power shortfall issues as a result of increased industrialization, as well as due to constraints on non-availability of electricity in the interior and further power generation challenges. In this sense, the energy sources are human-powered systems, which are classified as non-conventional sources of energy. Bamboo compares favorably to other materials of building such as timber, concrete and steel in terms of energy needs during construction, simplicity of usage and safety, stiffness per unit area of material and strength. Bamboo's adaptability is partly owing to its anatomical structure, which adds to its mechanical qualities. Bamboo is the best to use everywhere due to its simplicity in production [1]. Aside from numerous of conventional methods and kinds where bamboo is largely employed for residential construction of buildings and houses, a number of commercially made items and components are used in construction of building [2]. Slivers of Bamboo are continually used for bamboo mats weaving, which have a broad range of uses such as wall paneling, handicrafts, furniture, wall papers, and so on, demonstrating the vast usage of slivers of bamboo in the industries and business manufacturing [3]. There is a significant influence of human activities on workings of Earth system such as growth in population, development of economy, and rising demands of energy. This enhances the need of dependable and reliable supply of energy that is robust to internal and external challenges which can conform unforeseen shocks in future. It is vital to emphasize that energy transformation should viewed as a means for dealing with grand energy challenges rather than global challenge [4]. In the current scenario, there is immediate requirement to identify alternative forms of power generation. The technologies of renewable or alternative energy are already acknowledged to have the potential to considerably cover the power demand resulting in reduction of emissions. To contribute to the sustainable development and prevent global catastrophe, it requires a speedy and worldwide shift to technology of renewable or alternative energy sources [5]. According to the reports and study, the renewable or alternative sources of energy may increase its proportion of total primary supply of energy from fifteen percent (in 2015) to sixty-three percent (in 2050). This probable growth of renewables along with increased energy efficiency may generate ninety-four percent of the reduction in emissions. While actual numbers may differ, the current scenario assessments agree that energy efficiency and alternative energy are more important to achieve the climate goals [6].

Alternative or renewable energies having lower environmental impacts can be considered to be only the possible solution for sustainability challenge which is been fought since long back. The global adoption of renewable energy remains restricted despite of growing knowledge of its numerous benefits. For the long term period, the traditional methods of power generation with exhaustible fuels like gas, oil and coal is usually seen as unreliable due to growing knowledge of environmental impacts [7]. Papadis, E. and Tsatsaronis, G. [8] in their paper examine the historical evolution of worldwide decarbonization facts and evaluated that technology pertaining to every sector. They assess the technological solutions whether feasible and sustainable for future trends of energy field and presented the analysis of issues in the view of economical, technical, societal and ecological challenges. The current state of affairs in the energy sector's decarbonization is far away from adequacy. Recent advances in atmospheric changes and rising emissions of carbon dioxide globally demonstrate that there is an urgent need to boost the efforts greatly for decarbonization of the energy issues [8]. Keeping view towards the severe challenges of energy crisis and its generation, many researchers have worked and are working on these issues to find out the solution. Modak J. P. and his colleagues [9 to 12] have constructed human powered machinery capable of energizing the process units requiring 3-7 HP which can be operated intermittently. The HPFM driven machines were designed and developed for wood turning [10], chaff cutter [11] and electricity generation [12] etc. which motivated the author to design and fabricate the human powered bamboo slicing machine. Sakhale, C. N. et al [13] had designed and developed the comprehensive bamboo processing machine run by an electric motor which comprises of four operations namely, (a) Bamboo cross cutting, (b) Bamboo Splitting, (c) Sliver cutting operation and (iv) Stick making. This machine is operated by means of electric motor which is again pointing towards the limitations on availability of electric power.

Therefore, with respect to a context of human powered operated systems as few of the forms of non-traditional energy, the bamboo slivering machine run by HPFM was designed, constructed and experiments were performed by identifying various process parameters (e.g. independent and dependent parameters) applying the design of experiments and experimentation theory [14]. The whole world is experiencing power and energy shortages as a result of lack of power in the interior and rural region. This is also due to various limitations on generation of additional power and energy. Thus, since this is the human operated machine and doesn't require electricity to run, this human powered machine is the best option in such energy crisis situation because the human energy is easily and globally available in ample quantity in every corner of the world. Human energy is proven to be the form of energy which does not have any severe impacts on climate, environment and atmosphere etc. The unskilled, semiskilled operator can operate this machine easily; hence it is very useful for the people facing the problems of power shortages which add to the enhancement of bamboo technology for low profiled people from the point of view of human powered mechanization.

2 Experimental Machine Set Up

The experimental machine set up consists of three major units viz. HPFM unit is bicycle driven unit which is energy unit with a flywheel and gear pair for speed raising, Unit of transmitting mechanical power comprising of gear pair for amplification of torque and clutch, and processing unit (used to cut the bamboo sliver) which consists of sliver cutter, feeder, adjusting knobs and two pairs of spring loaded rollers etc. These three units assemble the experimental set up of human powered bamboo slivering machine as shown in figure 1. The unit of HPFM, unit of transmitting mechanical power and processing unit (bamboo sliver cutting unit) are shown in figures 2, 3 and 4 respectively.

Figure 1: *Human powered bamboo slivering machine.*

Figure 2: *HPFM Unit.*

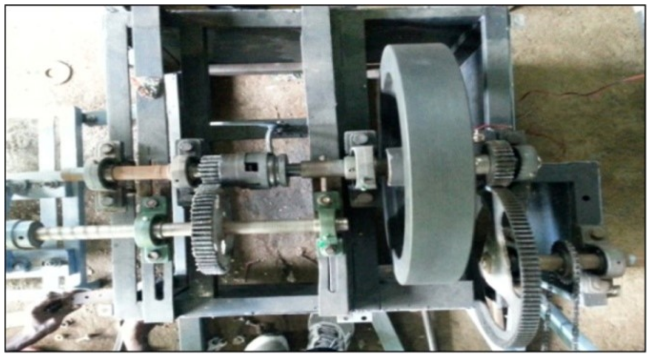

Figure 3: *Mechanical power transmission unit.*

Figure 4: *Different views of bamboo sliver cutting unit.*

2.1 Working Details of Experimental Set Up

When pedals of the bicycle driven unit are operated by operator, the energy is stored in the flywheel. Power of maximum cycling has an impact due to fatigue, rate of pedaling, composition of fiber and size of muscle. Rolling and aerodynamic friction restrict cycling speed, and any mismatch in applied vs necessary power leads to the variations in energy of the system[15]. When the flywheel stores sufficient required energy after pedaling, the flywheel energy is transmitted by engagement of clutch to the bamboo slivering unit via mechanical power transmission unit which commences the unit of bamboo sliver cutting to run. The feeder of slivering unit is fed with split bamboo which passes through the first pair of the push-in rollers and it further goes through the second pair of push-out rollers. Split bamboo strikes the cutter when it leaves push-out rollers which commence the cutting of sliver. The cutter is placed exactly in front of second pair of rollers. The sliver cutting action takes place instantly after the engagement of clutch and continues for the duration of about 5 to 20 seconds until flywheel stops rotating. The effect of increasing bicycle mass is insignificant with the most widely used gear ratios more than 1.5 [16]. The machine may be operated at various speeds by selecting the appropriate torque amplification gear ratio supplied on the slivering unit shaft. The CAD model of experimental machine set up is shown in figure 5 and that of different views of slivering unit is shown in figure 6.

