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Experimental Based Mathematical Model with Artificial Neural Network Simulation Model for Cotton Pre-Cleaning Machine

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Abstract

Many countries are producing cotton in the world and cotton proves the back bone of economics of farmer, the world's textile trade and industry. Conversion cotton into thread and into cloths is main agriculture based business in India. The quality of textile products are mainly depends on the quality of cotton lint. Less contamination of cotton gives good quality of lint. This paper presents the experimental work on cotton pre cleaner to be executed for establishing appropriate generalized empirical model for cotton pre-cleaning operation. It also presents an experimental investigation. Sequential classical experimentation technique has been used to perform experiments for various moisture contents of seeded cotton, different varying speed of spiked shaft.

Index Terms – Cotton Pre-Cleaner, Dimensional Analysis, Buckingham's π theorem, Pre-cleaner

I. Introduction

Cotton is a natural vegetable fiber. Many countries are producing cotton in the world and cotton proves the back bone of economics of farmer, the world's textile trade and industry. It is also called as white gold [1]. In India, the cultivation and production of cotton and cloth is major Agro based businesses. It has prominent role in the Indian economy. It is providing employment directly to 60 lakh farmers of the country and indirectly to around 4-5 crore people. The cotton based rural industries which includes cleaning and ginning of cotton.

The cotton in India has relatively high level of contamination. The range of contaminations is about 10-12%, though it is handpicked from the farm. There is broad range of contaminants in cotton. It is numbering over 20 types. Leaves, strings, feather, paper, inorganic matter like sand, dust, oily substances and chemicals like grease or oil etc are the major types of contaminants [2]. Contamination is not being grown with boll in the tree. The contamination is mostly added in fresh cotton during pickling and handling. The contaminations are added in different stages of processing of cotton at ginnery like during pre-ginning (46%), ginning (44%) and during pressing (10%). The Cotton International Textile's Manufacturer's Federation, Zurich listed Indian cotton as most contaminated in the world. It clearly indicates the importance of pre cleaning the cotton.

For cotton pre-cleaning process there is a need of maximum processing torque and the energy to be supplied to the system should minimum. There is quantitative relationship amongst various dependent and independent variables of the system for cotton pre-cleaning. That is known as mathematical model of this cotton pre-cleaning process. The relationship between dependent and independent parameter are known to be based on the available literature, generalize quantitative relationship are not known sometimes due to complexity of phenomenon. Hence, formulating the quantitative relationship based on the logic is not possible in the case of complex phenomenon. On account of no possibility of formulation of theoretical model which is on logic based is left with the only alternative of formulating experimental data based model. Hence, it is proposed to formulate such model in present investigation. The methodology as suggested by H. Schenck Jr. [3] has been used for the planning of experimentation on a model of cotton

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pre-cleaning machine. The objective of experimentation is to generate design data for cotton cleaning on cotton pre-cleaner machine by establishing an experimental model and to predict the performance of it. During experimentation, the independent process variables identified to affect the cleaning process and shall be varied over widest possible range.

The photograph of model cotton pre-cleaner is shown in “(1)”. A 1440 rpm, single phase induction motor is used to drive the experimental model. The speed of spiked shaft varies from 150 to 400 rpm, has been achieved through a combination of ‘V’ belt drive, stepped pulley and chain drive. The motor gives the power to power transmission shaft through belt drive. This shaft just transmits the power to first spiked shaft through chain drive; the other end of spiked shaft transmits the power to remaining three spiked shafts through chain drive. The moment of Inertia is calculated.

II. EXPERIMENTAL PROCEDURE

Following variables are identified, which affect the cotton pre-cleaner machine for cotton cleaning as shown in Table I.

The following ten independent process variable are identified such as Distance Between spikes cylinder, Pitch distance between spike, Acceleration due to Gravity, Inertia of rotating shaft, Distance between grid bar, Weight of cotton, Moisture of cotton, Distance between Grid and spike, Volume of container. The dependent process variables are processing torque, power consumption, weight of trash, and processing time.

