Formulation of Experimental Mathematical Model, Artificial Neural Network Simulation and RSM (Response Surface Methodology) Model for Cross Cutting Operation of Bamboo

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Abstract: At present individual machines are available for all processing mentioned above. 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. The present work reports the design of experimental work to be executed for establishing approximate generalized empirical model for Bamboo(machining properties) processing operations such as cross cutting, external knot removal(two side planning), splitting, internal knot removal, sliver(slats) and stick making, on the basis of experimentation data chosen, using methodology of engineering experimentation. Out of all processing operations, formulation and analysis only for cross cutting operation is completely mentioned in this paper. 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. This paper presents an experimental investigations and Sequential classical experimentation technique has been used to perform experiments for various sizes of bamboo at different varying speed. An attempt of mini-max principle has been made to optimize the range bound process parameters for minimizing processing torque, Energy, and time required for bamboo cross cutting operation. The test results proved that processing torque, Energy, and time values were significantly influenced by changing important seven dimensionless π terms. The process parameters grouped in π terms were suggested the effective guidelines to the manufacturer for improving productivity by changing any one or all from the available process parameters.

Keywords: Bamboo Processing Torque, dimensional analysis, Buckingham’s π theorem, regression analysis, Mini-max principle, LPP, Opto-coupler, Optimization, Artificial Neural Network, Response surface design.

I. INTRODUCTION

Initial treatment to raw bamboo before ready for actual work is called bamboo processing [1] 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. At present individual machines are available for bamboo processing [5],[6],[7]. But, operating of these machines for individual operations consumes time [8], materials and also power requirement due to which cost of the operation carried out for the bamboo processing is very high. Also instead of purchasing individual machine to carry out these four operations required four different machines which again is a costly project so it was decided to form a single machine, which would carry out all four operations on a single machine to be benefited from cost point of view and time.

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

Hence, it was decided to design and fabricate the machine, which would upgrade the disadvantages offered by the present processing machines [2-4],[8]. The machine was designed [11-15], fabricated and tested (shown in figure 1) for all successful test runs and found with good results. The processed bamboo and cross cutting operation is shown in figure 2. Out of all processing operations, formulation and analysis only for sliver cutting operation is completely mentioned in this paper.

Figure 2: Figure shows Processed Bamboo (Bamboo...
samples and cross cut bamboo) and varieties of cross cutters

A. Need for formulating generalized experimental data based models

In view of forgoing it is obvious that one will have to decide what should be the minimum processing torque required, and energy to be supplied to the system for getting appropriate sizes of processed bamboo in minimum time. By knowing this one can establish bamboo machining properties. This would be possible if one can have a quantitative relationship amongst various dependent and independent variables of the system. This relationship would be known as the mathematical model of this bamboo processing operation. It is well known that such a model for the bamboo processing cannot be formulated applying logic [10]. The only option with which one is left is to formulate an experimental data based model [10]. Hence, in this investigation it is decided to formulate such an experimental data based model. In this approach all the independent variable are varied over a widest possible range, a response data is collected and an analytical relationship is established. Once such a relationship is established then the technique of optimization [16],[18] can be applied to deduce the values of independent variables at which the necessary responses can be minimized or maximized. In fact determination of such values of independent variables is always the puzzle for the operator because it is a complex phenomenon of interaction of various independent variables and dependant variables shown in table 1(a). It is well known that mathematical modeling of any bamboo processing operation is possible by applying methodology of experimentation [17]. The same is adopted in the present work.