The phenomena have been observed to be complicated owing to fluctuation in the dependent pi terms which fluctuates because of continual change in the angular or rotational speed of the bamboo slivering machine shaft. The variance in bamboo slivering machine shaft is decreasing rapidly. It is concerning with the resistance of operational process and inertial resistances, rely on linearly varying load torque due to fluctuations in human power or energy, bamboo material quality and non linear or varying cross sectional area of bamboo.

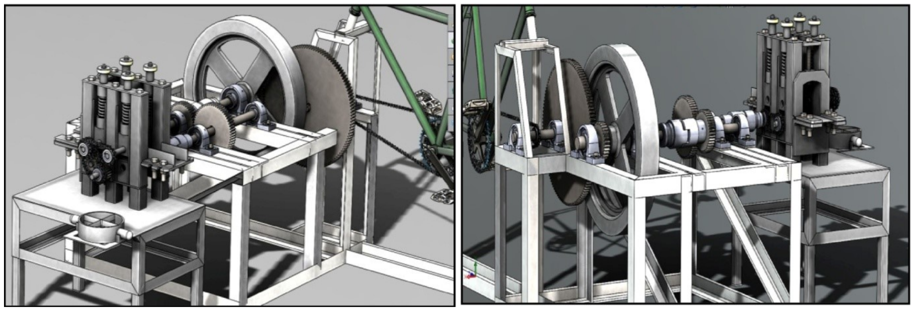

Figure 5: *CAD Model of Experimental set up (different views).*

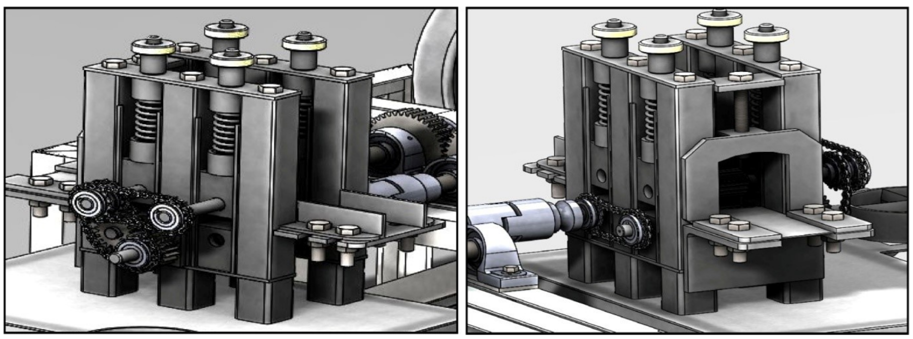

Figure 6: *CAD Model of Slivering Unit (different views).*

In the existing manual slivering machines, the manufacturers were capable of making the bamboo slivers of 1.0 to 1.5 feet long, but this HPFM driven machine can effectively manufacture the bamboo slices of 1.5 to 2.5 feet in length. The majority of the available manually operated slivering machineries are hand operated, but the present HPFM driven machine is powered by bicycle where the leg muscles are used which are marked superior to the arm muscles keeping view towards the power and energy requirements, and approaching output in the less operating time. Previously in all HPFM driven machines, most of the researchers have worked upon only the average torque of their operation. In the present research, the models are constructed for resistive torque (average) as well as resistive torque (total) in the bamboo slivering phenomena so that the influence of input factor upon the responses can be compared for both.

3 Experimental Design and Methodology

The methodology of theory of experimentation [14] was applied in this work. By applying the method of dimensional analysis using the approach of design of experiments (DoE), mathematical models for various dependent and independent process parameters were formulated after the proper determination of variables in the phenomenon of bamboo sliver cutting. Experiment design includes benefits like increasing the result attained, reducing variability, and bringing the result closer to the aim, as well as shortening the time period and lowering the cost. Several independent and dependent factors in the phenomena of cutting the slivers were identified which are shown in table 1, dimensional analysis was applied for the formation of pi-terms of all factors or parameters and independent (input) factors' pi-terms were reduced (refer table 2) to lessen the intricacy and achieve simplicity in the nature of the phenomena of cutting the slivers. Test planning to determine the experimental plan, test envelope, test sequence and test points was also performed. And after experimental design, experiment conduction and filtering or purifying experimental records, the models were formulated, optimized and reliability was also determined.

Table 1: Process parameters in sliver cutting phenomenon

Sr. No.	Parameters	Unit	Dimension	Type of Parameter
1	E_f= Stored Flywheel Energy	N-mm	ML^2T^{-2}	Independent
2	t_f= Speeding-up time of flywheel	Second	T	
3	Ω_f= Flywheel angular speed	Rad/s	T^{-1}	
4	L_b = Bamboo split length	mm	L	
5	g = Gravitational Acceleration	mm/s^2	LT^{-2}	
6	t_b = Bamboo split thickness	mm	L	
7	G = Gear Ratio	--	$M^0L^0T^0$	
8	W_b = Bamboo split width	mm	L	
9	E_c = Elastic Modulus of Cutter	N/mm^2	$ML^{-1}T^{-2}$	
10	C_H = Central (Horizontal) Distance between pairs of roller	mm	L	
11	Φ_c = Cutter's Cutting Angle	Degree	-	
12	L_{rc} = Cutter Tip to Roller Centre Distance	mm	L	
13	E_b = Elastic Modulus for Bamboo	N/mm^2	$ML^{-1}T^{-2}$	
14	C_V = Central (Vertical) Distance between pairs of rollers	mm	L	
15	n = Number of Slivers	--	$M^0L^0T^0$	Dependant
16	t_p = Processing Time	Second	T	
17	T_r = Torque (resistive)	N-mm	ML^2T^{-2}	

