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Statistical Prediction of Power Consumption

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A statistical technique for determining the power consumption in turning is introduced. This technique is based on mathematical representation of the cutting conditions taken at random. The consumed power is measured for various cutting speeds, feeds, depths of cut and work piece materials. The experimental procedure is carried out for different rake angles, as well as different coolants.

A general equation for the power consumption as a function of the previous conditions is constructed. It was also possible to derive a family of equations for the determination of the power consumption related to each individual variable.

The proposed statistical procedure is feasible for other cutting operations, and by applying such a technique, the experimental time will be reduced.

Introduction

The effect of various machining parameters on the power consumption has been reported by numerous researchers. The general procedure was to change one parameter at a time and study its effect. Such a technique does not really give good indication of the combined effect of the various parameters acting together.

A better technique is to change all the parameters at the same time, and study their effects on the power consumption, using statistical methods [1-8].

It is necessary to design the experiment in such a way that the experimental error variation due to extraneous sources [9] can be systematically controlled. The factorial experiment method allows the effect of each factor to be estimated and tested independently through the analysis of variance. In addition the interaction effects are easily assessed.

Thus, by adopting this technique of experimentation coupled with statistical analysis, a mathematical model could be developed to estimate the power consumption at various levels of the machining parameters.

Experimental Technique

Six independent variables were chosen for the factorial design:

1. Workpiece material (cold drawn SAE 1020, hot rolled SAE 1095).
2. Type of coolant (Dry, Wet).
3. Tool rake angle, α (3°, 5°)
4. Depth of cut, d (0.5, 0.8, 1.0 mm)
5. Cutting velocity, v (22, 45 m/min)
6. Longitudinal feed, f (0.075, 0.150, 0.300 mm/rev)

All the combinations of the six variables were used, and each combination was repeated three times. Thus, the total number of the experiments conducted were 432.

These experiments should have been run at random sequence, according to the requirements of the