Table 1(a): Dependent and Independent variable of Cross Cutting

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Variables</th>
<th>Unit</th>
<th>(M^0L^0T^n)</th>
<th>Dependant/Independent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(T_p)= Processing torque</td>
<td>N-mm</td>
<td>(ML^0T^n)</td>
<td>Dependant</td>
</tr>
<tr>
<td>2</td>
<td>(E)= Energy</td>
<td>Kw-hr</td>
<td>(ML^0T^n)</td>
<td>Dependant</td>
</tr>
<tr>
<td>3</td>
<td>(t_p)= Processing Time</td>
<td>Second</td>
<td>T</td>
<td>Dependant</td>
</tr>
<tr>
<td>4</td>
<td>(\omega)= speed of shaft</td>
<td>rev/ sec</td>
<td>(T^n)</td>
<td>Independent</td>
</tr>
<tr>
<td>5</td>
<td>(D_b)= diameter of bamboo</td>
<td>mm</td>
<td>L</td>
<td>Independent</td>
</tr>
<tr>
<td>6</td>
<td>(A_c)= Cross section Area of bamboo</td>
<td>mm²</td>
<td>L²</td>
<td>Independent</td>
</tr>
<tr>
<td>7</td>
<td>(L)= distance of cutter from bearing</td>
<td>mm</td>
<td>L</td>
<td>Independent</td>
</tr>
<tr>
<td>8</td>
<td>(D_c)= diameter of cutter</td>
<td>mm</td>
<td>L</td>
<td>Independent</td>
</tr>
<tr>
<td>9</td>
<td>(t_c)= width of cutter</td>
<td>mm</td>
<td>L</td>
<td>Independent</td>
</tr>
<tr>
<td>10</td>
<td>(f)= feed rate</td>
<td>mm/sec</td>
<td>(LT^n)</td>
<td>Independent</td>
</tr>
<tr>
<td>11</td>
<td>(g)= acceleration due to gravity</td>
<td>mm/sec²</td>
<td>(LT^n)</td>
<td>Independent</td>
</tr>
<tr>
<td>12</td>
<td>(E_g)= modulus of elasticity of bamboo</td>
<td>N/mm²</td>
<td>(ML^0T^n)</td>
<td>Independent</td>
</tr>
<tr>
<td>13</td>
<td>(E_c)= modulus of</td>
<td>N/mm²</td>
<td>(ML^0T^n)</td>
<td>Independent</td>
</tr>
</tbody>
</table>

B. Brief description of application of theory of experimentation

The approach adopted for formulating generalized experimental model suggested by Hilbert Schenck Jr [17] is indicated 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 set up, 5) Execution of experimentation, 6) Purification of experimentation data, 7) Formulation of the model, 8) Model optimization, 9) Reliability of the model, 10) ANN simulation of the experimental data. The first six steps mentioned above constitute design of experimentation. The seventh step constitutes of model formulation where as eighth and ninth steps are respectively optimization and reliability of model. The last step is ANN simulation of model.

II. EXPERIMENTAL PROCEDURES

Bamboo processing machine shown in figure 1 is utilized for Cross cutting operation. The process of formulation of mathematical model for bamboo Cross Cutting operation and its analysis is mentioned this paper. For experimentation purpose bamboo samples of different sizes and varieties were collected. In bamboo processing, the objective of the experiment is used to gather information through experimentation for formulation of mathematical model for Cross Cutting operation. During bamboo processing operations for the measurement resistance torque, torque without load (i.e., load torque) and torque with load (i.e., driving torque) is measured using specially designed electronic kit shown in figure 3. The difference of driving and load torque is process resistance torque. Energy and time is measured using energy meter and stopwatch respectively. Pilot experiments were performed to select test envelope and test points of process parameters for experimental design. These process parameters were listed in Table 1(b) and used in experimental design for the investigation of process parameters like processing Energy, torque and during Cross Cutting operation. The observed values of processing torque, energy and time are recorded for formulation of mathematical model. In cross cutting operation, observations were taken at three speeds (1440, 1800, 2160 rpm) and five different feeds using three cutters of different diameter, no. of teethes and thickness for different sizes of bamboo.
welded to shafts. Electronic circuit, Circuit fitted to machine and output (current drawn, torque, speed) of measurement given to personal computer along with Energy meter.