Fig. 1 Cotton Pre-Cleaner

TABLE I

VARIABLES RELATED TO COTTON PRE-CLEARING PROCESS

Sr.	Variables	Symbol	Unit	MLT	Types of Variable

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N o.					
1	Angular velocity	ω	Rad/s	$M^0L^0T^{-1}$	Independent
2	Distance Between Spikes Cylinder	L_S	m	$M^0L^1T^0$	Independent
3	Pitch Distance between spike	P_S	m	$M^0L^1T^0$	Independent
4	Acceleration due to Gravity	g	m/s^2	$M^0L^1T^{-2}$	Independent
5	Inertia of Rotating shaft	I	$Kg\text{-}m^2$	$M^1L^2T^0$	Independent
6	Distance between grid bar	L_G	m	$M^0L^1T^0$	Independent
7	Weight of cotton	W	kg	$M^1L^0T^0$	Independent
8	Moisture of cotton	M	Dimensionless	$M^0L^0T^0$	Independent
9	Distance between Grid and spike	L_C	m	$M^0L^1T^0$	Independent
10	Volume of container	V	m^3	$M^0L^3T^0$	Independent
11	Processing Torque	T	N-m	$M^1L^2T^{-2}$	Dependent
12	Power Consumption	P	$kg\ m^2/s^3$	$M^1L^2T^{-3}$	Dependent
13	Weight of Trash	w	kg	$M^1L^0T^0$	Dependent

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14	Processing Time	t	s	$M^0L^0T^1$	Dependent

The extraneous variables, which are difficult to be controlled during experimentation on an experimental cotton pre-cleaning machine are Climate Condition, Manpower limitation, Errors of instrumentation may occur because of heating electric motor.

Test planning for experimentation would be carried out by deciding the Test Envelop, Test Point, and Test Sequence. The test envelop is a range in which variable is varied during experiment. It is decided by following consideration. i) Time and fund available, ii) Previously established data about the process under study. The range of variation in which the variable has a significant effect on, the variation of dependent variable should be selected. The test point are the discrete values of independent variables at which, experiment are conducted. The selection of the test point depends on the approximate variation in dependent variables as independent variables are varied. This variation can be constant, linear, non-linear or combination of all. Test sequence is the order in which test points are varied during the proposed experimentation.

The speed of shaft varied from 200 rpm to 400 rpm with step of 250rpm, 320 rpm, 360 rpm, and 400 rpm. Each speed of shaft is considered as test point. Weight of cotton fed to the machine is varied from 0.5 kg. to 2.0 kg in a step of 0.75 kg, 1.00 kg and 1.5kg. Each weight is considered as test point. It was decided to vary from 6.5% to 9.5%. The gap between grid bar and spike are kept from 0.02m to 0.03m.

Table II

EXPERIMENTATION PLAN

Sr. no	Ratio	Test Envelop Range	Test point	Test sequence
1	$\pi_1 = \omega V^{1/6} / g^{1/2}$	39.4989 to 78.996	39.4989, 49.3725, 63.1968, 71.0964, 78.996	1,4,2,3,5
2	$\pi_2 = L_S / V^{1/3}$	Constant		
3	$\pi_3 = P_S / V^{1/3}$	Constant		
4	$\pi_4 = I / (W V^{2/3})$	0.34970 to 1.398838	0.34970, 0.46627, 0.69941, 0.93255, 1.398838	2,5,3,4,1
5	$\pi_5 = L_G / V^{1/3}$	Constant		

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6	$\pi_6 =$ M	6.5 to 9.5	6.5, 7.5, 8.5, 9.5	1,3,2
7	$\pi_7 = L_C / V^{1/3}$	0.05226 To 0.07840	0.05226, 0.06533, 0.07840	2,3,1

III. DESIGN OF EXPERIMENTS

It is well known that a model for the man machine system cannot be formulated by applying the logic [3]. Hence, in this investigation, it is decided to formulate such an experimental data base model. In this approach all the independent variable has 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 can be applied to deduce value of independent variables at which the necessary response can be minimized or maximized. In fact determination of such values of independent variables is always the puzzle for the operator it is a complex phenomenon of interaction of various independent variables such as geometrical parameters of the pre-cleaner machine. It is known that mathematical modeling of any man machine system is possible applying the methodology of experimentation [4]. The same is adopted in the present work

