Formulation and Comparison of Experimental based Mathematical Model with Artificial Neural Network Simulation Model for Optimal Performance of Cotton Pre-Cleaning Machine

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Abstract

Cotton is a natural vegetable fiber produced in many countries of the world. Cotton is the backbone and basic foundation of the world's textile trade and industry. The cultivation and production of cotton and cloth had been the main agro based businesses in India. This paper presents the formulation and comparison of experimental based mathematical model with artificial neural network simulation model for optimal performance of cotton pre-cleaning machine. The appropriate generalized empirical model for cotton pre-cleaning operation is established. An approach of mini-max principal is used for minimizing process torque of spiked shaft.
Keywords: Cotton Pre-Cleaner, Dimensional Analysis, Buckingham's π theorem, ANN

I. INTRODUCTION

Cotton is a natural vegetable fiber produced in many countries of the world. It is a natural fiber and harvested from the cotton plant. It is also called as white gold (C.S. Mirani, 1995). Cotton is the backbone of the textile trade and industry of the world. In India, farming of cotton and production of cloth is the main Agro based businesses in India. It plays a vital role in the Indian economy by providing employment directly to 60-lak farmers of the country and indirectly to around 4-5 crores people. This indicated the importance of cotton based rural industries which includes cleaning and ginning of cotton.

The Indian cotton has relatively high level of contamination about 10-12% despite being handpicked from the farm. There is wide range of contaminants in cotton numbering over 20 types. (P. G. Patil et al., 2008) described the types of contaminants. These are leaves, strings, feather, paper, inorganic matter like sand, dust, oily substances and chemicals like grease or oil etc. Contamination is not being grown with boll in the tree. These are mostly added in fresh cotton during pickling. The contaminations are added in different stages of processing of cotton at ginnery.

A. Need and Salient Features of Generalized Experimental Data Based Models

For cotton pre-cleaning process there is a need of maximum processing torque and the energy to be supplied to the system should minimum. This would be possible if, there is quantitative relationship amongst various dependent and independent variables of the system. This relationship is known as mathematical model of this cotton pre-cleaning process. The formulating experimental data based model is helped when quantitative relationship based on the logic is not possible in the case of complex phenomenon. Hence, in this present investigation the formulation of such model is done. The methodology as suggested by (Schenck Jr., 1961) has been used for the planning of experimentation on a model of cotton pre-cleaning machine by keeping objective of experimentation to generate design data for cotton cleaning on cotton pre-cleaner machine. It is done by establishing an experimental model and to predict the performance of it. In this experimentation, the independent process variables identified which have the influence on the cleaning process. These variables shall be varied over widest possible range.

The photograph of model cotton pre-cleaner is shown in figure (Fig.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.

B. Theory of Experimentation

The approach adopted for formulating generalized experimental models suggested by Hilbert Schenck Jr. The steps are indicated below.

- Identification of independent, dependent and extraneous variables.
- Reduction of independent variables adopting dimensional analysis.
- Test planning comprising of determination of test envelope, test point, and test. Sequence and experimentation plan.
- Physical design of an experimental set-up.
- Execution of experimentation.
- Purification of experimental data.
- Formulation of model.
- Reliability of the model.
- Model optimization.
- ANN Simulation of the experimental data

Fig. 1: Cotton Pre-cleaner

II. EXPERIMENTAL PROCEDURE

Independent process variables and deprndent process variables are identified (see table I). 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.

The Test Envelop, Test Point, and Test Sequence are decided for test planning for experimentation. The test envelop is a range in which variable is varied during experiment. Time, fund available, previously established data about the process under study are the main factors for the test envelop. 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 is 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 this 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. The test envelops and Test point are decided.

Table - 1
Variable related to Cotton Preclearing Process

Sr. No.	Variables	Symbol	Unit	MLT	Types of Variable
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*
14	*Processing Time*	*t*	*s*	$M^0L^0T^1$	*Dependent*

III. DESIGN OF EXPERIMENT

It is well known that a model for the man machine system cannot be formulated by applying the logic (Schenck Jr.,1961). Hence, it is decided to formulate such an experimental data base model for this research. All the independent variable has varied over a widest possible range, a response data is collected. An analytical relationship is established. The technique of optimization can be applied to deduce value of independent variables. 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.

In this work, 300 experimentations were designed on the basis of sequential classical experimental design technique. 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. 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 (Agrawal, J. F., 1990).

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. Dimensional analysis offers a method for reducing complex physical problem to the simplest form prior to obtaining the quantitative solution (Agrawal et al., 2003).