### III. DESIGN OF EXPERIMENTS

In this study, 270 experiments were designed on the basis of sequential classical experimental design technique [9],[10] that has been generally proposed for engineering applications. The basic classical plan [17] consists of holding all but one of the independent variables constant and changing this one variable over its range. The main objective of the experiments consists of studying the relationship between 12 independent process parameters with the E, Tp and tp dependent responses for cross cutting operation. Simultaneous changing of all 12 independent parameters was cumbersome and confusing. Hence all 12 independent process parameters were reduced by dimensional analysis. Buckingham’s π theorem was adapted to develop dimensionless π terms for reduction of process parameters. This approach helps to better understand how the change in the levels of any one process parameter of a π terms affects E, Tp and tp response for Cross Cutting of bamboo. A combination of the levels of parameters, which lead to maximum, minimum and optimum response, can also be located through this approach. Regression equation models of Cross Cutting were optimized by mini-max principle.

#### A. Formulation of Approximate Generalized Experimental Data Base Model By Dimensional Analysis

As per dimensional analysis [16], Processing Energy(E) was written in the function form as :-

\[ T_p = f(\alpha, \omega, A, \phi, F, \phi_c, P) \]  \hspace{1cm} (1)

By selecting Mass (M), Length(L), and Time (T) as the basic dimensions, the basic dimensions of the forgoing quantities were mentioned in table 1(a) and 1(b):

According to the Buckingham’s - theorem, (n- m) number of dimensionless π terms were formed. In this case n is 12 and m=3, so π1 to π12 dimensionless groups were formed. By choosing ‘ω’, ‘g’ and ‘Ec’ as a repeating variable, eleven π terms were developed as follows:

\[
\left( \frac{\omega^6 \times T_p}{g^3 \times Ec} \right) = f(\Phi_c) \left( \frac{\omega^4 \times AC}{g^2} \right) \left( \frac{\omega^2 \times Lc}{g} \right) \left( \frac{\omega \times f}{g} \right) \left( \frac{E_b}{Ec} \right) \left( \frac{\omega^5 \times P}{g \times Ec} \right) \] \hspace{1cm} (2)

#### B. Reduction of independent variables/dimensional analysis

When n (no. of variables) is large, even by applying Buckingham’s π theorem number of π terms will not be reduced significantly than the number of all independent variables. Thus, much reduction in number of variables is not achieved. It is evident that, if we take the product of the π terms it will also be dimensionless number and hence a π term. This property is used to achieve further reduction of the number of variables. Thus few π terms are formed by logically taking the product of few other π terms and final mathematical equations are given below:

\[ T_p(\pi_{03}) = K_c \left( \frac{g^3 \times E_c}{\omega^6} \right) \left( \frac{\omega^4 \times AC}{g^2} \right) \left( \frac{\omega^2 \times Lc}{g} \right) \left( \frac{\omega \times f}{g} \right) \left( \frac{E_b}{Ec} \right) \left( \frac{\omega^5 \times P}{g \times Ec} \right) \] \hspace{1cm} (3)

\[ E(\pi_{02}) = K_c \left( \frac{g^3 \times E_c}{\omega^6} \right) \left( \frac{\omega^2 \times Lc}{g} \right) \left( \frac{\omega \times f}{g} \right) \left( \frac{E_b}{Ec} \right) \left( \frac{\omega^2 \times P}{g \times Ec} \right) \] \hspace{1cm} (4)

\[ t_p(\pi_{03}) = K_c \left( \frac{1}{\omega} \right) \left( \frac{\omega^4 \times AC}{g^2} \right) \left( \frac{\omega^2 \times Lc}{g} \right) \left( \frac{\omega \times f}{g} \right) \left( \frac{E_b}{Ec} \right) \left( \frac{\omega^5 \times P}{g \times Ec} \right) \] \hspace{1cm} (5)

The relationship between various parameters was unknown. The dependent parameter π01, π02 and π03 i.e. relating to Tp, E, and tP were bear an intricate relationship with remaining terms (ie. π1 to π12) evaluated on the basis of experimentation. The true relationship is difficult to obtain. The possible relation may be linear, log linear, polynomial with n degrees, linear with products of independent πi terms. In this manner any complicated relationship can be evaluated and further investigated for error. Hence the relationship for Tp was formulated as:

\[ \pi_{01} = k_1 \times (\pi_1)^{a_1} \times (\pi_2)^{b_1} \times (\pi_3)^{c_1} \times (\pi_4)^{d_1} \times (\pi_5)^{e_1} \times (\pi_6)^{f_1} \times (\pi_7)^{g_1} \] \hspace{1cm} (6)