Table 2: Process parameters' Pi terms

Parameters	Pi terms of parameters	Equations of Pi terms	Details of Equations of Pi terms
Independent / Input parameters	π_1	$\pi_1 = \frac{E_f}{L_h^3 E_b}$	Refers to the flywheel energy
	π_2	$\pi_2 = \omega_f \sqrt{\frac{L_b}{g}}$	Refers to the flywheel angular speed
	π_3	$\pi_3 = t_f \sqrt{\frac{g}{L_b}}$	Refers to the speeding-up time of flywheel
	π_4	$\pi_4 = G$	Refers to the gear ratio
	π_5	$\pi_5 = \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)$	Refers to the machine's geometrical parameters
	π_6	$\pi_6 = \frac{E_c}{E_b}$	Refers to the elastic modulus of materials
	π_7	$\pi_7 = \varphi_c$	Refers to cutter's cutting angle
Dependent / Output Parameters	π_{D1}	$\pi_{D1} = t_p \sqrt{\frac{g}{L_b}}$	Refers to the time of processing or operational time
	π_{D2}	$\pi_{D2} = n$	Refers to the sliver numbers
	π_{D3}	$\pi_{D3} = \frac{T_r}{L_b^3 E_b}$	Refers to the torque (resistive)

3.1 Experimental Procedure

Classical experimentation plan [14] was utilized to perform the experiment. The experiment was designed and performed to accommodate the whole test envelope along with entire test points contained in the vicinity of test envelope. All independent pi terms with the exception of one are kept fixed at their predetermined fixed level values in experimental classical plan, and the aforementioned independent pi terms within attention are changed throughout the largest feasible range as determined by the test envelope.

The experimental procedure comprises of the processing of split bamboo of different widths, of different lengths (2.5, 2.0 and 1.5 in feet) having variety of diameters (50 to 60, 40 to 50 and 30 to 40 in mm). The machining process of sliver making from bamboo was performed at four different speeds (600, 500, 400 and300 in rpm). The process was performed at different gear ratios as1/4, 1/3 and 1/2. As a result, numerous bamboo varieties are employed during experiment to assess the machine's real practicality and feasibility. With the help of specifically built electronic kit (proper instrumentation) as shown in figure 7, flywheel speeding-up time, sliver numbers, torque (resistive) and processing time etc. are estimated and noted. In this experiment, one hundred and eight total sets of readings were performed. Table 3 gives the sample observation and experiment plan. For independent parameters related to slivering unit, the experimental observations are taken and some sample observations are presented in table 4. The experimental observations for energy unit as well as for the response factors of slivering phenomena are also taken and noted which are depicted in table 5.

Figure 7: *Designed electronic instrumentation system and experimental reading generation.*

3.2 Model Formulation

During experimentation the data of various dependent and independent variables are gathered. To formulate the mathematical model, the interrelation between dependent pi terms and independent pi terms in the sliver cutting phenomena is developed. Since the formulation of the model is performed pertaining to the data produced through the experiments, it is also termed as generalized experimental model. The models formulated for the dependent variables like time of processing (t_p), sliver number (n), resistive torque-average (T_{ravg}) and resistive torque-total (T_{rtotal}) are given in equations 1, 2, 3 and 4 respectively.

$$t_P = 5.15\,X10^{-10}\sqrt{\frac{L_b}{g}}\left\{\begin{array}{c}\left(\frac{E_f}{L_b^3 E_b}\right)^{0.2889}\left(\omega_f\sqrt{\frac{L_b}{g}}\right)^{0.1564}\left(t_f\sqrt{\frac{g}{L_b}}\right)^{-0.1769}\\ (G)^{-0.3499}\left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)^{0.0371}\left(\frac{E_c}{E_b}\right)^{-3.1676}(\varphi_c)^{-30.5644}\end{array}\right\} \quad (1)$$

Table 3: Sample observations for pedal powered Slivering Operation and Plan of Experiment (where Gear Ratio = 0.33)

Sr. No.	Bamboo Diameter Range (D_b) mm	Gear Ratio (G)	Bamboo split length (L_b) ft	Bamboo split length (L_b) mm	Speed (N) rpm	Bamboo split width (W_b) mm	Bamboo split thickness (t_b) mm	Flywheel speeding-up time (ω_f) sec	Processing Time (t_p) sec	Sliver number (n)
1	40-50	0.33	1.5	457.5	300	31	4.1	31.4	60	4
2	40-50	0.33	1.5	457.5	400	31.5	4.5	41.87	55	4
3	40-50	0.33	1.5	457.5	500	31.2	4.7	52.33	70	5
4	40-50	0.33	1.5	457.5	600	31.4	4.22	62.8	80	6
5	40-50	0.33	2	610	300	35	9.1	31.4	65	4
6	40-50	0.33	2	610	400	35.1	9.6	41.87	70	5
7	40-50	0.33	2	610	500	35.5	9	52.33	85	6
8	40-50	0.33	2	610	600	35.3	9.4	62.8	95	6
9	40-50	0.33	2.5	762.5	300	25.4	15.1	31.4	45	3
10	40-50	0.33	2.5	762.5	400	24.8	15.7	41.87	60	4

Table 4: Sample Observation table showing independent factors of bamboo sliver cutting unit

Sr. No.	Processing unit related independent factors or input parameters														
	D_b (mm)	W_b (mm)	t_b (mm)	L_b (ft)	L_b (mm)	N (rpm)	ω_f (rad./s)	G	E_b (N/mm²)	E_c (N/mm²)	C_H (mm)	C_V (mm)	L_{rc} (mm)	φ_c (deg)	φ_c (rad.)
1	40-50	31	4.1	1.5	457.5	300	31.4	0.33	20000	206000	115	65	45	15	0.261667
2	40-50	31.5	4.5	1.5	457.5	400	41.86667	0.33	20000	206000	115	65	45	15	0.261667
3	40-50	31.2	4.7	1.5	457.5	500	52.33333	0.33	20000	206000	115	65	45	15	0.261667
4	40-50	31.4	4.22	1.5	457.5	600	62.8	0.33	20000	206000	115	65	45	15	0.261667
5	40-50	35	9.1	2	610	300	31.4	0.33	20000	206000	115	65	45	15	0.261667
6	40-50	35.1	9.6	2	610	400	41.86667	0.33	20000	206000	115	65	45	15	0.261667
7	40-50	35.5	9	2	610	500	52.33333	0.33	20000	206000	115	65	45	15	0.261667
8	40-50	35.3	9.4	2	610	600	62.8	0.33	20000	206000	115	65	45	15	0.261667
9	40-50	25.4	15.1	2.5	762.5	300	31.4	0.33	20000	206000	115	65	45	15	0.261667
10	40-50	24.8	15.7	2.5	762.5	400	41.86667	0.33	20000	206000	115	65	45	15	0.261667
11	40-50	25.1	15.4	2.5	762.5	500	52.33333	0.33	20000	206000	115	65	45	15	0.261667
12	40-50	25	15.6	2.5	762.5	600	62.8	0.33	20000	206000	115	65	45	15	0.261667