In this research, 300 experimentations were designed on the basis of sequential classical experimental design technique that has been generally proposed for engineering applications. There are several quite simple ways in which a given test can be made compact in the operating plan without loss in generality or control. The best and the most powerful of these is dimensional analysis. This powerful technique may use for making the experimentation compact without loss in generality or control. It is also serves as a neat and rapid way of deriving certain functional relationship without recourse to complex theory. Once, all the variables involved in the system are known, an experimenter can immediately reduce their number by dimensional analysis [3] by applying Buckingham theorem which states, If any equation is dimensionally homogeneous, it can be reduce to a relationship among a complete set of dimensionless products.

The Buckingham's π Theorem is used for the dimensional analysis of proposed machine after identifying the dependant and independent variables. The empirical relation among the dependent and independent variables was developed on the basis of dimensional analysis [6]. Dimensional analysis offers a method for reducing complex physical problem to the simplest form prior to obtaining the quantitative solution.

A. Formulation of Generalize Experimental Data based Model By Dimensional analysis

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Processing torque, ‘ T ’ is function of ω, L_S, P_S, g, I, L_G, W, M, L_C, and V. thus the processing torque-T is dependent variable and others are independent variables.

Mathematically,

$$T = f\left(\omega, L_S, P_S, g, I, L_G, W, M, L_C, V\right) \qquad (1)$$

Or , it can be written as

$$f_1(T, \omega, L_S, P_S, g, I, L_G, W, M, L_C, V) = 0 \qquad (2)$$

Where V, g, W are considered as repeating variables

(i.e. m=3).

Total number of variables are ten (n=10) and repeating variable are three, hence the number of π terms are

(n-m) =10-3=7

Thus , seven π terms are formed hence, equation (2) is written as

$$f_1\left(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7\right) = 0 \qquad (3)$$

Writing the equation in terms of π terms, therefore,

$$\pi_1 = (W)^{a1}(g)^{b1}(V)^{c1}\,\omega \qquad (4)$$

$$\pi_2 = (W)^{a2}(g)^{b2}(V)^{c2}\,L_S \qquad (5)$$

$$\pi_3 = (W)^{a3}(g)^{b3}(V)^{c3}\,P_S \qquad (6)$$

$$\pi_4 = (W)^{a4}(g)^{b4}(V)^{c4}\,I \qquad (7)$$

$$\pi_5 = (W)^{a5}(g)^{b5}(V)^{c5}\,L_G \qquad (8)$$

$$\pi_6 = (W)^{a6}(g)^{b6}(V)^{c6}\,M \qquad (9)$$

$$\pi_7 = (W)^{a7}(g)^{b7}(V)^{c7}\,L_C \qquad (10)$$

Each π term is solved by the principle of dimensional homogeneity. These π terms are as shown in table III

Table III

INDEPENDENT DIMENSIONAL RATIO

Sr. No	Independent Dimensional	Nature of Basic Physical Quantities

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	Ratio or π Terms	
1	$\pi_1 = \omega V^{1/6} / g^{1/2}$	Parameter related to angular speed
2	$\pi_2 = L_S / V^{1/3}$	Parameter related geometrical parameter of machine
3	$\pi_3 = P_S / V^{1/3}$	Parameter related geometrical parameter of machine
4	$\pi_4 = I / (W V^{2/3})$	Parameter related to Inertia of Machine
5	$\pi_5 = L_G / V^{1/3}$	Parameter related geometrical parameter of machine
6	$\pi_6 = M$	Percentage of moisture
7	$\pi_7 = L_C / V^{1/3}$	Parameter related geometrical parameter of machine

Terms are arranged in Table III on the basis of the nature of basic physical quantities. Each dependant π terms (π_{01}) is assumed to be function of available independent π terms.

$$\pi_{01} = T / \left(W g V^{1/3} \right) \quad (11)$$

$$T / \left(W g V^{1/3} \right) = f \left(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7 \right) \quad (12)$$