#### C. Model Formulation

It is necessary to correlate quantitatively various independent and dependent terms involved in this very complex phenomenon. This correlation is nothing but a mathematical model as a design tool for such situation. The mathematical model for Cross Cutting operation is shown below:

\[ \Pi_{60} = \text{Mathematical Equation for Processing torque} \ (T_p) \]
\[ T_p = 13746.7489 \times \left( \frac{g^2 \times Ec}{\omega^2} \right) \times \left( \frac{\omega^4 \times Ac}{g^2} \right) \times \left( \frac{\omega^4 \times P}{g \times Ec} \right) \times \left( \frac{x}{\omega} \right) \]

\[ \Omega^\alpha = \text{Mathematical Equation for Energy (E)}: \]

\[ E = 25686208290x \left( \frac{g^2 \times Ec}{\omega^2} \right) \times \left( \frac{\omega^4 \times Ac}{g^2} \right) \times \left( \frac{\omega^4 \times P}{g \times Ec} \right) \times \left( \frac{x}{\omega} \right) \]

\[ \Omega^\beta = \text{Mathematical Equation for Processing time (t_p):} \]

\[ t_p = 2.590598x \left( \frac{1}{\omega} \right) \times \left( \frac{g^2 \times Ec}{\omega^2} \right) \times \left( \frac{\omega^4 \times Ac}{g^2} \right) \times \left( \frac{\omega^4 \times P}{g \times Ec} \right) \times \left( \frac{x}{\omega} \right) \]

\[ \text{IV. RELIABILITY OF MODEL} \]

Reliability of model is established using relation

\[ \text{Reliability} = 100\% - \text{mean error} - \text{mean error} = \left[ \sum_{i=1}^{n} x_i f_i \right] \]

where, \( x_i \) is % error and \( f_i \) is frequency of occurrence. System Reliability (\( R_p \)) is given by relation

\[ 1 - \prod_{i=1}^{n} (1 - R_i) = 1 - \left[ \left( 1 - R_{\text{p}} \right) \times \left( 1 - R_{\text{p}} \right) \right] \]

where \( R_i \) is the reliability of individual model i.e., energy, torque, and time. Therefore total reliability of cross cutting model is equal to

\[ 1 - \prod_{i=1}^{n} (1 - R_i) = 0.945129 \]

\[ \text{V. PROCESS PARAMETERS SELECTION BY MINI-MAX PRINCIPLE} \]

From above mathematical models the obvious aim was to minimize the values of \( T_p, E, \) and \( t_p \). The ultimate objective of this work is not merely developing the models but to find out best set of variables, which will result in maximization/minimization of the response variables [18]. In this section attempt is made to find out the limiting values of three response variables viz. processing torque, energy and time. To achieve this, limiting values of independent variable \( \pi \) term viz. \( \pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7 \) are put in the respective models. In the process of minimization, minimum value of independent \( \pi \) term is put in the model if the index of the term was positive and maximum value is put if the index of the term was negative. The limiting values of these response variables are computed in table 2 for Cross Cutting operation.

\[ \text{VI. SENSITIVITY ANALYSIS} \]

The average values of the change in the dependent \( \pi \) term due to the introduced change of \( \pm 10\% \) in each independent \( \pi \) term. This is defined as sensitivity. The total % change in output for \( \pm 10\% \) change in input is shown in table 3. Nature of variation in response variables due to increase in the values of independent \( \pi \) terms is given in table 3.

\[ \text{Table 2: Limiting Values of Response Variables (Torque: N-mm, Energy: KW-hr, Time: Seconds)} \]