Table 5: Observation (sample) table for dependent factors and energy unit

Sr. No.	Energy unit related independent factors				Dependent or Output Factors		
	I_f (kg.m^2)	g (mm/s^2)	E_f (N-m)	t_f (sec)	t_p (sec)	Res. Torque- Avg. T_r (N-mm)	n
1	3.44	9810	4710.698	50	70	21692.86	3
2	3.44	9810	6783.405	35	75	23760	3
3	3.44	9810	1695.851	30	35	20728.57	3
4	3.44	9810	3014.847	35	40	23387.5	3
5	3.44	9810	4710.698	45	55	23045.45	4
6	3.44	9810	6783.405	55	60	24208.33	4
7	3.44	9810	1695.851	25	45	21711.11	2
8	3.44	9810	3014.847	30	45	23336.36	3
9	3.44	9810	4710.698	30	65	23169.23	3

$$n = 174.1406 \left\{ \begin{matrix} \left(\frac{E_f}{L_b^3 E_b}\right)^{0.5082} \left(\omega_f \sqrt{\frac{L_b}{g}}\right)^{-0.3148} \left(t_f \sqrt{\frac{g}{L_b}}\right)^{-0.1208} \\ (G)^{-0.5089} \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)^{-0.1823} \left(\frac{E_c}{E_b}\right)^{1.3087} (\varphi_c)^{-1.4871} \end{matrix} \right\} \tag{2}$$

$$T_{ravg.} = 1.08E + 10\left(L_b^3 E_b\right) \left\{ \begin{matrix} \left(\frac{E_f}{L_b^3 E_b}\right)^{0.7824} \left(\omega_f \sqrt{\frac{L_b}{g}}\right)^{-1.0005} \left(t_f \sqrt{\frac{g}{L_b}}\right)^{-0.351} \\ (G)^{-1.4423} \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)^{0.0889} \left(\frac{E_c}{E_b}\right)^{4.289} (\varphi_c)^{23.515} \end{matrix} \right\} \tag{3}$$

$$T_{rtotal} = 7.68\, X10^{10}\left(L_b^3 E_b\right) \left\{ \begin{matrix} \left(\frac{E_f}{L_b^3 E_b}\right)^{0.7188} \left(\omega_f \sqrt{\frac{L_b}{g}}\right)^{-1.2769} \left(t_f \sqrt{\frac{g}{L_b}}\right)^{0.0101} \\ (G)^{-1.3708} \left(\frac{W_b t_b C_H C_V L_{rc}}{L_b^5}\right)^{0.0265} \left(\frac{E_c}{E_b}\right)^{-7.5718} (\varphi_c)^{6.7265} \end{matrix} \right\} \tag{4}$$

4 Response Surface Methodology (RSM) Approach

The response surface method's benefit as a strong analytical methodology is that, as compared to the conventional strategy, it provides a sharper visual depiction of focused connection [17]. RSM is a set of statistical as well as mathematical approaches which can be used to model and analyze issues wherein an interest response is influenced by numerous factors and the goal is to maximize this response. The RSM equation is given as:

$$Y_R = f(x_1, x_2) + E \tag{5}$$

Here, E is the error having Y_R response

x_1 is Operational parameter 1

x_2 is Operational parameter 2

Let E(Y$_R$) be the responses expected, then it is given by:

$$E(Y_R) = \eta = f(x_1, x_2) \tag{6}$$

Here response surface is the surface that is represented or notified by, $\eta = f(x_1, x_2)$

The type of connection between independent variables and the response is uncertain & unknown in the majority of RSM applications. Hence, the RSM's first step is to discover suitable and good approximate solution to the real functional relation between collection of independent variables and Y_R. In most cases, a polynomial of lower order in some area of independent or input parameters is often used. If response modeling is done well by functional linearity of input or independent parameter, the function of approximation results in the model of first order is:

$$Y_R = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots\cdots\cdots + \beta_n x_n + E \tag{7}$$

If the system has a curve, the greater degree polynomials like the model of second order must be utilized such as:

$$Y_R = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum\sum_{i<1}^{n} \beta_{ij}\, x_i x_j + E \tag{8}$$

The fitted surface is then utilized to perform the analysis of response surface. Analyzing the fitted surface is roughly comparable to analyze the actual data when the fitted surface is a good approximation of the underlying or real function of response.

4.1 Design of the Response Surface

Design of experiment, construction of model of response surface, testing of adaptability of model, search for optimum combination strategy and other procedures are included in the design of response surface. The accompanying second model of response surface may be utilized to generate a response surface of three-dimensions and contour line of two-dimensions, which intends to rapidly determine the correct values of response for various elements [18]. A quadratic surface can be appropriately fitted with the help of the RSM approach and aids in optimizing process variables with small number of tests/experiments while also analyzing parameter interaction. RSM is a statistical strategy that employs quantifiable information from relevant experiment to develop a model of regression and optimize an output or response parameter that is impacted by numerous input or independent factors [19]. Response Surface Approach is a descriptive statistics of experiments wherein the output is assumed to be fixed by one or more controllable parameters. The basic purpose of response surface approach is to identify an optimal response by employing a succession of experiment designs. This notion drives the need to carry out tests properly by selecting the correct design and motivates the pursuit of operating circumstances with a variety of controllable elements that result in an optimal response [20].

According to the approach of dimensional analysis adopted in this work, the total seven numbers of π terms were formed affecting the responses of the phenomena. Because these π terms are dimensionless, they may be simply divided in to three classes. To create the response surface, these three classes are transformed into 3-dimensions in space. Thus,

$$X = \pi_1 \times \pi_2 \times \pi_3, Y = \pi_4 \times \pi_5 \times \pi_6 \times \pi_7, Z = \pi_{D1} \tag{9}$$

The X, Y (input) and Z (output) ranges are more flexible and variant. As a result, the scaling of aforementioned factors X, Y (input) and Z (output) is depicted below by the use of principle of scaling:

$$x = \frac{X}{\max(X)}\ ,\ y = \frac{Y}{\max(Y)}\ ,\ z = \frac{Z}{\max(Z)} \tag{10}$$

5 Construction of Model by RSM

Models of RSM in conjunction with experiment design can be used as statistical and mathematical tools. This technique not only performs well in the optimizing facts, but it has also been validated for the approach of analysis and is useful for enrichment of product [21]. The numerical as well as experimental responses can be approximated by the use of response surface approach. There is requirement of two stages such as approximation function to be well defined and design & creation of the experimental plan. Therefore, it was decided to develop RSM model and compare its performance with the mathematical model developed in this investigation. The process variable values were established to evaluate their influence on the output variables in a total of 108 tests of readings in the experiment. Response surface approach was used to plan the design of experiments and carry out the studies of behavior of process variables. By the use of "MATLAB R2009a", the construction of response surface models and the selection of acceptable models were carried out. For the output parameters, total resistive torque, sliver number, process time and average resistive torque, regression equations of best fitting for the chosen model were produced [22]. For finding out the influence of various process variables on the characteristics of output responses, the equations of response surface are derived from the data of experiments and displayed in the figures 8 to 11. Sample calculations for processing time of RSM models are given in table 6, whereas table 7 gives the concerned calculations for number of slivers. The response surface calculations are also performed for torque-average and torque-total and are presented in tables 8 and 9 respectively.