It is assumed that this form comes out to be

$$\pi_{01} = K_1 (\pi_1)^{a1} (\pi_2)^{b1} (\pi_3)^{c1} (\pi_4)^{d1} (\pi_5)^{e1} (\pi_6)^{f1} (\pi_7)^{g1} \quad (13)$$

Equation is modified as by taking log on both sides, we got

$$\begin{aligned} \text{Log} (\pi_{01}) &= \text{Log} (k_1) + a \text{ Log} (\pi_1) + b \text{ Log} (\pi_2) + \\ & c \text{ Log} (\pi_3) + d \text{ Log}(\pi_4) + e \text{Log}(\pi_5) + f \text{ Log}(\pi_6) + g \text{ Log}(\pi_7) \end{aligned} \quad (14)$$

This linear relationship now can be viewed as the hyper plane in eight dimensional spaces. To simply further let us replace log terms by capital alphabet terms implies,

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Let , Log (π_D) = Z, Log (k) = K, Log (π_1) = A, Log (π_2) = B, Log (π_3) = C, Log (π_4) = D, Log (π_5) = E, Log (π_6) = F, Log (π_7) = G.

Putting the above values in "(14)"

$$Z = [K] + [a\,A] + [b\,B] + [c\,C] + [d\,D] + [e\,E] + [f\,F] + [g\,G] \quad (15)$$

This is true linear relationship between A to G to reveal π_{01}, π_{02}, π_{03} and π_{04}.

It is necessary to correlate qualitatively 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 processing torque is shown below

$$\pi_{01} = 0.5571\ \pi_1^{0.0614}\,\pi_2^{0.4164}\,\pi_3^{0.2121}\,\pi_4^{0.8083}\,\pi_5^{0.1051}\,\pi_6^{0.3966}\,\pi_7^{-0.0902} \quad (16)$$

In order to quantify or evaluate the behaviour of the real phenomenon to obtain result on account of appropriate interaction of independent pi terms. An attempt has been made here using experimental data base modelling. This method is adopted here for quantitative analysis of model of process torque. The indices of the model are the indicator of how the phenomenon is getting affected because of the interaction of various independent π terms in the models

It can be observed from the above model, the influence of index of $\boldsymbol{\pi_4}$ of independent terms on the response variable. The following primary conclusions appear to be justified by above predicting equation. The absolute index of π_4 is highest i.e. 0.8083.This term related to weight of cotton. The positive values of index indicates that π_{01} the process torque increases with the increase in this π_4 term and vice versa. The absolute index of π_7 is lowest i.e. - 0.0902. This term is related to distance between Grid bar and Spike. The negative values of index indicates that π_{01} i.e. process torque increases inversely with variation in this π_7 term and vice versa as shown in "(2)".

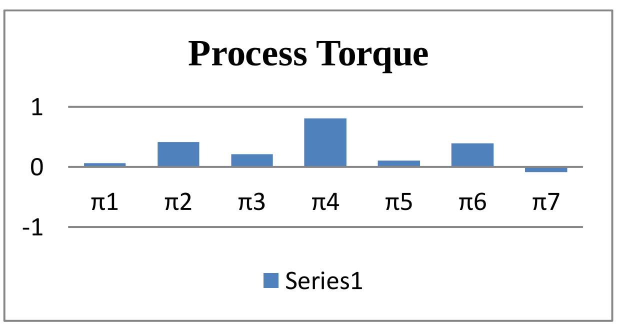

Fig.2 Influence of Pi terms on Dependent Pi terms (π_{01})

III. Estimation of Limiting Values of Response Variable

Four mathematical models have been developed for the phenomenon. The ultimate objective of this work is not merely developing the model, but to find out the best set of variables which will result in maximization/minimization of the response variables. In this section, attempt is made to find out limiting values of four response variables, viz. process torque, power consumption, cleaning percentage and process

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time. To achieve this, limiting values of independent π terms viz. π_1, π_2, π_3, π_4, π_5, π_6, π_7 are put in the respective model. In the process of maximizing, maximum values of independent π terms are put in the model, if the index of term was positive and minimum value is put if the index of the term was negative. In the process of minimization, the minimum value of independent π term is put in the model, if the index of term was positive and maximum value is put if the index of term was negative.

The Maximum π_{01} =2.85161.