<table>
<thead>
<tr>
<th>Max and Min. of Response ( \pi ) terms</th>
<th>Cross Cutting operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque ( (\pi_1) )</td>
<td>Energy ( (\pi_2) )</td>
</tr>
<tr>
<td>Maximum</td>
<td>Minimum</td>
</tr>
<tr>
<td>1036.9</td>
<td>41.63</td>
</tr>
</tbody>
</table>

\[ \text{VII. MODEL OPTIMIZATION} \]

The ultimate objective of this work is not merely developing the models but to find out best set of independent variables, which will result in maximization/minimization of the objective functions[16],[18]. In this case there are three different models corresponding to the Processing torque \( (T_p) \), Energy required \( (E) \), Processing time \( (t_p) \) for processing operations. There are thus three objective functions corresponding to these models. The objective functions for Processing torque, Energy and time required for processing of bamboo need to be minimized. The models have non linear form; hence it is to be converted into a linear form for optimization purpose. 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 Cross Cutting Operation.

Taking log of both the sides of the Equation 1, we get

\[
\log(\Pi_0) = \log(K) + \log\left(\frac{g^{-b} \times Ec}{\omega^b}\right) + 0.216\log
\]

\[
\left(\frac{\omega^b \times Ac}{g}\right) - 0.012\log \left(\frac{\omega^b \times n \times C \times L}{g^b}\right) + 0.5258 \times 0.2558
\]

\[
\left(\frac{\omega^b \times f}{g} + 4.4044\log \left(\frac{Ec}{Eh}\right) + 0.148\log (N_i)\right) - 0.1516\log (\Phi_c) + 0.638\log
\]

\[
\left(\frac{\omega^b \times P}{g^b}\right) \ldots \ldots
\]

\[
Z = K + K_0 + a \times X_1 + b \times X_2 + c \times X_3 + d \times X_4 + e \times X_5 + f \times X_6 + g \times X_7
\]

\[
Z = \log(13746.7489) + \log(22426.16) + 0.216 \log(\pi_i) - 0.012 \log(\pi_i) + 0.5258 \log(\pi_i) + 0.4044 \log(\pi_i) + 0.148 \log
\]

\[
(\pi_i) - 0.1516 \log \left(\frac{\pi_i}{1638}\right) + 0.638 \log(\pi_i)
\]

\[
Z = \log(4.1382 + 4.3507 + 0.216 \times X_1 - 0.012 \times X_2 + 0.5258 \times X_3 + 4.4044 \times X_4 + 0.148 \times X_5 - 0.1516 \times X_6 + 0.638 \times X_7)
\]

\[
Z (\text{Torque: } \Pi_{o2} \text{ min}) = 4.1382 + 4.350755 + 0.216 \times X_1 - 0.012 \times X_2 + 0.5258 \times X_3 + 4.4044 \times X_4 + 0.148 \times X_5 - 0.1516 \times X_6 + 0.638 \times X_7
\]

\[
Z (\text{Energy: } \Pi_{o2} \text{ min}) = 10.4097 + 4.350755 + 0.2522 \times X_1 + 0.1355 \times X_2 - 0.6696 \times X_3 + 8.9289 \times X_4 + 1.2877 \times X_5 - 1.4664 \times X_6 + 1.2558 \times X_7
\]

\[
Z (\text{Time: } \Pi_{o2} \text{ min}) = 0.4138 - 2.2634019 + 0.3765 \times X_1 + 0.0972 \times X_2 - 0.8163 \times X_3 + 1.4988 \times X_4 + 0.2861 \times X_5 - 0.7388 \times X_6 + 0.0001 \times X_7
\]

Thus, eqn (13, 14 and 15) will be objective for minimization for the purpose of purpose of formulation of the linear programming problem. Putting the constraints equations and solving the problem, Thus, \(Z_{\text{min}}\) for \(\Pi_{o1} = 41.635\) and vales of independent terms are obtained by taking antilog of \(X_1, X_2, X_3, X_4, X_5, X_6, X_7\) are 2486.603, 3404854, 0.015372, 0.03222, 40, 0.209333 and 0.292731. Similarly, \(Z_{\text{min}}\) for \(\Pi_{o2} = 1039993\) and vales of independent terms are obtained by taking antilog of \(X_1, X_2, X_3, X_4, X_5, X_6, X_7\) and \(X_8\) are 2486.603, 155686, 0.115288, 0.03222, 40, 0.209333 and 0.292731.

\[
Z_{\text{min}}\) for \(\Pi_{o3} = 0.264874\) and vales of independent terms are obtained by taking antilog of \(X_1, X_2, X_3, X_4, X_5, X_6, X_7\) and \(X_8\) are 2486.603, 155686, 0.115288, 0.03222, 40, 0.209333 and 0.292731.

