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EXPERIMENTAL INVESTIGATION OF VARIOUS PARAMETERS ON POWER CONSUMPTION FOR STEEL IN TURNING OPERATION

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ABSTRACT

Machining has been a core activity of the manufacturing industry. The effectiveness of machining is controlled among other factors by the machinability of the material that is machined. At the same time cost is also important factor in manufacturing industry. To decrease the manufacturing cost, the power required to carry out the machining process should be reduced. So efforts are directed towards achieving an empirical relationship with the independent variable's effect on the dependent variable (Power consumption). Analysis of variance technique is used to check the adequacy of the model and to check the significance of the coefficient of the model. In this work the power consumption model is developed for steel (work material) by taking carbide as tool material. The models are helpful to reduce power required for machining by proper selection of cutting parameters namely Speed, Feed, and Depth of cut.

KEYWORDS— Speed, Feed, Depth of cut, Design of Experiment, Multiple regression

INTRODUCTION

The accelerated application of automation to machining process has focused on the desirability of reliable machinability data to ensure optimum production from modern costly equipment. Even in conventional production, much more should be done to provide reliable data for manufacturing engineers enabling them to set realistic standards of performance for the different machining operations. Different mathematical models can be used to describe the functional relationship of the machining measures of performance (response) and the cutting conditions. As indicated in Figure 1 the measures of performance investigated are power consumption while the cutting conditions are cutting speed, feed rate and depth of cut. It should be mentioned that the selection of a mathematical model type must be made on the basis of the physical behavior Of the system.

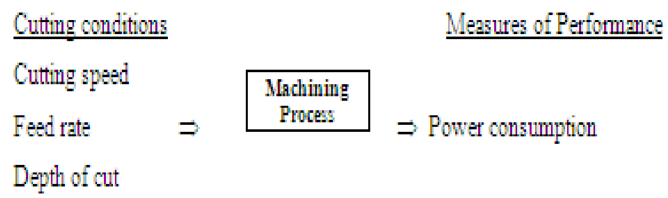

Fig.1 Inputs and Outputs of Machining Process

Here in our case power consumption is taken as machining measure of performance to develop mathematical model taking speed, feed and depth of cut as cutting variables. The power consumption estimates are wholly based on the experience of the machine operator most of the time. He sets parameter values depending upon the various materials to get the required power consumption. There are number of factors affecting the power consumption as listed below.

Factors affecting Power consumption

(a) Cutting speed
(b) Feed
(c) Depth of cut
(d) Work piece material
(e) Machine tool rigidity and accuracy
(f) Tool material

As per present day scenario cost is a critical factor. Trial and error methods adopted in the past lead to high cost of the end product. Where power consumption is a critical factor, the above-mentioned trial and error method lead to high machining cost thereby increasing the product cost. In this competitive environment high cost and low quality products do not survive. Keeping in mind the above condition (scenario) it is important to find an empirical relationship between power consumption and various factors affecting its outcome. Here in our case we consider the cutting speed, feed and depth of cut as variables and their effect on the consumption of the power.

CUTTING FORCES AND POWER DURING CUTTING

Machineability rating based on the cutting force is important, where it is necessary to limit the values of the cutting force in keeping with the rigidity of the machine and to avoid vibrations during machining. If the cutting force is high and consequently the power consumption is also high, a larger machine tool may be required thus increasing the overhead cost and unit cost of the parts produced. The higher the cutting forces induced under a set of cutting conditions during the machining of a material, the lower is its machinability index. The determination of magnitude and direction of cutting forces during machining is important for design and selection of proper machine tool, cutting tool and accessories.
Whenever a single point cutting tool is cutting the metal, the resultant cutting force, P in oblique directions can be resolved in three directions at right angles.

- Vertical chip pressure (main or tangential component Pz).
- Horizontal work pressures (axial component Px).
- Horizontal feeding pressure (radial component Py).