5.1 Model Construction for Processing Time

Equation of response surface or equation of polynomial of the response surface model of fifth order is evaluated and developed for output variable, processing time and is given below:

$$\begin{aligned} t_P\sqrt{\frac{g}{L_b}} = {} & 0.6522 + 0.1308x - 0.232y - 0.2394x^2 + 0.2493xy - 0.003853y^2 + 0.01659x^3 \\ & - 0.03742x^2y - 0.03488xy^2 + 0.547y^3 + 0.1101x^4 - 0.3119x^3y \\ & + 0.02459x^2y^2 + 0.02152xy^3 - 0.316y^4 - 0.03037x^5 + 0.0904x^4y \\ & + 0.03629x^3y^2 - 0.01943x^2y^3 - 0.006172xy^4 + 0.04596y^5 \end{aligned}$$

Goodness of fit: summed Square of residuals or SSE: 1.123,
R square (R^2): 0.5872,
R-square (adjusted): 0.4923,
RMSE- Root Mean Square Error: 0.1136

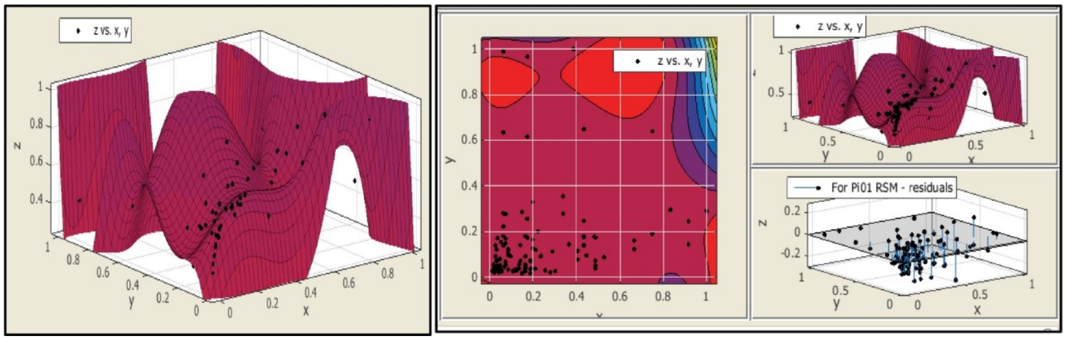

Figure 8: *RSM model and Contour, RSM and Residual plot for processing time.*

5.2 Model Construction for Number of Slivers

Equation of response surface or equation of polynomial of the response surface model of fifth order is evaluated and developed for output variable, sliver numbers and is given below:

$$\begin{aligned} n = {} & 0.3129 + 3.279x - 0.1789y - 19.41x^2 + 7.776xy - 0.7621y^2 + 43.66x^3 + 19.83x^2y \\ & - 38.92xy^2 + 4.978y^3 - 32.36x^4 - 85.82x^3y + 39.02x^2y^2 + 44.54xy^3 \\ & - 6.561y^4 + 5.319x^5 + 56.09x^4y + 1.971x^3y^2 - 24.32x^2y^3 - 17.63xy^4 \\ & + 2.497y^5 \end{aligned}$$

Goodness of fit: summed Square of residuals or SSE: 1.188,
R square (R^2): 0.6012,
R-square (adjusted): 0.5095,
RMSE- Root Mean Square Error: 0.1169

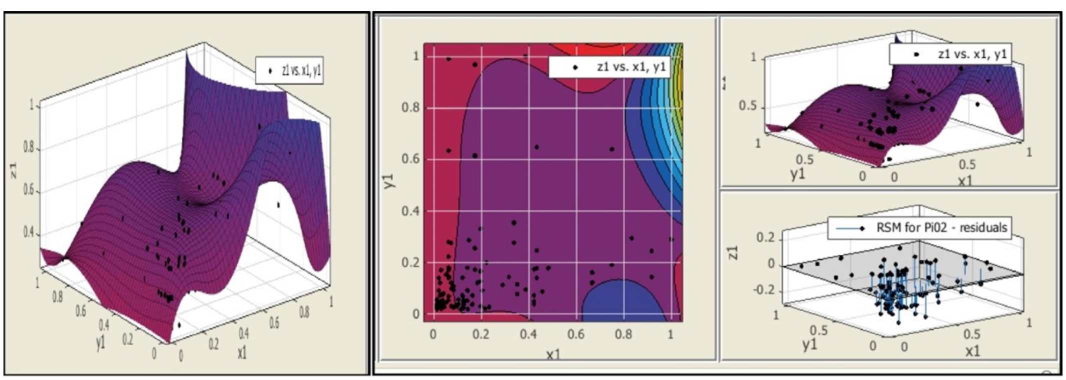

Figure 9: *RSM model and Contour, RSM and Residual plot for number of slivers.*

5.3 Model Construction for Resistive Torque (Average)

Equation of response surface or equation of polynomial of the response surface model of fifth order is evaluated and developed for resistive torque-average and is given below:

$$Avg.\frac{T_r}{L_b^3 E_b} = 0.6923 - 0.797x - 4.251y + 10.73x^2 + 5.562xy + 20.83y^2 - 35.71x^3 - 48.27x^2y + 33.36xy^2 - 55.86y^3 + 45.79x^4 + 85.2x^3y + 33.56x^2y^2 - 94.12xy^3 + 73.59y^4 - 19.5x^5 - 53.96x^4y - 20.04x^3y^2 - 5.127x^2y^3 + 56.55xy^4 - 34.83y^5$$

Goodness of fit: summed Square of residuals or SSE: 4.625,
R square (R^2): 0.2288,
R-square (adjusted): 0.05148,
RMSE- Root Mean Square Error: 0.2306