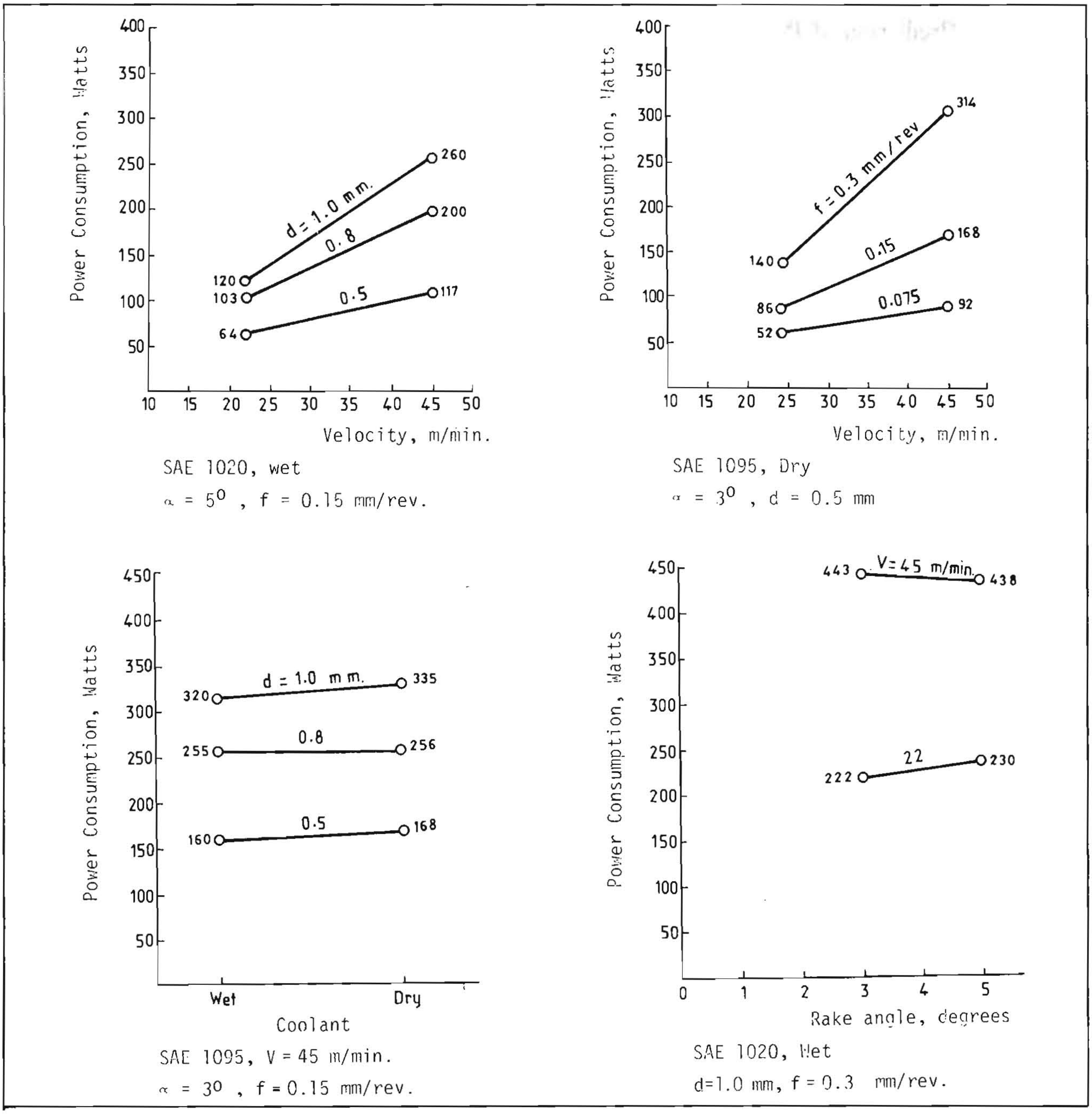

Fig.1: The effect of various parameters on the power comsumption.

factorial design technique. But due to the difficulties arose during changing the workpiece material, and the cutting tool at random order, a randomized block design was used.

The combinations of the first three variables were chosen at random and were kept constant for each set of experiments. Hence, eight sets of experiments were conducted with the depth of cut, cutting velocity, and the feed combinations being randomly selected within each set.

Carbide tipped cutting tools were used in the turning experiments, while the cutting forces, required for calculating the power consumption, were measured by means of an electrical two-component force dynamometer using inductive transducers.

Statistical Analysis

The regression analysis was used to arrive at the best estimate of the relationship between the variables. Assuming that the power consumption can be expressed as a linear combination of the other parameters, a multiple regression model was developed to relate the variables with the power consumption

$$Y = a_0 + a_1 x_1 + a_2 x_2 + ...a_n\, x_n$$

where y = estimated power consumption
x = machining variables
a = constant coefficients
n = number of independent variables

The coefficients in the model (a_0, a_1,.....,a_n) were estimated using least-square fitting.

The multiple linear correlation coefficient (r) was calculated according to the following equation,

$$r^2 = 1 - \frac{S_Y^2}{S_y^2}$$

where $S_Y^2 = \frac{1}{m-n-1} \sum_{i=1}^{m} (y_i - Y_i)^2$

m = number of data points

Y_i = estimated power consumption

y_i = observed power consumption

S_y^2 = variance of observed power consumption

Nevertheless, an F-test was performed to evaluate the significance of the fitting and to indicate the degree of confidence.

$$F = \frac{r^2\,(m-n-1)}{n\,(1-r^2)}$$

Analysis of the Results

The effect of the various parameters on the power consumption showed the same pattern for the eight sets of experiments. Typical representations are shown in Fig. 1.

It is clear from the figure that the power consumption increases with the increase of the cutting velocity, the depth of cut, and the feed. The effect of both, the coolant and the rake angle, was found to be negligible.

