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FORMULATION OF GENERALIZED FIELD DATA BASED MODEL FOR THE ELECTRICAL ENERGY EXPENDITURE DURING WHEAT GRINDING OPERATION

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ABSTRACT

This paper highlights the detailed methodology of mathematical model formulation for the electrical energy expenditure during the wheat grinding operation. This paper details the formulation of field data based model to analyze the impact of various machining field parameters on the electrical energy expenditure during the wheat grinding operation. In all, 34 independent variables are studied to analyze their effect on the dependent variable electrical energy expenditure. The independent variables are then grouped to form 7 dimensionless pi terms using the Buckinham's Pi Theorem. Further, a model is developed using matrix analysis and the effect of the independent pi terms on the dependent pi term is established. Model derived by combining positive and negative pi terms, further analyzes the effect of the independent variables on the electrical energy expenditure. The models are validated to gauge the accuracy. Formulation of mathematical model and sensitivity analysis reveals that the environmental conditions in the workshop, majorly, ambient temperature, highly influences the electrical energy expenditure. Other significant parameter that has a direct relationship with electrical energy consumption is parameters related to the power generation in the machine. As the motor speed increases, the electrical energy expenditure shall increase. An increase in the values of other parameters such as distance between the pulleys, pulley rpm and diameter ratio also result increase in electrical energy expenditure.

Keywords: *Wheat grinding; Field data based model; Sensitivity; Optimization.*

1. Introduction

Wheat is a major food staple in India, and is crucial to India's food economy. With wheat production of 70 to 75 million tons annually and a large demand, India's wheat economy is now the second largest in the world.

In the olden days, household had a 'chakki' to mill the wheat. It consisted of two stone disks, each about 20" in diameter, and 3" thick. In it, the lower disk was fixed while the top disk was rotated to ground the wheat. The top disk had a hole to feed the wheat. As the top disk was rotated, it scraped the wheat spreading it out to the outer edge. The scraping surfaces of both the stones were corrugated. The top disk sat on a spindle located on the bottom disk. The different length spindles were used to determine the coarseness of the output.

Modern flour mills, popularly known an 'Atta Chakki' machines use rotating millstones and are often driven by electric motors. The millstones do not touch each other when in operation. There is a gap between the static bedstone and rotating runnerstone which is determined by the size of the grain. Grain is fed from a chute into a hole, known as the eye, in the centre of the runnerstone. An intricate system of groves, known as furrows, distributes the grains across the millstone surface and also serves to ventilate and cool the millstones. The grinding surfaces of the millstones are known as lands and are divided into areas called harps. Once ground, the flour passes along narrow groves called cracking, and is expelled from the edge of the millstones.

2. Experimental Setup

Wheat grinding operation is carried on a wheat grinding machine popularly known as 'Atta Chakki'. A motor provides the power to turn the runnerstone at a given rotational speed. The power and the rotation per minute of the motor are determined during the research. The wheat grinding operation is carried out by an operator. The anthropometric as well as personal data such as age, skill, years in operation etc, of the operators are determined and taken as input variables for the system. Similarly environmental parameters are also

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taken as input variables. The machine parameters play a significant role in deciding the electrical energy expenditure and form part of the input variables.

A series of experiments were performed to study the effects of these variables on the electrical energy expenditure during the wheat grinding operation. These experiments were carried out to investigate the effects of various field input parameters mentioned above on the electrical energy expenditure during the operation i.e. total electrical energy consumed during grinding wheat into flour. The output was measured and recorded using appropriate storage devices (personal computer) for further analysis.

3. Need to formulate the field data based model

Data sets contain information, often much more than can be learned from just looking at plots of those data. Models based on observed input and output data (from real life situation) help us abstract and gain new information and understanding from these data sets. They can also serve as substitutes for more process-based models in applications where speed is critical or where the underlying relationships between different activities are poorly understood.

Thus, it is not possible to plan such activities on the lines of design of experimentation[1], especially for the dynamic system (which exists in wheat grinding process). When one is studying any completely physical phenomenon but the phenomenon is very complex, to the extent that it is not possible to formulate a logic based model correlating causes and effects of such a phenomenon, then one is required to go in for the field data based models[2]. In view of the dynamic nature of the context under investigation (which reveals complex phenomenon), it was decided to formulate a field data based model in the present investigation rather than using a theoretical approach.