And Minimum π_{01} = 1.60686.

IV. Model Optimization

The models have nonlinear form, hence it is to be converted into a linear form of optimization process [7]. This can be solved as a linear programming problem using the Big M-Method in M S Solver. The optimize values are tabulated in table IV

Table IV

Optimum Values of Response Variable

Maximization								
	k	pi1	pi2	pi3	pi4	pi5	pi6	pi7
	0.557	0.061	0.4164	0.212	0.808	0.105	0.396	-0.090
Maximum Value		39.499	0.4783	0.130	0.349	0.0261	6.500	0.0523
Minimum Value		78.998	0.4783	0.130	1.398	0.0261	9.500	0.0784

V. Computation of The Predicted Values by '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 model. For development of ANN researcher has to recognize the inherent patterns "(4)". Once this is accomplished training the network is mostly a fine tuning process.

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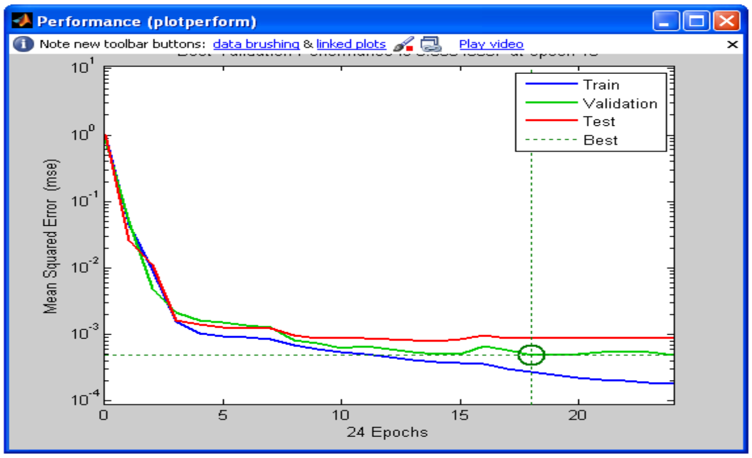

Fig. 4 Validation Performance of Pi01

Table V

VARIOUS ERRORS OBTAINED FROM ANN SIMULATION

Sr. no	Errors	π_{01}
1	Average Error	-0.228%
2	Mean Square Error	8.015%
3	Root Mean Square Error	2.831%

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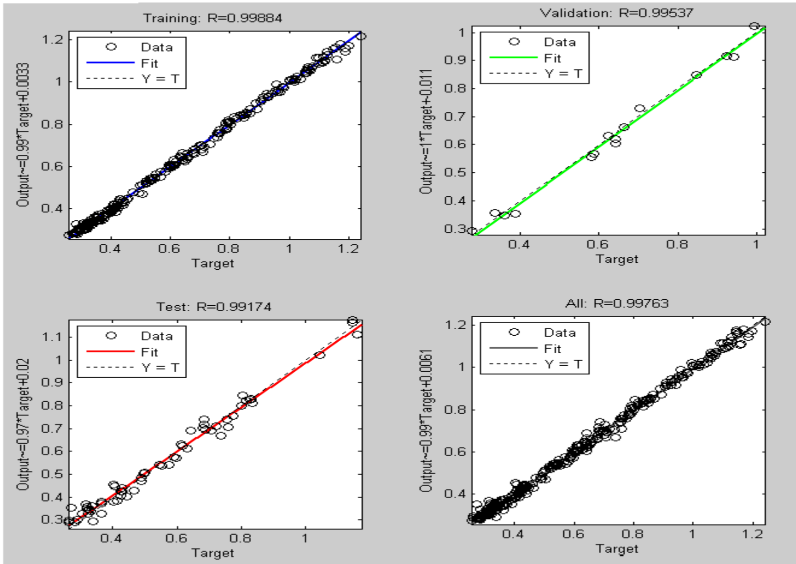