VIII. COMPUTATION OF THE PREDICTED VALUES BY ‘ANN’

In this research the main issue is to predict the future result. 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. For development of ANN the designer has to recognize the inherent patterns. Once this is accomplished training the network is mostly a fine-tuning process. An ANN consists of three layers (representing the synapses) and the output layer. It uses nodes to represent the brains neurons and these layers are connected to each other in layers of processing. The specific mapping performed by ANN depends on its architecture and values of synaptic weights between the neurons. ANN as such is highly distributed representation and transformation that operate in parallel and has distributed control through many highly interconnected nodes. ANN were developed utilizing this black box concepts. Just as human brain learns with repetition of similar stimuli, an ANN trains itself within historical pair of input and output data usually operating without a priory theory that guides or restricts a relationship between the inputs and outputs. The ultimate accuracy of the predicted output, rather than the description of the specific path(s) or relationship(s) between the input and output, is the goal of the model. The input data is passed through the nodes of the hidden layer(s) to the output layer, a non linear transfer function assigns weights to the information as it passes through the brains synapses. The role of ANN model is to develop a response by assigning the weights in such a way that it represents the true relationship that really exists between the input and output. During training, the ANN effectively interpolates as function between the input and output neurons. ANN does not an explicit description of this function. The prototypical use of ANN is in structural pattern recognition. In such a task, a collection of features is presented to the ANN; it must be able to categories the input feature pattern as belonging to one or more classes. In such cases the network is presented with all relevant information simultaneously. The results of ANN are shown in figure 4, 5, and 6.
Figure 4: Performance analysis of ANN and Comparison of actual and computed data by ANN (for $\Pi_{01}$, Processing Torque)

Figure 5: Performance analysis of ANN and Comparison of actual and computed data by ANN (for $\Pi_{02}$, Processing Energy)
IX. RESPONSE SURFACE METHODOLOGY FOR THE CROSS CUTTING OPERATION

This section describes the use of response surface methodology in the cross cutting operation.

A. “Response Surface Methodology approach”

This section describes the basic of response surface methodology.

Surface Response Method : The response surface methodology, or RSM, is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response.

The equation for the RSM is

$$y = f(x_1, x_2) + \varepsilon$$  

where, $x_1, x_2$ are process parameters and $\varepsilon$ represents error observed in the response $y$.

if we denote the expected responses by $E(y) = f(x_1, x_2) = \eta$  

Then the surface represented by $\eta = f(x_1, x_2)$ is called a response surface.

In most RSM applications, the form of relationship between the response and the independent variables is unknown. Thus the first step in RSM is to find a suitable approximation for the true functional relationship between $y$ and the set of independent variables. Usually a low order polynomial in some region of independent variables is employed. If the response is well modeled by a linear function of independent variables, then the approximating function is the first order model.
For Response variable torque, response surface equation is

\[
\left( \omega \times T_p \right) = 18.25 + 15.34x - 3.539y - 1.572x^2 - 0.1398x^2y + 0.1213y^2 + 0.06692x^3 + 0.002859xy + 0.0002859x^2y + 0.0001695x^3y + 2.383e-005x^2y^2 - 1.735e-005x^4y + 7.944e-006y^4 \ldots \text{(Eqn.23)}
\]

Goodness of fit: SSE: 1.574e+005, R-square: 0.2813, Adjusted R-square: 0.2419, RMSE: 24.84
D. Optimization of RSM Models

Optimized values of RSM models are found form RSM graph as per the objective function of the response parameter. If the objective function is maximization then select the highest part of the graph and choose the values for optimization. If the objective function is minimization then select the lowest part of the graph and choose the values for optimization. Figures 8, 10, and 12 shows scaled minimum values for energy, torque and time.