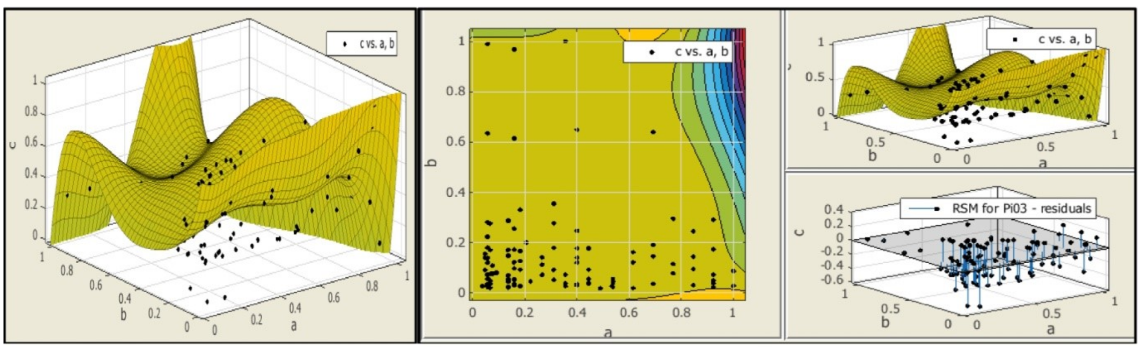

Figure 10: *RSM model and Contour, RSM and Residual plot for resistive torque (average).*

5.4 Model Construction for Resistive Torque (Total)

Equation of response surface or equation of polynomial of the response surface model of fifth order is evaluated and developed for resistive torque-total and is given below:

$$Tot.\frac{T_r}{L_b^3 E_b} = 0.4953 + 0.1362x - 2.104y - 0.1849x^2 + 6.717xy + 8.484y^2 + 1.592x^3 - 48.01x^2y + 22.54xy^2 - 22.86y^3 - 4.218x^4 + 83.75x^3y + 21.07x^2y^2 - 57.81xy^3 + 30.33y^4 + 3.145x^5 - 46.48x^4y - 28.69x^3y^2 + 11.58x^2y^3 + 29.08xy^4 - 14.14y^5$$

Goodness of fit: summed Square of residuals or SSE: 39.15,
R square (R^2): 0.1634,
R-square (adjusted): 0.1511,
RMSE- Root Mean Square Error: 0.1697

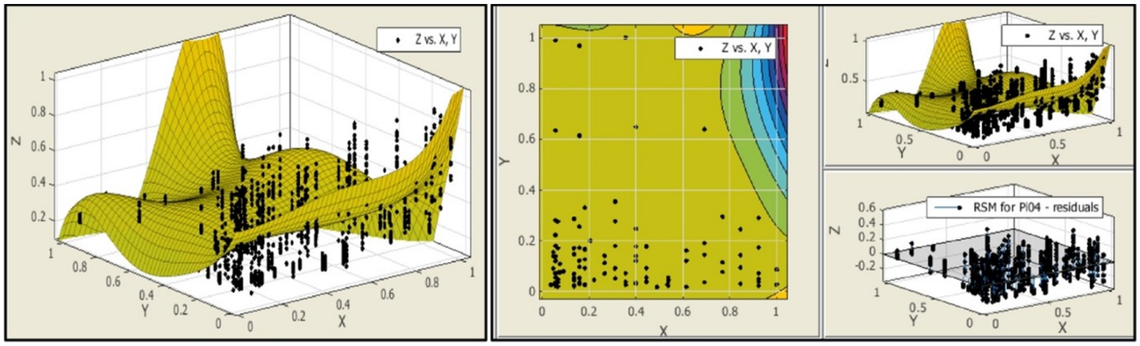

Figure 11: *RSM model and Contour, RSM and Residual plot for resistive torque (average).*

Table 6: Sample Calculation of RSM Model for processing time

Π_{D1}= tp(Model)	X=K'*Π1*Π2*Π3	Y=Π4*Π5*Π6*Π7	Π_{D1}= tp (Exp)	Π_{D1}= tp(RSM)	Xmax	Ymax	Zmax	X/Xmax =X'	Y/ymax= Y'	Z/Zmax =Z'	(Poly.Model)Z'
46.48245	1.80134E-07	3.31362E-06	40	66.92421	2.88 E-06	1.18 E-05	110	0.0625	0.280843	0.363636	0.6084
57.45825	4.26985E-07	3.3829E-06	50	68.22344	2.88 E-06	1.18 E-05	110	0.148148	0.286714	0.454545	0.62021
65.78584	9.72948E-07	3.27376E-06	50	69.84033	2.88 E-06	1.18 E-05	110	0.337577	0.277464	0.454545	0.63491
68.48212	2.88215E-06	3.4232E-06	65	64.12058	2.88 E-06	1.18 E-05	110	1	0.29013	0.590909	0.58291
41.74024	8.77505E-08	8.59642E-07	40	70.37635	2.88 E-06	1.18 E-05	110	0.030446	0.072858	0.363636	0.63978
51.47401	2.08001E-07	8.23248E-07	55	71.01566	2.88 E-06	1.18 E-05	110	0.072169	0.069774	0.5	0.6456
57.71298	5.4167E-07	8.56385E-07	60	72.05478	2.88 E-06	1.18 E-05	110	0.18794	0.072582	0.545455	0.65504
63.60235	1.17001E-06	9.23072E-07	60	72.3402	2.88 E-06	1.18 E-05	110	0.405949	0.078234	0.545455	0.65764
37.86127	5.86032E-08	4.3084E-07	45	71.1143	2.88 E-06	1.18 E-05	110	0.020333	0.036515	0.409091	0.64649
46.80633	1.38911E-07	4.41105E-07	60	71.47164	2.88 E-06	1.18 E-05	110	0.048197	0.037385	0.545455	0.64974

Table 7: Sample Calculation of RSM Model for number of slivers

Π_{D2}= n(Model)	X=Π1*Π2*Π3	Y=Π4*Π5*Π6*Π7	Π_{D2}= n(Expem)	Π_{D2}= n(RSM)	Xmax	Ymax	Zmax	X/Xmax =X'	Y/ymax =Y'	Z/Zmax =Z'	(Poly.Model)Z'
3.067968	8.34133E-07	3.31362E-06	3	3.088089	1.33 E-05	1.18 E-05	7	0.0625	0.280843	0.428571	0.44116
3.739983	1.9772E-06	3.3829E-06	4	3.978539	1.33 E-05	1.18 E-05	7	0.148148	0.286714	0.571429	0.56836
4.318878	4.50535E-06	3.27376E-06	5	4.61021	1.33 E-05	1.18 E-05	7	0.337577	0.277464	0.714286	0.6586
4.561559	1.33461E-05	3.4232E-06	5	4.844311	1.33 E-05	1.18 E-05	7	1	0.29013	0.714286	0.69204
2.460794	3.519E-07	8.59642E-07	2	2.675928	1.33 E-05	1.18 E-05	7	0.026367	0.072858	0.285714	0.38228
3.034989	8.34133E-07	8.23248E-07	3	3.256655	1.33 E-05	1.18 E-05	7	0.0625	0.069774	0.428571	0.46524
3.403551	2.17222E-06	8.56385E-07	4	3.946803	1.33 E-05	1.18 E-05	7	0.16276	0.072582	0.571429	0.56383
3.714002	4.692E-06	9.23072E-07	4	4.301708	1.33 E-05	1.18 E-05	7	0.351563	0.078234	0.571429	0.61453
1.907783	2.10202E-07	4.3084E-07	2	2.49514	1.33 E-05	1.18 E-05	7	0.01575	0.036515	0.285714	0.35645
2.324459	4.98256E-07	4.41105E-07	2	2.889732	1.33 E-05	1.18 E-05	7	0.037333	0.037385	0.285714	0.41282