4. Formulation of field data based model

4.1 Wheat grinding process as a system

Figure 1 is a block diagram that depicts the process during wheat grinding operation can be effectively explained with the Block Representation of wheat grinding phenomenon under study.

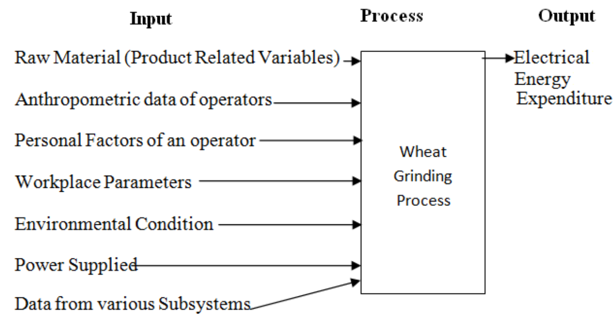

Figure 1: Block Representation of wheat grinding phenomenon

4.2 Identification of independent, dependent variables

The term variables are used in a very general sense to apply to any physical quantity that undergoes change. If a physical quantity can be changed independent of the other quantities, then it is an independent variable. If a physical quantity changes in response to the variation of one or more number of independent variables, then it is termed as dependent or response variable. Initially the independent and dependent variables under study were identified. Personal factors are also considered just to identify the effect of personal factors on Electrical Energy Expenditure in Wheat Grinding Operation. Table 1 and Table 2 depict the independent and dependent variables along with the MLT indices and test envelops respectively.

Table 1: List of Identified Independent (Input) Variables for Wheat grinding Process

S.no	Type	Variable Name	Symbol	MLT indices	Test Envelop
1	C1	Wight of Wheat	Ww	$M^1L^0T^0$	2 constant
2	A1	Total Height	Th	$M^0L^1T^0$	149.86 to 182.88
3	A2	Shoulder Height	Sh	$M^0L^1T^0$	127 to 157.48
4	A3	Waits Height	Wh	$M^0L^1T^0$	73.66 to 101.6
5	A4	Wrist Height	Wrh	$M^0L^1T^0$	60.96 to 91.44
6	A5	Arm Span	As	$M^0L^1T^0$	161.84 to 201.16
7	A6	Arm Reach	Ar	$M^0L^1T^0$	61.9 to 87.12
8	A7	Elbow Height	Eh	$M^0L^1T^0$	95.91 to 115.21
9	A8	Elbow Span	Es	$M^0L^1T^0$	37.46 to 47.29

10	P1	Experience of the Operator	Eo	$M^0L^0T^1$	5 to 30
11	P2	Age of the Operator	Ao	$M^0L^0T^1$	22 to 56
12	P3	Body Mass Index – Prime (BMI)	BMI	$M^0L^0T^0$	14.4 to 32
13	E1	Ambient Temperature	At	$M^0L^0T^0$	35 to 41
14	E2	Illumination at Workplace	Iwi	$M^0L^0T^0$	247 to 410
15	E3	Illumination outside Workplace	Iwo	$M^0L^0T^0$	2400 to 3400
16	E4	Noise Level at Work Place	No1	$M^0L^0T^0$	53 to 68
17	E5	Noise Level at Work Place (While machine is working)	No2	$M^0L^0T^0$	86 to 98
18	W1	Hp of the Machine Motor	HP	$M^1L^2T^{-3}$	7.5 to 20
19	W2	Motor Speed	Ms	$M^0L^0T^{-1}$	960 to 1440
20	W3	No. of Phases	P	$M^0L^0T^0$	3 constant
21	W4	Pulley Diameter Ratio	PDr	$M^0L^0T^0$	0.66 to 1
22	W5	Pulley RPM Ratio	PRr	$M^0L^0T^0$	0.66 to 1
23	W6	Distance Between pulleys	Dpp	$M^0L^1T^0$	70 to 72.5
24	W7	Hooper Height	Hh	$M^0L^1T^0$	150 to 155.5
25	W8	Break Height	Bh	$M^0L^1T^0$	48 to 54.4
26	D1	Drum Diameter	Dd	$M^0L^1T^0$	40.64 to 50.8
27	D2	Drum Width	Dw	$M^0L^1T^0$	7 to 8
28	GS1	Stone Hardness	Sh	$M^0L^0T^0$	8 constant
29	GS2	Stone Surface Roughness	Ra	$M^0L^1T^0$	0.00002 to 0.00004
30	GS3	Stone Density	Sd	$M^1L^{-3}T^0$	2.21 to 2.90
31	GS4	Stone Weight1	Sw1	$M^1L^0T^0$	23 to 41.5
32	GS5	Stone Weight2	Sw2	$M^1L^0T^0$	20.7 to 35.2
33	S1	Shaft Diameter	Dsh	$M^0L^1T^0$	3.95 to 4.15
34	S2	Shaft Length	Sl	$M^0L^1T^0$	80 to 81.5