Out of these the first one that is Pz, is the most predominant as regards power absorbed and the other two although absorbing some power, are generally neglected. In order to account for the friction to overcome, generally 30% of the power is added to the power calculated on the basis of Pz.
From the numerous experiments performed, the following relation for the cutting pressure on a single point has been established.

$$\mathbf{P = C\, d^{a} f^{b}}$$

where,
p = pressure
d = depth of cut
f = feed
C = constant
And a and b are constants depending on the metal being cut and other factors

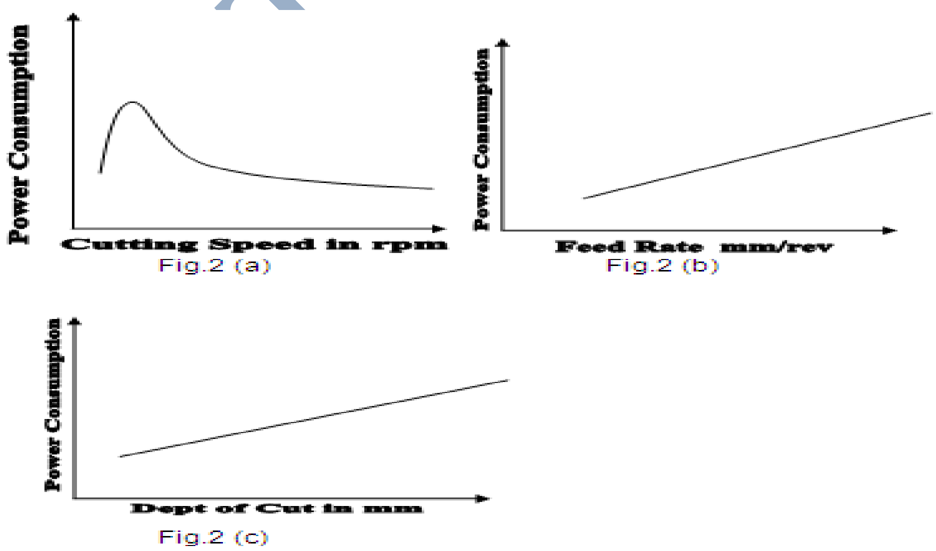

Fig.2 Graphs (Power consumption v/s Parameters)

EFFECT OF CUTTING SPEED: Experimental studies have revealed that at lower ranges of speed, the values of all the three components of power consumption have an upward trend. With increase in speed, the components of the power consumption to drop after reaching a peak value and become fairly stabilized at higher speed ranges.

EFFECT OF FEED: Experiments show that at lower speed values, the power consumption changes exponentially with feed and at higher speeds the change is linear.
EFFECT OF DEPTH OF CUT: If the depth of cut is doubled power consumption also gets doubled. This straight variation occurs when the ratio of depth of cut to feed exceeds.
In order to be able to satisfy a wide range of measuring requirements, micro picks-up can be divided into three groups or skid tracing systems.

DESIGN OF EXPERIMENTS

Experiments occupy a central place in science. Investigators perform experiments in virtually all fields of inquiry usually to discover something about a particular process or a system. Literally experiments are set of actions, which he has to resort, in order to ask nature questions to us. Design of Experiments is a series of tests in which purposeful changes are made to the input variables of a process or system so as to observe and identify the reasons for changes in the output response.
The following features are of great importance while designing the experiments.

- Striving to minimize the total number of trials.
- The simultaneous variation of all the variables determining a process according to special rules called algorithms.
- The use of a mathematical apparatus formalizing many actions of the experiments.
- The selection of a clear-cut strategy permitting the experimenter to make substantiated decisions after each series of trials or experiments.

A. ROLE OF EXPERIMENTAL DESIGN

Experimental design is a critically important tool in the engineering world for improving the performance of a manufacturing process. It also has extensive application in the development of new processes. The application of experimental design techniques early in process development can result in

- Improved process yields.
- Reduced variability and closure conformance to nominal or target requirements.
- Reduced development time.
- Reduced overall costs.