Table 8: Sample Calculation of RSM Model for resistive torque-average

Π_{D3}= TrAvg(Model)	X=K'*Π1*Π2*Π3	Y=Π4*Π5*Π6*Π7	Π_{D3}= TrAvg (Expem)	Π_{D3}= TrAvg (RSM)	Xmax	Ymax	Zmax	X/Xmax =X'	Y/ymax =Y'	Z/Zmax =Z'	(Poly.Model)Z'
17182.67	1597491.83	3.31362E-06	21500	28399.7	27689858	1.18 E-05	72136.36	0.057692	0.280843	0.298047	0.39369
20248.48	3786647.302	3.3829E-06	20840	36055.76	27689858	1.18 E-05	72136.36	0.136752	0.286714	0.288897	0.49983
21692.74	8628428.096	3.27376E-06	23580	44429.01	27689858	1.18 E-05	72136.36	0.31161	0.277464	0.326881	0.6159
19978.21	25559869.29	3.4232E-06	24107.69	17368.3	27689858	1.18 E-05	72136.36	0.923077	0.29013	0.334196	0.24077
16748.77	1597491.83	8.59642E-07	24475	34518.48	27689858	1.18 E-05	72136.36	0.057692	0.072858	0.339288	0.47852
19625.27	3786647.302	8.23248E-07	20909.09	37511.39	27689858	1.18 E-05	72136.36	0.136752	0.069774	0.289855	0.52001
20191.66	9861060.681	8.56385E-07	22533.33	39424.74	27689858	1.18 E-05	72136.36	0.356125	0.072582	0.312371	0.54653
20832.13	21299891.07	9.23072E-07	25591.67	41114.09	27689858	1.18 E-05	72136.36	0.769231	0.078234	0.354768	0.56995
16054.83	1863740.469	4.3084E-07	2366.667	40160.12	27689858	1.18 E-05	72136.36	0.067308	0.036515	0.032808	0.55673
18924.21	4417755.185	4.41105E-07	2008.333	42915.66	27689858	1.18 E-05	72136.36	0.159544	0.037385	0.027841	0.59492

Table 9: Sample Calculation of RSM Model for resistive torque-total

Π_{D3}= Tr tot(Model)	X=K'*Π1*Π2*Π3	Y=Π4*Π5*Π6*Π7	Π_{D3}= Tr tot(Exp)	Π_{D3}= Tr tot(RSM)	Xmax	Ymax	Zmax	X/Xmax =X'	Y/ymax =Y'	Z/Zmax =Z'	(Poly.Model)Z'
19935.54	1597492	3.44 E-06	21700	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.229387	0.352075
19935.54	1597492	3.44 E-06	21900	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.231501	0.352075
19935.54	1597492	3.44 E-06	23500	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.248414	0.352075
19935.54	1597492	3.44 E-06	22700	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.239958	0.352075
19935.54	1597492	3.44 E-06	21000	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.221987	0.352075
19935.54	1597492	3.44 E-06	21400	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.226216	0.352075
19935.54	1597492	3.44 E-06	20100	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.212474	0.352075
19935.54	1597492	3.44 E-06	19700	33306.29	27689858	1.22 E-05	94600	0.057692	0.280843	0.208245	0.352075
20890.26	3786647	3.51 E-06	21700	41079.93	27689858	1.22 E-05	94600	0.136752	0.286714	0.229387	0.434249
20890.26	3786647	3.51 E-06	22200	41079.93	27689858	1.22 E-05	94600	0.136752	0.286714	0.234672	0.434249

6 Optimization of RSM Models

According to the objective function of the response variables in this human powered bamboo slicing process, RSM models' optimum values are noted from the plot of response surface model. For the maximization objective function, highest part of the plot or graph is to be selected and accordingly the values for optimization are chosen. For the minimization objective function, the lowest part of the graph is to be selected and accordingly the values for optimization are chosen. The scaled values for process time, sliver numbers, resistive torque-average and total resistive torque are shown in figures 8 to 11 respectively.

6.1 Analysis of the Models

It is of prime importance to study and note the behavior and impact of indices of the different pi terms of independent factors on all pi terms of output factors. This influence was studied and is depicted below. The indices and constants of pi terms of independent factors on output pi terms are given in Table 10.

Table 10: Indices and Constant of Response variables

Pi terms	Processing Time (tp)	Number of slivers (n)	Resistive torque-average	Resistive torque-total
K	5.15×10^{-10}	174.1406	1.08×10^{10}	7.68×10^{10}
π_1	0.2889	0.5082	0.7824	0.7188
π_2	0.1564	-0.3148	-1.0005	-1.2769
π_3	-0.1769	-0.1208	-0.351	0.0101
π_4	-0.3499	-0.5089	-1.4423	-1.3708
π_5	0.0371	-0.1823	0.0889	0.0265
π_6	-3.1676	1.3087	4.289	-7.5718
π_7	-30.5644	-1.4871	23.515	6.7265

The models for the dependent pi terms π_{D1}, π_{D2}, π_{D3} are given in equations 11, 12, 13 and 14 for process time, sliver numbers, resistive average torque and resistive total torque respectively as under:

$$\pi_{D1} = t_P\sqrt{\frac{g}{L_b}} = 5.15\times10^{-10}(\pi_1)^{0.2889}(\pi_2)^{0.1564}(\pi_3)^{-0.1769}(\pi_4)^{-0.3499}(\pi_5)^{0.0371}(\pi_6)^{-3.1676}(\pi_7)^{-30.5644} \quad (11)$$

$$\pi_{D2} = n = 174.1406\,(\pi_1)^{0.5082}(\pi_2)^{-0.3148}(\pi_3)^{-0.1208}(\pi_4)^{-0.5089}(\pi_5)^{-0.1823}(\pi_6)^{1.3087}(\pi_7)^{-1.4871} \quad (12)$$

$$\pi_{D3} = \frac{T_r}{L_b^3E_b} = 1.08\times10^{10}(\pi_1)^{0.7824}(\pi_2)^{-1.0005}(\pi_3)^{-0.351}(\pi_4)^{-1.4423}(\pi_5)^{0.0889}(\pi_6)^{4.289}(\pi_7)^{23.515} \quad (13)$$

$$\pi_{D3} = \frac{T_r}{L_b^3E_b} = 7.68\times10^{10}(\pi_1)^{0.7188}(\pi_2)^{-1.2769}(\pi_3)^{0.0101}(\pi_4)^{-1.3708}(\pi_5)^{0.0265}(\pi_6)^{-7.5718}(\pi_7)^{6.7265} \quad (14)$$

The equations 13 & 14 represent the models of resistive torque (average) and resistive torque (total) i.e.