4.3 Formation of different Pi terms formulated by Buckingham's Pi theorem

There are several quite simple ways in which a given test can be made compact in operating plan without loss in generality or control. The best known and the most powerful of these is dimensional analysis. In the past dimensional analysis was primarily used as an experimental tool whereby several experimental Variables could be combined to form one.

Using this principle modern experiments can substantially improve their working techniques and be made shorter requiring less time without loss of control. Deducing the dimensional equation for a phenomenon reduces the number of independent variables in the experiments. The exact mathematical form of this dimensional equation is the targeted model. This is achieved by applying Buckingham's π theorem (Hibert, 1961).

Initially it was necessary to formulate relationships such as

Z1=f[(C1)(A1,A2,A3,A4,A5,A6,A7,A8),(E1,E2,E3,E4, E5), (W1,W2,W3,W4,W5,W6,W7,W8),(D1,D2),(GS1,GS2,GS,GS4,GS5)(S1,S2)] (1)

Where

- Product related variable(C1)
- Anthropometric Data of an operator (A1,A2,A3,A4,A5,A6,A7,A8)
- Environmental conditions(E1,E2,E3,E4, E5)
- Workplace Parameters(W1,W2,W3,W4,W5,W6,W7,W8)
- Grinding Drum Parameters (D1,D2)
- Grinding Stone Parameters (GS1,GS2,GS,GS4,GS5)
- Power transmission shaft parameters (S1,S2)

The pi terms are formulated by applying Buckingham's Pi theorem in order to combine the variables and facilitate further analysis.

Thirty four independent variables are grouped into seven independent pi terms and a separate pi term is formulated for dependent variable electrical energy expenditure as depicted in table 3 below.

Table 2: List of Identified Independent (Response) Variables for Wheat grinding Process

S.no	Type	Variable Name	Symbol	MLT indices	Unit of Measurement
1	Ee	Electrical Energy Expenditure	Ee	$M^0L^2T^{-3}$	Minutes

Table 3. List of different Dimensional Pi terms formulated by Buckingham's Pi theorem

S.no	Independent Dimensionless Ratio	Independent Dimensionless Ratio	Nature of Basic Physical Quantities
1	π_1	π_1= (Th)(Sh)(Wh)(Wrh)/ (As)(Ar)(Eh)(Es)	Anthropometry related Pie Term
2	π_2	π_2=(Eo)(BMI)/ Ao	Personal Factors of operator
3	π_3	π_3= (At) (No1)/ (Iwi) (No2)	Environmental Conditions
4	π_4	π_4= $(Dpp^2)(Hh^2)(Bh^2).(Ww^3)(Ms^9)(p)^s(PDr)(PRr)/HP^3$	Power Generation Parameters
5	π_5	π_5=Dd/Dw	Drum Related Parameters
6	π_6	π_6= $(sh)(Ra^6)(Sd^2)/(Sw1)(Sw2)$	Stone Related
7	π_7	π_7=Dsh/Sl	Shaft Related
S.no	**Dependent Dimensionless Ratio**	**Dependent Dimensionless Ratio**	**Nature of Basic Physical Quantities**
1	π_8	π_8=(Ec)(Ms)/HP	Electrical Energy Expenditure

4.4 Approach for formulation of models based on observed data

It is necessary to correlate quantitatively various independent and dependent terms involved in this phenomenon. This correlation is a mathematical model as a design tool for such situation. The Mathematical model for wheat grinding operation is as given below.