Experimental design methods also play a major role in engineering design activities, where new products are developed and existing ones improved. Some applications of experimental design in engineering design include:

- Evaluation and comparison of basic design configurations.
- Evaluation of material alternatives.
- Selection of design parameters so that the product will work well under a wide variety of field conditions, i.e., so that the product is robust.
- Determination of key product design parameters that impact product performance.

B. FACTORIAL EXPERIMENT

This project uses the factorial experiment model for Design of Experiments. In factorial experiment the effects of a number of different factors are investigated simultaneously. The treatment consists of all combinations that can be performed from different factors. In the general case “an experiment in which all the possible combinations of the factor levels are realized is called a factorial experiment”.
The first step in designing an experiment for obtaining a linear model is based on variations of the factors on two levels. In this case, the number of trials required for realization of all possible combinations of their levels can be found using simple formula:

$$\mathbf{N = l^{k}}$$

where,

$N \rightarrow$ the number of trials

$k \rightarrow$ the number of factors

$l \rightarrow$ the number of levels

If the number of trials becomes too large, then fractional factorial design is considered for minimizing the number of trials. In this case the above formula becomes.

$$\mathbf{N = l^{k-r}}$$

where,

$r \rightarrow$ replication (proper replication is chosen to reduce the no of trials)

(For example, for ½th i.e. $1/2^1$ replication, r=1 & for ¼th i.e. $1/2^2$ replication, r=2)

In this project the three optimization parameters are Cutting speed, Feed and Depth of cut.
Assuming the three factors as X_1, X_2 and X_3, each at two levels as +1 and –1, the design is called 2^3 factorial design. The number of possible trials in this case will be, $N = 2^3$ i.e. 8

C. SELECTION OF THE LEVELS

The selection of levels for the five independent control variables depends upon various factors such as type of machine tool, machine tool capacity, cutting tool used and cutting material etc.For convenience of recording and processing the experimental data, the upper and lower levels of parameter are coded as +1 and -1 respectively. The coded values of any intermediate levels are calculated by using the expression.

Coded variable $X_i = (X – X_{avg}) / V.I.$

where,

$X_i \rightarrow$ required coded value of variable X

$X \rightarrow$ natural variable

$X_{avg} \rightarrow$ average variable

V. I. $\rightarrow$ variation interval

$X_{avg} = (X_{max} + X_{min}) / 2$ & $V.I. = (X_{max} – X_{min}) / 2$

The design matrix or the set of trials, which are obtained considering the three independent variables, is shown in the following table:

Suffix h $\rightarrow$ Higher value

Suffix l $\rightarrow$ Lower value

$X_1 \rightarrow$ Speed (v) $X_2 \rightarrow$ Feed (f) $X_3 \rightarrow$ Depth of cut (d)

Table 3.1: Representation of Design matrix

Sl. No.	X_1	X_2	X_3	Speed (v)	Feed (f)	Depth of cut (d)
1	-1	**-1**	-1	V_l	F_l	D_l
2	+1	-1	-1	V_h	F_l	D_l
3	-1	+1	-1	V_l	F_h	D_l
4	+1	+1	-1	V_h	F_h	D_l
5	-1	-1	+1	V_l	F_l	D_h
6	+1	-1	+1	V_h	F_l	D_h
7	-1	+1	+1	V_l	F_h	D_h
8	+1	+1	+1	V_h	F_h	D_h

REGRESSION ANALYSIS

In regression analysis, our purpose is modeling or predication. Our goal is the development of a statistical model that can be used to explain variability and to predict values of the dependent variable or response variable (called the Y variable because, its values are plotted on the vertical Y-axis). The development of this model is based upon the values of at least one explanatory variable or independent variable (denoted by X since it is plotted on the horizontal X-axis of a two dimensional graph).

a. DEVELOPING THE SIMPLE LINEAR REGRESSION MODEL

In a scatter diagram, we can usually get a rough idea of the nature of relationship that exists between two variables. The mathematical form of this relationship can range from simple to the complex. In general the statistical model can be expressed as;

Response = Model + Error

We attempt to fit a mathematical function to the relationship between the variables. Since the variables are rarely perfectly related and measurement is rarely made without error, almost without exception, we are faced with the fact that there will be 'error' in our prediction model. In other words, there will be a difference between the value of the response variable predicted by the model and the actual observed Y value. This difference is called 'Residual'.