$\pi_{D3\,Avg.}$ and $\pi_{D3\,Total}$ respectively. The primary conclusions of above models are described below which appear to be justified from the analysis.

(i) In case of π_{D1} and π_{D2}, the factors π_1 (refers to flywheel energy) and π_6 (refers to material elasticity) having highest indices viz.0.2889 and 1.3087 respectively, are the most influencing terms in these models. The positive values of these indices indicate that flywheel energy and material elasticity have strong impact on π_{D1} and π_{D2} respectively. Whereas for $\pi_{D3\,Avg.}$ and $\pi_{D3\,Total}$, the factor π_7 (refers to cutter's cutting angle) having highest indices viz.23.515 and 6.7265 respectively, are the most influencing terms in these models. The positive value of these indices indicates that there is a significant influence of cutter's cutting angle on $\pi_{D3\,Avg}$ as well as $\pi_{D3\,Total}$ respectively.

(ii) The factors π_5 (refers to machine's geometrical factors) having lowest indices viz. 0.0371 and 0.0889 for π_{D1} and $\pi_{D3Avg.}$ respectively is the least influencing term in these models, hence there is a need to improve machine's geometrical factors for these models of π_{D1} and $\pi_{D3\,Avg.}$ Whereas for π_{D2} and $\pi_{D3Total}$, the factors π_1 (refers to flywheel energy) and π_3 (refers to speeding-up time of flywheel) respectively are the terms which makes least influence in this model and the improvement is needed for the same.

(iii) When there are negative indices then it indicates that there is a need of improving that particular model. It shows that π_{D1} has inverse effects with π_3, π_4, π_6 and π_7, π_{D2} has inverse relationship with π_2, π_3, π_4, π_5 and π_7, $\pi_{D3\,Avg.}$ has also inverse effects with π_2, π_3 and π_4, and $\pi_{D3\,Total}$ has inverse impacts with π_2, π_4 and π_6.

(iv) In case of π_{D1}, the constant term is having the value less than one (i.e. 5.15×10^{-10}), and therefore it is not having effect of magnification in the calculated value from numerous term's product of this model; whereas for π_{D2}, $\pi_{D3\,Avg.}$ and $\pi_{D3\,Total}$, constant term had a value greater than one (i.e. 174.1406, 1.08×10^{10} and 7.68×10^{10} respectively), hence those constants have a greater effect of magnification in the calculated value from numerous term's product of their respective models.

The influence of independent or input factors in terms of sensitivity on output factors is given in table 11. This table shows the sequence of influence in increasing order from left to right.

Table11: Sequencial influence of input pi-factors upon output pi-factors

Dependent Pi-factors	**Sequence of input pi-factors as per influence**						
Processing time: Π_{D1}	π_5 (Machine's geometrical parameters)	π_2 (Flywheel angular speed)	π_3 (Speeding -up time of flywheel)	π_1 (Flywheel energy)	π_4 (Gear ratio)	π_6 (Elastic modulus of materials)	π_7 (Cutter's cutting angle)
Sliver numbers: Π_{D2}	π_3 (Speeding-up time of flywheel)	π_5 (Machine's geometrical parameters)	π_2 (Flywheel angular speed)	π_1 (Flywheel energy)	π_4 (Gear ratio)	π_6 (Elastic modulus of materials)	π_7 (Cutter's cutting angle)
Torque resistive-(average) Π_{D3} Tr-avg	π_5 (Machine's geometrical parameters)	π_3 (Speeding-up time of flywheel)	π_1 (Flywheel energy)	π_2 (Flywheel angular speed)	π_4 (Gear ratio)	π_6 (Elastic modulus of materials)	π_7 (Cutter's cutting angle)
Torque resistive-(total) Π_{D3} Tr-total	π_3 (Speeding-up time of flywheel)	π_5 (Machine geometrical parameters)	π_1 (Flywheel energy)	π_2 (Flywheel angular speed)	π_4 (Gear ratio)	π_7 (Cutter's cutting angle)	π_6 (Elastic modulus of materials)

It is notified that cutter's cutting angle is the most influencing factor in case of output factors processing time (π_{D1}), sliver numbers (π_{D2}) and resistive torque-avg ($\pi_{D3\,avg}$). But for resistive torque-total ($\pi_{D3\,total}$), elastic modulus of materials is most impacting factor. Thus overall, the cutter's cutting angle and elastic modulus of materials are having more influence on all response factors. Furthermore, machine's geometrical parameter is the least influencing factor in case of processing time (π_{D1}) and resistive torque-avg ($\pi_{D3\,avg}$) whereas speeding-up time of flywheel is having less impact on output factors like sliver numbers (π_{D2}) and resistive torque-total (π_{D3} total). Thus in general, machine's geometrical parameter and speeding-up time of flywheel are having lesser impacts on the response or output factors. The remaining input factors such as flywheel energy, flywheel angular speed and gear ratio have moderate influence over the output variables.

7 Discussion and Conclusions

(i) The properties of machining such as torque (resistive) and time of processing for human powered or pedal powered bamboo slivering process are established through theory of experiments.

(ii) Because data is acquired through real testing and actual experiments, the finding and related concluding remarks of this work accurately indicate the level of engagement of many independent factors

(iii) The analysis of the models in this research work gives the exact behaviour of the independent variables with respect to the particular response variables in terms of level of influence, level of impact, level of improvement if any etc. in case of human powered bamboo slivering machine. It also gives an idea about the magnification effects of the constants in these models.

(iv) RSM models give the scaled values for resistive torque (total), resistive torque (average), process time, and sliver numbers that are involved in the bamboo slivering machine run by pedal power.

(v) The comparative analysis of R-square value of RSM model with the formulated mathematical model gives idea of accuracy of fitness of different factors involved in the human driven bamboo sliver making phenomena. The numerical as well as experimental responses can be approximated by using the response surface approach.

(vi) The developed response surface equations and the relatively plotted graphs gives the appropriate investigation about the impact of different operational factors on numerous characteristics responses like resistive average torque, process time, resistive total torque and sliver numbers which are responsive in human driven bamboo slivering phenomena.

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