4.4.1 Formulation of models based on observed data

Seven independent pi terms (π_1, π_2, π_3, π_4, π_5, π_6 and π_7) and one dependent pi term (π_8) were decided during experimentation and hence are available for the model formulation. Each dependent π term is the function of the available independent terms

$$\pi_8=f(\pi_1, \pi_2, \pi_3, \pi_4, \pi_5, \pi_6, \pi_7) \quad (2)$$

A probable exact mathematical form for the dimensional equations of the phenomenon could be relationships assumed to be of exponential form[5]. For example, the model representing the behavior of dependent pi term π_8 with respect to various independent pi terms can be obtained as under.

$$\pi_8=a_0\, \pi_1^{a1} * \pi_2^{a2} * \pi_3^{a3} * \pi_4^{a4} * \pi_5^{a5} * \pi_6^{a6} * \pi_7^{a7} \quad (3)$$

There are eight unknown terms in the equation (3) i.e. constant of proportionality a_0 & indices a_1, a_2, a_3, a_4, a_5, a_6, a_7.

The values of exponent a_1, a_2, a_3, a_4, a_5, a_6, a_7 are established independently at a time, on the basis of data collected through classical experimentation. There are eight unknown terms in the equation(3), curve fitting constant a_0 and indices a_1, a_2,a_3,a_4,a_5,a_6,a_7. To get the values of these unknowns we need minimum a set of seven set of all unknown dimensionless pi terms.

$$Z=A+bX+CY…….. \quad (4)$$

The equation 3 can be brought in the form of equation (4) by taking log on both sides.

$$LOG\ \pi_8=LOG\ a_0 + a_1\ LOG\ \pi_1 + a_2 LOG\ \pi_2 + a_3\ LOG\ \pi_3 + a_4\ LOG\ \pi_4 + a_5\ LOG\ \pi_5 + a_6\ LOG\ \pi_6 + a_7\ LOG\ \pi_7 \quad (5)$$

After solving using MATLAB, the mathematical model formulated is

$$\pi_8= 0.0578\ \pi_1^{-0.9940} * \pi_2^{0.0307} * \pi_3^{0.5022} * \pi_4^{0.1313} * \pi_5^{-0.0103} * \pi_6^{0.0583} * \pi_7^{-0.9144} \quad (6)$$

4.4.2 Formulation of Models Based on combination of observed data

Two more independent pi terms (π_a, π_b) were formed and already formed one dependent pi term (π_8) were decided during experimentation and hence are available for the model formulation.

π_a is formed by the product of the positive independent π as specified in equation(6).

$$\pi_a = (\pi_2 * \pi_3 * \pi_4 * \pi_6) \quad (7)$$

π_b is formed by the product of the negative independent π as specified in equation(6)

$$\pi_b = (\pi_1 * \pi_5 * \pi_7) \quad (8)$$

Each dependent π term is the function of the available independent terms

$$\pi_8=f(\pi_a, \pi_b) \quad (9)$$

A probable exact mathematical form for the dimensional equations of the phenomenon could be relationships assumed to be of exponential form [26]. For example, the model representing the behavior of dependent pi term π8 with respect to various independent pi terms can be obtained as under.

$$\pi_8=a_0\, \pi_a^{a1} * \pi_b^{a2} \quad (10)$$

Therefore two unknown terms in the equation 10 i.e. constant of proportionality a_0& indices a_1, a_2.

The values of exponent are a_1 and a_2 are established independently at a time, on the basis of data collected through classical experimentation. There are three unknown terms in the equation (10) curve fitting constant a_0 and indices a_1 and a_2. To get the values of these unknowns we need minimum a set of three set of all unknown dimensionless pi terms.

After solving using MATLAB, the mathematical model formulated is as indicated herein

$$\pi_8 = 17.374\ \pi_a^{0.1025} * \pi_b^{-0.5508} \quad (11)$$

5.0 Graphical Analysis of combination of observed data for Individual Mathematical Model for dependent pi term Electrical Energy Expenditure (Ee)

Figure 2 depicts 2-D graph with dependent pi term π8 is plotted on Y axis and the product of all independent pi terms is plotted on the X axis.