Figure 2 represents the main effect of the rake angle, the coolant, and the work material on the mean values of the power consumption for the different

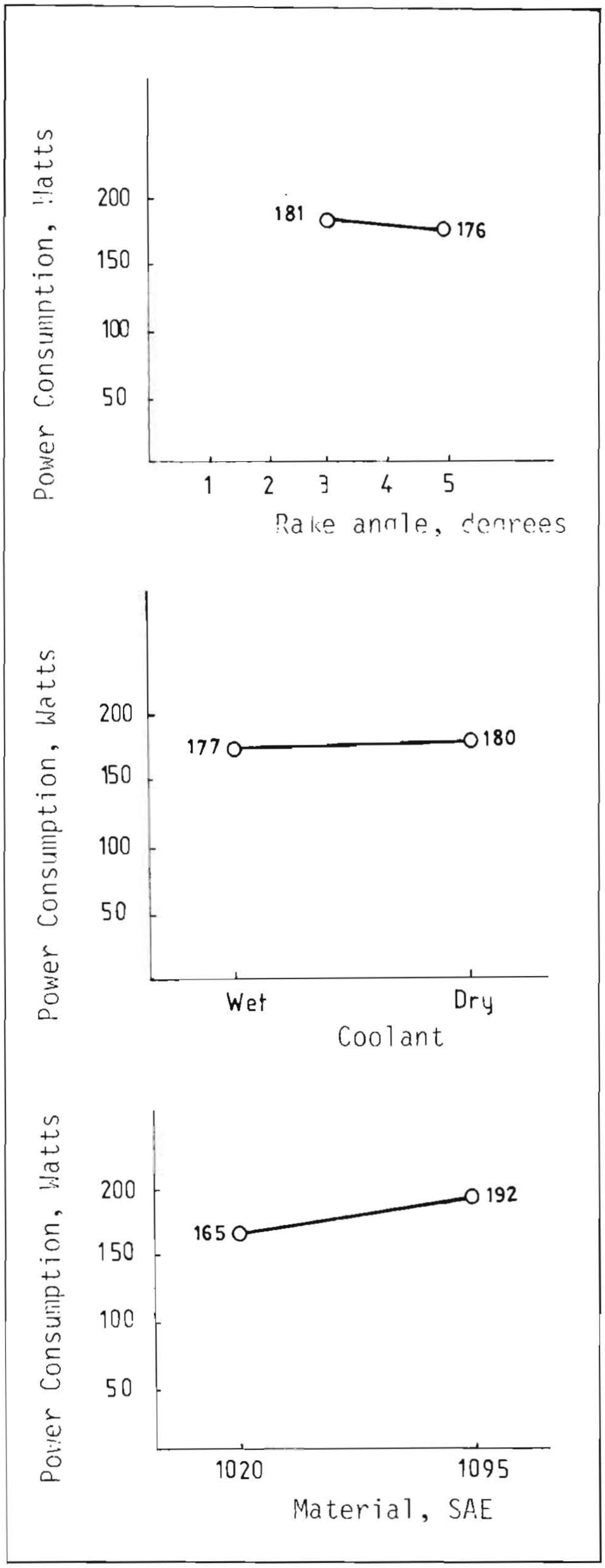

Fig. 2: The main effect of rake angle, coolant, and work material on the mean values of power consumption.