Fig. 5 Regression Plot of Pi01

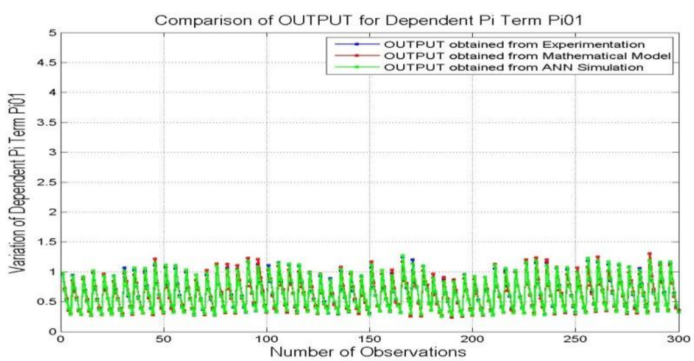

Fig. 6 Comparison of Output for Dependent π Terms π_{01}

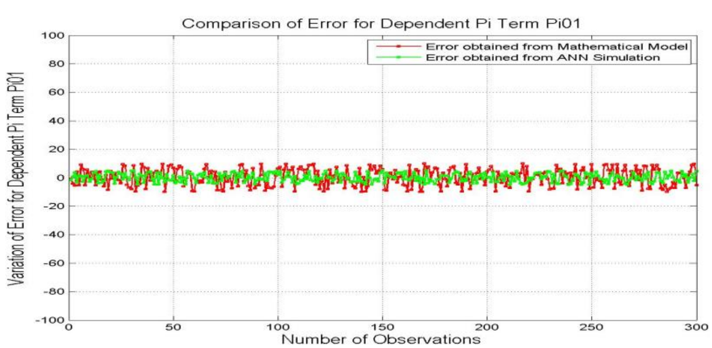

Fig. 7 Comparison of Errors for Dependent π Terms π_{01}

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VI. Result and Discussion

The experimental data, collected by experimentation are converted to the interpretable form and are analysed to draw some logical results for useful discussion. The influence of the independent π terms has been studied by analysing the indices of the various π in model. Through the technique of sensitivity analysis the change in the value of a dependent π terms caused due to an introduced changes in the values of individual π term is evaluated.

The ultimate objective of this work is not merely developing the model, but to find out the best set of variables which will result in maximization of the response variables. In this section, attempt is made to find out limiting values of response variables

One of the main issues in the research is the prediction of future results. The experimental data based modelling achieved through mathematical models for the dependant π terms. In such a complex phenomenon involving non linear systems, it is also planned to develop a model using Artificial Neural Network (ANN). The regression plot as shown in "(5)" gave the values of Coefficient of Correlation (R) for this models. These are as follows in table IV.

Regression values (R) measures the correlation between output and target. The R value one means a close relationship and zero means a random relationship. The values of R for this model is closer to one. Hence, this models show close relation between their respect output and target.

The output of this network can be evaluated by comparing it with the observed data and the data calculated from the mathematical models as shown in "(6)". This gives authenticity to the developed mathematical model and ANN simulation Model.

The standard errors of the estimate of the predicted or computed values of the dependant variables are found to be very low. The curve obtained by output for Conventional approach and ANN "(7)" are seen to be very close and overlapping.

VII. Conclusion

The data in the present work are collected by performing actual experimentation. Due to this the findings of the present study seem to be useful.

The design data, economic viability and feasibility, low cost of fabrication will help to start a small scale industry in the field of cleaning and processing of cotton.

The trends for the behavior of the models demonstrated by graphical analysis, influencing analysis and sensitivity analysis are found complementary to each other. These trends are found to be truly justified through some possible physics of the phenomenon.

It is observed from the first model (π_{01}), the influence of index of independent terms π_4 i.e. pi terms related to weight of cotton on the response variable. The absolute index of π_4 is highest i.e. 0.8083.This term is related to weight of cotton. The positive values of index indicates that π_{01} the process torque increases with the increase in this π_4 term and vice versa. The absolute index of π_7 is lowest i.e. - 0.0902. This term is related to distance between Grid bar and Spike. The negative values of index indicates that π_{01} i.e. process torque increases inversely with variation in this π_7 term and vice versa. The pi terms that are direct influence on π_{01} as per their index value are π_4, π_2, π_6, π_3, π_5, π_1, π_7.

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The value of the dependent pi term for optimum (Maximum) Process Torque is found to be 1.2416.

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