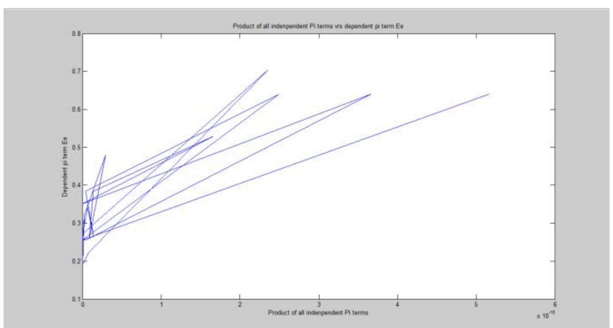

Figure 2 : 2-D Plot of Product of all independent pi terms Vs dependent Pi term π_8

It can be observed from the plot that as the product of the independent pi terms increases, the Electrical Energy Expenditure time Ee, as tends to gradually increase. 8 peaks observed, needs involvement of 16 mechanisms.

Figure 3 depicts 2-D graph, dependent pi term π_8 is plotted on Y axis and the product of all positive independent pi terms is plotted on the X axis.

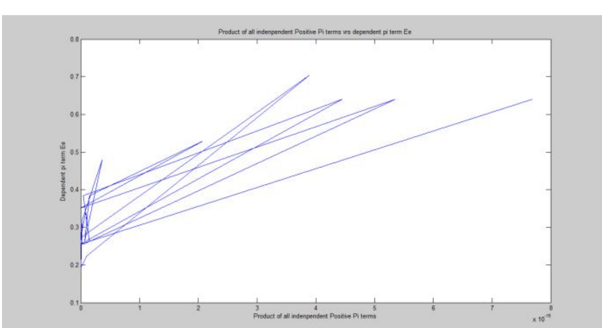

Figure 3 : 2-D Plot of Product of all independent Positive pi terms Vs dependent Pi term π_8

It can be observed from the plot that as the product of the independent positive pi terms increases, the Electrical Energy Expenditure Ee, as tends to gradually increase. 8 peaks observed, needs involvement of 16 mechanisms.

Figure 4 depicts 2-D graph, dependent pi term π_8 is plotted on Y axis and the product of all negative independent pi terms is plotted on the X axis.

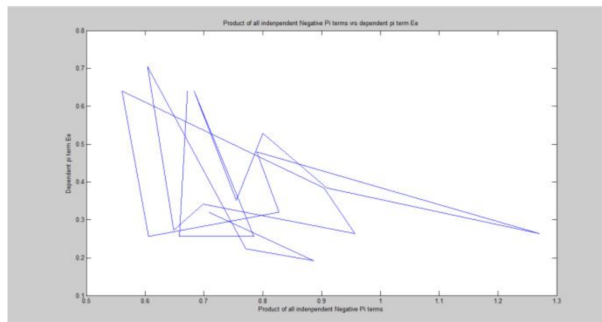

Figure 4: 2-D Plot of Product of all independent negative pi terms Vs dependent Pi term Pt

It can be observed from the plot that as the product of the independent negative pi terms increases, the Electrical Energy Expenditure Ee, as tends to gradually increase. 7 peaks observed, needs involvement of 14 mechanisms.

6.0 Model Sensitivity Analysis

The influence of the various independent π terms has been studied by analyzing the indices of the various π terms in the models. Through the technique of sensitivity analysis, the change in the value of a dependent π term caused due to an introduced change in the value of individual π term is evaluated. In this case, change of ± 10 % is introduced in the individual independent π term independently (one at a time).Thus, total range of the introduced change is ±20 %. The effect of this introduced change on the change in the value of the dependent π term is evaluated .The average values of the change in the dependent π term due to the introduced change of ± 10 % in each independent π term. This defines sensitivity. The total % change in output for ±10% change in input is shown in Table 4

The graphical distribution of the sensitivity analysis of the formulated model with respect to different pi terms is shown in figure 5.