The simplest form of a mathematical model or relationship between two variables has a straight-line or linear relationship.

$$Y_i = b_0 + b_1X_i$$

where,

Y_i = the fitted or predicted value of Y for observation i

b_0 = the Y intercept or regression constant

b_1 = t he slope of Y with X or the regression coefficient

b. MULTIPLE REGRESSION

In a simple regression model, the focus was on a model in which one independent or explanatory variable X was used to predict the values of a dependent or response variable Y. In multiple regressions two or more explanatory variables can be used to predict the value of the dependent variable.

Assuming a linear relationship between each independent variable X and the dependent variable Y, the regression equation representing the fit for this multiple regression model (a plane is fitted to the data plotted in 3D space) with two independent variables would be, \

$$\mathbf{Y_i = b_0 + b_1 X_{1i} + b_2X_{2i}}$$

where,

Y_i = the predicted value of Y for observation i

b_0 = the Y intercept or regression constant

b_1 = the regression coefficient for variable X_1 which represents the slope of Y with X_1 holding variable X_2 constant

b_2 = the regression coefficient for variable X_2 which represents the slope of Y with X_2 holding variable X_1 constant.

The models for a multiple regression analysis are similar to the simple linear regression model except that they contain more terms. For e.g. suppose we think that the mean time E(y) required to perform a data-processing job increases as the computer utilization increase and that the relationship is curvilinear. Instead of using a straight-

line model $E(y) = b_0 + b_1 X_i$ to the model we might use quadratic model.

$$\mathbf{Y_i = b_0 + b_1X_1 + b_2X_1^2}$$

where,

X_1 is a variable that measures computer utilization.

A quadratic model is referred to as a second order linear model. Graph is like a parabola and allows for some curvature in the relationship in contrast to a straight line or first order linear model.

For our example, we would accept curvature in the response surface and would use a second order linear model.

$$\mathbf{Y_i = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_2 + b_4X_1^2 + b_5X_2^2}$$

c. MODEL BUILDING IN REGRESSION ANALYSIS

The first step in construction of regression model is to hypothesize the form of the deterministic portion of the probabilistic model. This model building or model construction stage is the key to success (or failure) of regression analysis. If the hypothesized model does not reflect at least approximately the true nature of the

relationship between response and the independent variables X_1, X_2... etc, the modeling effort will usually be unrewarded.
By model building we mean, writing a model that will provide a good fit to a set of data and that will good estimates of the mean value of Y and good predictions of future values of Y for given values of independent variables.
To illustrate, suppose you want to relate the demand Y for a given brand of personal computer to advertising expenditure X, and the second order model.

$$\mathbf{Y = b_0 + b_1X + b_2X^2}$$

Would permit you to predict Y with a very small error of prediction unfortunately, if the first order is chosen erroneously.

$$\mathbf{Y = b_0 + b_1X}$$

The errors of predictions for the second order model are relatively small in comparison to those for the first order model.

STATEMENT OF THE PROBLEM

To derive an empirical formula for the power consumption of steels by multiple regression method. The empirical formula is a relation between dependent (power consumption) variable and independent (various factors) variables. The variables (factors) selected in the experiment are cutting speed, feed, depth of cut, The experiment conducted is based on the principles of Design of experiments. Adequacy of the model is tested by Fisher's test. Significance of regression coefficients of the model is tested by student's t test. The model developed is helpful to select the optimal values of cutting parameters during machining to fulfill the objectives of the metal cutting.