A. Formulation of Generalize Experimental Data based Model by Dimensional Analysis

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,

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

Or, it can be written as

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

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

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

Writing the equation in terms of π terms, therefore,

Table - 2
Independent Dimensional Ratio

Sr. No	*Independent Dimensional Ratio or π Terms*	*Nature of Basic Physical Quantities*
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*

Each π term is solved by the principle of dimensional homogeneity. These π terms are as shown in (Table II)

Terms are arranged 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.

$$\pi_{01} = T / \left(W\ g\ V^{1/3}\right) \quad (4)$$

$$T / \left(W\ g\ V^{1/3}\right) = f\left(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7\right) \quad (5)$$

It is assumed that this form comes out to be

$$\pi_{01} = K_1 (\pi_1)^{a1} (\pi_2)^{b1} (\pi_3)^{c1} (\pi_4)^{d1} (\pi_5)^{e1} (\pi_6)^{f1} (\pi_7)^{g1} \quad (6)$$

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

$$\begin{aligned} \text{Log}\ (\pi_{01}) &= \text{Log}\ (k_1) + a\ \text{Log}\ (\pi_1) + b\ \text{Log}\ (\pi_2) + \\ &c\ \text{Log}\ (\pi_3) + d\ \text{Log}(\pi_4) + e\ \text{Log}(\pi_5) + f\ \text{Log}(\pi_6) + g\ \text{Log}(\pi_7) \end{aligned} \quad (7)$$

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,

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 Eq. vii

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

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

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

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

IV. SENSITIVITY ANALYSIS, RELIABILITY AND MODEL OPTIMIZATION

The influence of the independent π terms has been studied by analyzing the indices of the various π in model. Though 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. In this case of change of ±10% is introduced to the individual independent π term independently (one at a time). Thus, the total range of the introduced changes is ±10%. The effect of this introduced change on the change in the value of the dependent π term is evaluated.

The models have nonlinear form, hence it is to be converted into a linear form of optimization process (Daniel et al., 1998). This can be solved as a linear programming problem using the Big M-Method in M S Solver. The optimize values are tabulated.

V. COMPUTATION OF PREDICTED VALUE 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 (Paulraj, 2003). For development of ANN researcher has to recognize the inherent patterns as show in figure (Fig. 2). Once this is accomplished training the network is mostly a fine tuning process.

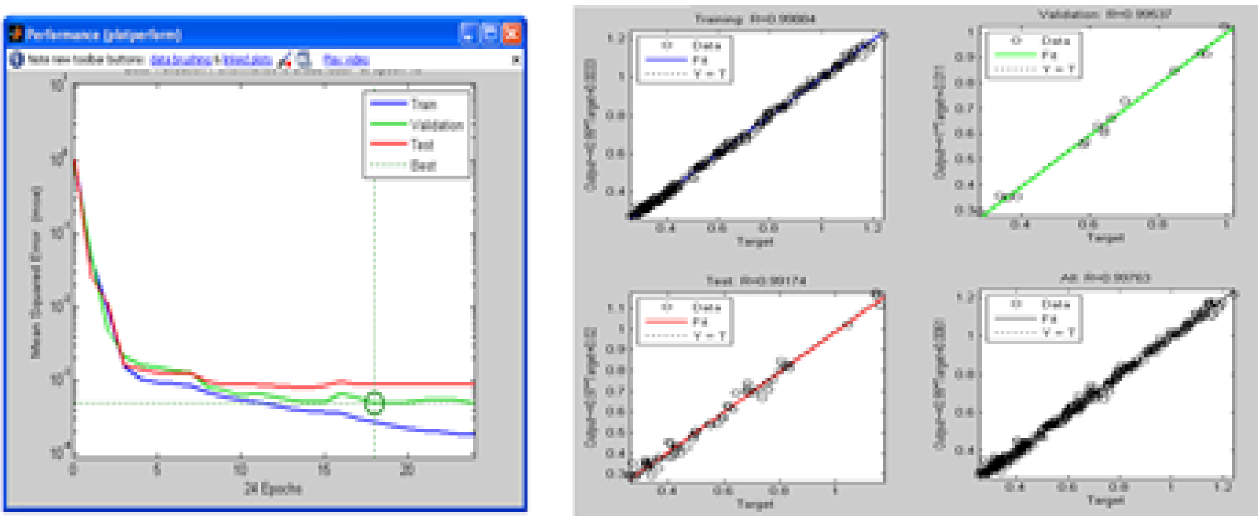

Fig. 2: Validation Performance of Pi01 and Regression Plot of Pi01

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 are seen to be very close and overlapping (Fig.3).

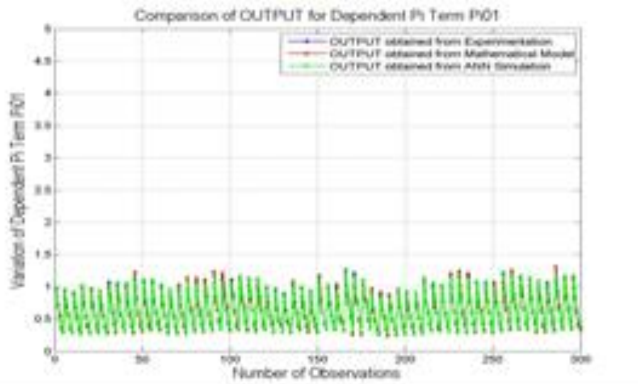

Fig. 3: Comparison of Output for Dependent π Terms π_{01}

VI. 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 behaviour 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 indicate 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 indicate 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.

The standard errors of the estimate of the predicted or computed values of the dependent variables are found to be very low. The curve obtained by output for Conventional approach and ANN are seen to be very close and overlapping due to less errors i.e. 0.0287,. This gives authenticity to the developed mathematical models and ANN. The value of the dependent pi term for optimum (Maximum) Process Torque is found to be 1.2416.

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