Table 4 : Sensitivity Analysis of the formulated model

Pi Terms	% change
π_1	-0.22075
π_2	0.006142
π_3	0.09586
π_4	0.026004
πi_5	-0.00207
π_6	0.011631
π_7	-0.20141

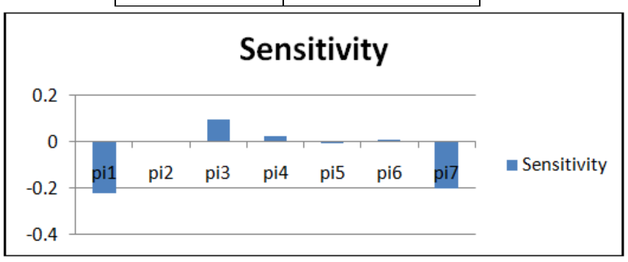

Figure 5: Graph of sensitivity analysis of the formulated model for Electrical Energy Expenditure

7.0 Model optimization for the Electrical Energy Expenditure

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 minimization of the objective functions. In this case, there is one objective functions corresponding to electrical energy expenditure during grinding process. The objective function for the electrical energy expenditure during wheat grinding process needs 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 as detailed below is applicable for wheat grinding operation.

Taking log of both the sides of the equation 4, we get the objective function

$$Z_{min} = \text{LOG}(0.0578)-0.9940\text{LOG}(\pi_1)+0.0307\text{LOG}(\pi_2)+0.5022\text{LOG}(\pi_3)+0.1313\text{LOG}(\pi_4)-0.0103\text{LOG}(\pi_5)+0.0583\text{LOG}(\pi_6)-0.9144\text{LOG}(\pi_7) \quad (12)$$

Subject to the following constraints

$$1X_1+0X_2+0X_3+0X_4+OX_5+OX_6+OX_7<= \text{LOG}(\text{Max } \pi_1)$$
$$1X_1+0X_2+0X_3+0X_4+OX_5+OX_6+OX_7>= \text{LOG}(\text{Min } \pi_1)$$
$$0X_1+1X_2+0X_3+0X_4+OX_5+OX_6+OX_7<= \text{LOG}(\text{Max } \pi_2)$$
$$0X_1+1X_2+0X_3+0X_4+OX_5+OX_6+OX_7>= \text{LOG}(\text{Min } \pi_2)$$

And so on up to

$$0X_1+0X_2+0X_3+0X_4+OX_5+OX_6+1X_7<= \text{LOG}(\text{Max } \pi_7)$$
$$0X_1+0X_2+0X_3+0X_4+OX_5+OX_6+1X_7>= \text{LOG}(\text{Min } \pi_7) \quad (13)$$

On solving the above problem by using MS solver we get values of X_1, X_2, X_3, X_4, X_5, X_6, X_7 and Z.

Thus π_8 min =Antilog of Z and corresponding to this value of the π_8 min the values of the independent π terms are obtained by taking the antilog of X1,X2,X3,X4,X5,X6, X7 and Z.

The optimized values are tabulated in table 5

Table 5: Optimized values of response variables for Electrical Energy Expenditure

Pi Terms	Log Values	Anti Log Values
Z	0.294	1.96
π_1	0.541	3.47
π_2	0.455	2.85
π_3	0.682322	4.80
π_4	7.823	66527315.6202
πi_5	0.86	7.24
π_6	-29.549	2.543E-30
π_7	-1.29	3.74

On substituting the values of π_1 to π_7 in equation (4), the mathematical model, we get

Z_{min} = 0.001kwh

Thus conclusion can be drawn that on reaching the optimized values of π_1 to π_7, one can minimize the value of response variable Electrical Energy Expenditure 0.001 kwhr.

8.0 Validation of the formulated generalized field data based model

The validity of the formulated model can be checked by comparing the actual experimental value of the pi term related with electrical energy expenditure and its values obtain from the formulated mathematical model. Table 6 and Figure 6 depicts Actual Electrical Energy Expenditure (Ee) Vs Model Predicted Electrical Energy Expenditure (Ee).

Table 6 : Actual Electrical Energy Expenditure (Ee) Vs Model Predicted Electrical Energy Expenditure (Ee)

Actual Ee	Ee (Model Predicted Ee)	% error
0.2	0.195173562	2.41%
0.16	0.205936804	-28.71%
0.16	0.162318260	-1.45%
0.2	0.181086306	9.46%
0.22	0.198054419	9.98%
0.22	0.232233710	-5.56%
0.18	0.145818882	18.99%
0.22	0.216239700	1.71%
0.2	0.212704932	-6.35%
0.2	0.203712864	-1.86%
0.16	0.166655396	-4.16%
0.2	0.193896413	3.05%
0.18	0.160746413	10.70%
0.22	0.263784876	-19.90%
0.16	0.145857250	8.84%
0.17	0.166562506	2.02%
0.22	0.204441847	7.07%
0.14	0.187011064	-33.58%
0.24	0.074719514	68.87%
0.2	0.176760763	11.62%