OBJECTIVES

- To derive empirical formula for the power consumption of steel by multiple regression method.
- The empirical formula is a relation between dependent variable (power) and independent variables (various factors).
- The variables (factors) selected in the experiment are cutting speed, feed and depth of cut.
- The experiment conducted is based on the principles of design of experiments.
- The model developed is helpful to select the optimal values of cutting parameters during machining to fulfill the objectives of the metal cutting

METHODOLOGY

The following methodology was adopted;

- The high and low values (two levels) of the cutting variables were selected based on the general condition during metal cutting.
- The numbers of experiments to be conducted (on Automatic lathe) were decided based on the principles of Design of experiments.
- The required numbers of work-pieces were made ready.
- Turning operation was carried out on Automatic Lathe for all possible combination of machining parameters (Design matrix).
- The Power consumption of the machined work-pieces were measured and recorded using energy meter.
- The results obtained by the experiments were used to develop an empirical relation using multiple regression method.

EXPERIMENTAL SET UP

Tool, work piece and equipments used

- Energy meter
- Kirloskar Automatic 1550 Lathe
- High speed steel and Tool holder
- Mild Steel Work-pieces

Table 8.1 Variables and its test levels

Parameters	Units	Designation		Test levels		X_{avg}	V. I.
		Natural form	Coded form	Low	High	(H+L)/2	(H-L)/2
Cutting speed	rpm	V	X_1	90	540	315	225
Feed	mm/rev	F	X_2	0.05	0.5	0.275	0.225
Depth of cut	mm	D	X_3	0.5	2.0	1.25	0.75

Table 8.2 Design Matrix

Trial No	Design Matrix			Variable Settings		
	X_1 v	X_2 f	X_3 d	Cutting speed (rpm)	feed (mm/rev)	Depth of cut (mm)
1	-1	-1	-1	90	0.05	0.5
2	+1	-1	-1	540	0.05	0.05
3	-1	+1	-1	90	0.5	0.05
4	+1	+1	-1	540	0.5	0.5
5	-1	-1	+1	90	0.05	2.0
6	+1	-1	+1	540	0.05	2.0
7	-1	+1	+1	90	0.5	2.0
8	+1	+1	+1	540	0.5	2.0

Table 8.3 Power Consumption Values

Sl. No	X1 v	X2 F	X3 D	P1 kwh	P2 Kwh
1	-1 90	-1 0.05	-1 0.5	0.31	0.28
2	+1 540	-1 0.05	-1 0.5	0.07	0.03
3	-1 90	+1 0.5	-1 0.5	0.33	0.38
4	+1 540	+1 0.5	-1 0.5	0.08	0.12
5	-1 90	-1 0.05	+1 2.0	0.29	0.32
6	+1 540	-1 0.05	+1 2.0	0.08	0.09
7	-1 90	+1 0.5	+1 2.0	0.36	0.36
8	+1 540	+1 0.5	+1 2.0	0.10	0.01

Table 8.4 Considering Interaction Effects

Sl. No	X_1	X_2	X_3	Lables	Yi = (P1+P2) / 2
1	_	_	_	(1)	0.295
2	+	_	_	a	0.05
3	_	+	_	b	0.355
4	+	+	_	ab	0.1
5	_	_	+	c	0.305
6	+	_	+	ac	0.085
7	_	+	+	bc	0.36
8	+	+	+	Abc	0.01

FORMULAES

$$b_1 = a = 1/4n\ [\ a - (1) + a\,b - b + ac - c + abc - bc\ ]$$

$$b_2 = b = 1/4n\ [\ b+ab+bc+abc-(1)-a-c-ac]$$

$$b_3 = c = 1/4n\ [\ c+ac+bc+abc-(1)-a-b-ab]$$

$$b_{12} = ab = 1/4n\ [abc-bc+ab-b-ac+c-a+ (1)]$$

$$b_{13} = ac = 1/4n\ [(1)-a+b-ab-c+ac-bc+abc]$$

$$b_{23} = bc = 1/4n\ [(1) +a-b-ab-c-ac+bc+abc]$$

$$b_{123} = abc = 1/4n\ [abc-bc-ac+c-ab+b+a-(1)]$$

$b_0 = 0.2056$ $b_1 = -0.13375$ $b_2 = 0.01125$ $b_3 = -0.005$ $b_{12} = -0.0175, b_{13} = -0.00875$ $b_{23} = -0.01625$ $b_{123} = -0.015$