X. ANALYSIS OF CROSS CUTTING OPERATION MODELS FOR DEPENDENT TERM Π₁₁, Π₁₂, Π₁₃ (EQN. 8, 9 AND 10)

The following primary conclusions appear to be justified from the above model.

1] The absolute index of (Cross cutting) π₄ is highest index of Π₁₁, Π₁₂ and Π₁₃ respectively viz. 4.404,8.928, 1.4988. The factor ‘π₄’ 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 Π₁₁, Π₁₂ and Π₁₃ respectively.

2] The absolute index of (Cross cutting) π₅ is lowest index of Π₁₁, Π₁₂ and π₁₃ is the lowest index of Π₁₃ respectively. The factor ‘π₅’ related to hook angle and feed is the least influencing term in this model. Low value of absolute index indicates the factor hook angle and feed needs improvement.

3] The indices of dependent terms are shown in table 4. The negative indices are indicating need for improvement. The negative indices are inversely varying with respect to π₄ for Π₁₁, Π₁₂ and Π₁₃ respectively.

| Table 4: Constant and Indices of Response variable |
|---|---|---|---|
| Pi terms | Cross cutting operation | Energy | Torque | Time |
| K | 10.4097 | 4.1382 | 0.4134 |
| Π₁ | 0.2522 | 0.216 | 0.3765 |
| Π₂ | 0.1355 | -0.012 | 0.0972 |
| Π₃ | -0.6696 | 0.5258 | -0.8163 |
| Π₄ | 8.9289 | 4.4044 | 1.4988 |
| Π₅ | 1.2877 | 0.148 | 0.2861 |

4] From above it is cleared that value of constant is 13746.7489, 25686208290 and 2.590598 for cross cutting model Π₁₁, Π₁₂ and Π₁₃, hence it has high magnification effect in the value computed from the product of the various terms of the model.

5] Sensitivity analysis of cross cutting operation indicates Cutter dimensions is most sensitive and ratio of elasticity of materials is least sensitive for model Π₁₁ and hence needs strong improvement. Similarly cutter dimension and power is most sensitive and ratio of elasticity of materials is least sensitive for model Π₁₂ and Π₁₃ respectively.

6] From experimentation the resultant minimum cutting force for cross cutting (Tₚ max /Distance from center of shaft to cutter tip i.e., (41.63 / 200) 0.20N and maximum cutting force is (1036.918375/300) 5.2 N.

7] The comparison of experimental, mathematical model and ANN model Cross Cutting operation are shown in the table 5.

| Table 5: Error Estimation for Cross Cutting Operation |
|---|---|---|---|
| Mean /Error | Energy | Time | Torque |
| meanexp | 0.0042 | 1.6944 | 17.2037 |
| meanann | 0.0042 | 1.6943 | 17.2022 |
| meanmath | 0.0039 | 1.5014 | 2.8156+009 |
| mean_absolute_error | 4.1259e-004 | 0.1626 | 1.4298 |
| mean_squared_error | 5.1760e-007 | 0.1497 | 8.4982 |

XI. CONCLUSIONS

1. The dimensionless π terms have provided the idea about combined effect of process parameters in that π terms. A simple change in one process parameter in the group helps the manufacturer to maintain the required E, Tₚ and tₚ values so that the productivity is increased.

2. The mathematical models developed with dimensional analysis for different sizes of bamboo can be effectively utilized for bamboo processing operations.

3. The computed selection of Cross Cutting process parameters by dimensional analysis provides effective guidelines to the manufacturing engineers so that they can minimize E, Tₚ and tₚ for higher performances.

4. 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 5. From the values of % 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 cutting forces and power estimation for bamboo processing machines.

5. RSM model can be also utilized for estimation of maximum and minimum values of response variables E, Tₚ and tₚ.

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