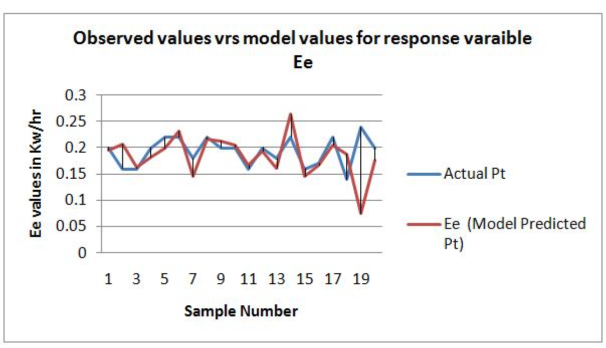

Figure 6: Actual Electrical Energy Expenditure (Ee) Vs Model Predicted Electrical Energy Expenditure (Ee)

Reliability of the model can be determined on the basis of the mean error.

Reliability = 100 – Percentage Mean Error

$$\text{Mean Error} = \frac{\sum(x_i * f_i)}{\sum(f_i)} \qquad (14)$$

Mean Error (Ee) = 2.65%

$$\text{Reliability} = 100 - \frac{\sum(x_i * f_i)}{\sum(f_i)}$$

Reliability = 97.35%

9.0 Interpretation and discussion

9.1 Mathematical model for Electrical Energy Expenditure

Referring to equation 6, it is observed that the absolute index of a_3 of π_3 term is the highest viz. 0.5022. This indicates the highest influence of the pi term π_3 on the electrical energy expenditure. Since index a_3, is positive, the relationship between electrical energy expenditure π_3 is direct, meaning that if value of π_3 increases, the electrical energy consumption shall increase. This pi term is related to the environmental conditions in the workshop. π_3 majorly has ambient temperature in the workshop in the numerator, this indicates that as the temperature inside the workshop increases, the electrical energy expenditure also increases. In order to reduce the electrical energy expenditure, the temperature in the work shop may be reduced. While doing so, one needs to take into consideration the impact of such reduction on other operational parameters.

Another significant pi term that has a direct relationship with electrical energy consumption is π_4. This pi term is related to the power generation parameters of the machine. As the motor speed increases, the electrical energy expenditure shall increase. An increase in the values of other parameters such as distance between the pulleys, pulley rpm and diameter ratio also result increase in electrical energy expenditure.

Another pi term that has high influence on the electrical energy expenditure is π_7. This pi term is related to the ratio of shaft diameter and shaft length. Since the index of π_7 is negatively, one can conclude that with increase in this ratio, the electrical energy consumption decreases. In order to reduce the electrical energy expenditure one needs to maximize this ratio. While doing so, one needs to take into consideration the impact of such reduction on other operational parameters.

Finally, pi term that is related to the personal factors of the operator is π_2. This pi term has almost no significance on the electrical energy consumption in wheat grinding operation.

9.2 Interpretation for Curve Fitting Constant

The magnitude of the curve fitting constant for the mathematical model as depicted in equation 6 for electrical energy expenditure is 0.0578. This value represents collectively the influence of various extraneous variables that affect the electrical energy expenditure but are not part of the study. Such extraneous factors in this case are related to factors such as vibration in the machine, condition of the machine components and power fluctuations etc.

9.3 Formulation of models based on combination of observed data for dependent pi term electrical energy expenditure

With reference to equation 11 one understands that the indexes a_1 and a_2 of π_a formed by the product of all positive pi terms and π b formed by the product of all the negative pi terms are 0.1025 and – 0.5508 respectively. It may be safely concluded that the positive pi terms put together have a significant and positive impact on the response variable electrical energy expenditure. In order to reduce the electrical energy expenditure, the parameters in $\pi_{2,}$ $\pi_{3,}$ $\pi_{4,}\pi_6$ should be decreased where as parameters in $\pi_{1,}$ $\pi_{5,}$ $\pi_7$should be increased.

9.4 Reliability of the model

From the values of percentage error, one can infer that the mathematical models can be successfully used for the computation of the values of dependent pi terms and subsequently that of the response variables.

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