$$Y_i=b_0+b_1X_1+b_2X_2+b_3X_3+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3+ b_{123}X_1X_2X_3$$

$$Yi = 0.2056-0.13375[(v-X_{avg}.v)/ VI_v]+0.01125[(f-X_{avg}.f) / VI_f]-0.005[(d-X_{avg}.d) / VI_d]-0.0175[(v-X_{avg}.v)/VI_v][(f-X_{avg}.f) / VI_f]- 0.00875 [(v-X_{avg}.v) / VI_v][(d-X_{avg}.d) / VI_d]-0.01625[(f-X_{avg}.f) / VI_f][(d-X_{avg}.d) / VI_d]-0.015[(v-X_{avg}.v) / VI_v] [(f-X_{avg}.f) / VI_f] [(d-X_{avg}.d) / VI_d]$$

$$=0.2056-0.13375[(v-315)/225]+0.01125[(f-0.275)/0.225]-0.005[(d-1.25)/.75]-0.0175[(v-315)/225][(f-0.275)/0.225]-0.00875[(v-15)/225][(d-1.25)/0.75]-0.01625[(f-0.275)/0.225] [(d-1.25)/.75]-0.015[(v-15)/225][(f-0.275)/0.225] [(d-1.25)/.75]$$

$$=0.2056-0.00059v + 0.18725 +0.05f - 0.01375 - 0.00666d + 0.00833 -0.0003456vf +0.00009504v- 0.10886f - 0.02993- 0.000051851vd + 0.000064814v + 0.01633d - 0.02041 - 0.09629fd + 0.12037f +0.02647d - 0.03309 - 0.00039506vfd + 0.00010864vd + 0.1244fd - 0.03422d + 0.00049382vf - 0.00013578v - 0.1555f + 0.04277$$

$$\boxed{Y_i = 0.346773 - 0.000565926v - 0.09399f + 0.001914d + 0.00014822vf + 0.000056789vd + 0.02811fd - 0.00039506vfd}$$

CONCLUSION

The mathematical empirical models for power consumption for the mild steel material give following conclusions.

- The models are more adequate only when interaction effects are considered.
- The model is helpful to select the optimized values of the cutting parameters for lower power consumption.
- The model is helpful to calculate the power consumed for the given values of cutting parameters.
- The model is helpful to in automation industries.

The model is more adequate only when interaction effects are considered. The mathematical model, which is developed using Design of experiments and multiple regressions technique, is helpful to select the optimized values of the cutting parameters.

SCOPE FOR FUTURE WORK

- The Power consumption models for different work pieces and tool combination and for different operation can be developed.
- Similarly mathematical models for other responses of metal cutting like surface roughness, tool life and metal removal rate can be developed.
- The objectives of the metal cutting can be used for the models (different responses like tool life, material removal rate and surface roughness) and cutting parameters can be optimized using C-programming concept.

REFERENCES

[1] Douglas C. Montgomery, ''Design and analysis of experiments'' John wil and sons, New York,1997.
[2] William Mendenhall, ''Statistics for engineering and computer sciences''Terry Sincich dellen publications, San Francisco, 1988.
[3] John E. Freund, "Mathematical statistics": Prentice hall of India Pvt Ltd., New Delhi, 1994.
[4] R. K. Jain, ''Production Technology'' Khanna Publications, New Delhi, 1995.
[5] B. L. Juneja & Shekon, ''Fundamental of machine tool'' New age International Pvt Ltd., New Delhi, 1987.
[6] HMT Bangalore. ''Production Technology'' Tata McGraw-Hill Publishing Company Ltd., New Delhi.