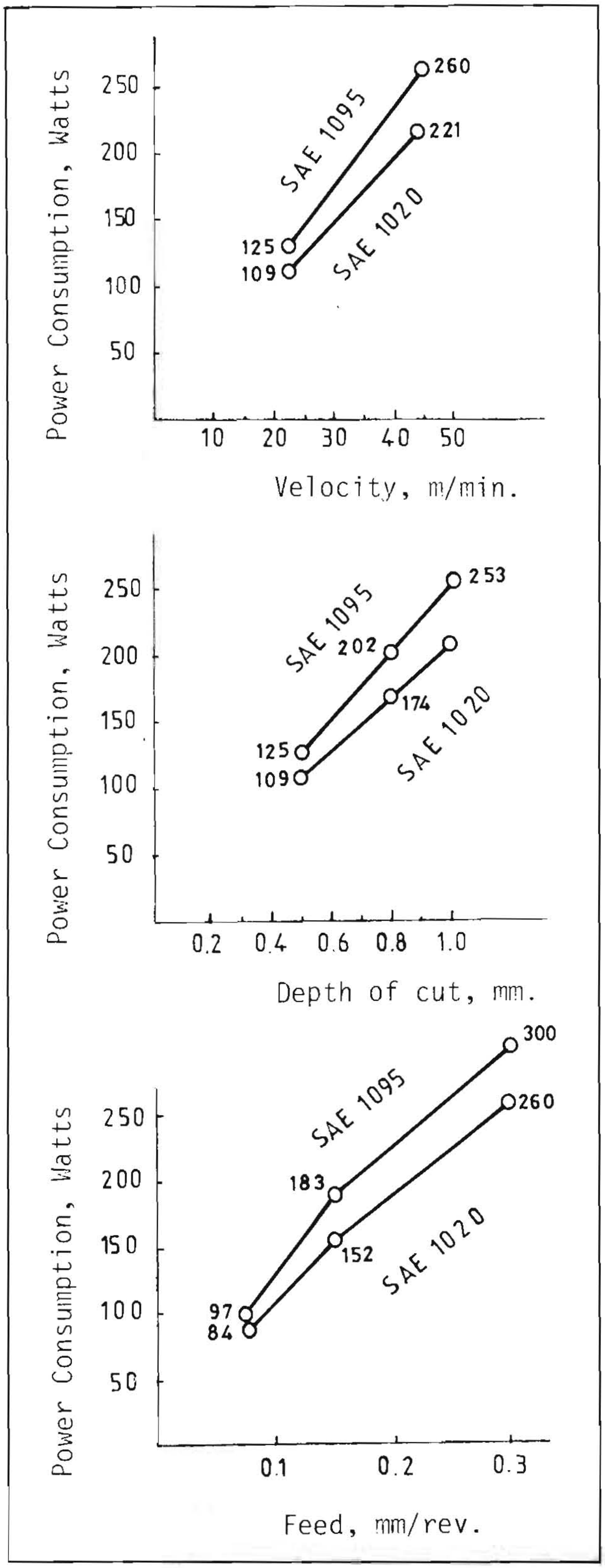

Fig. 3: The main effect of cutting velocity, depth of cut, and feed on the mean values of power consumption.

conditions. By increasing the rake angle from 3° to 5°, the power consumption was reduced by 2.8%. Thus, the effect of the change in the rake angle, in this case, is negligible as the two values chosen were very close.

Also, a drop of 1.7% in the power consumption proves that the coolant has no effect on the power within the experimental range. On the other hand, the influence of the work material is quite noticeable, as the power consumption was increased by 16% when substituting SAE 1020 by SAE 1095.

Therefore, the whole data were gathered in two groups, one for each material, neglecting the effect of both the rake angle and the coolant.

Figure 3 shows the main effect of the cutting velocity, the depth of cut, and the feed on the mean values of the power consumption for the two work materials. The power, as can be seen, increases with each one of the three variables at an average rate of,

a – SAE 1020:

4.87	watts per m/min., cutting velocity
209.38	watts per min., depth of cut
779.50	watts per mm/rev., feed

b – SAE 1095:

5.87	watts per m/min., cutting velocity
254.84	watts per min., depth of cut
910.76	watts per mm./rev., feed

A multiple regression analysis, applied to the experimental data, produced two equations relating the variables with the power consumption for the two work materials. The correlation coefficients (r) were calculated, and tested for significance with the F-test. The results obtained are as follows,

a- SAE 1020:

$$P = -304.18 + 4.81\ V + 220.64\ d + 769.89\ f$$

where P is the power consumption, watts
V is the cutting velocity, m/min
d is the depth of cut, mm.

f is the longitudinal feed, mm./rev.

$r = 0.9376$ (highly correlated)
$F = 514.322$ (significant at 0.005 level)

b- SAE 1095:

$$P = -372.55 + 5.82\ V + 261.40\ d + 904.61\ f$$

$r = 0.9272$ (highly correlated)
$F = 433.375$ (significant at 0.005 level)

The constants obtained from the regression equations match closely the average rates calculated from Fig. 3.

Conclusions

In this approach, the effects of some factors on power consumption are studied simultaneously through the use of a planned design for the collection and analysis of data. The influence of the rake angle and the coolant was found to be negligible within the used range of cutting conditions. A regression equation for each material was developed relating the variables, namely cutting velocity, depth of cut, and feed, with power consumption. Each equation was found to be highly correlated and significant at the 0.005 level. However, more experiments are required to study the effect of tool geometry, coolant, and work material, so that a more general model can be constructed taking into consideration, not only the cutting conditions but also the characteristics of the work material.

It is evident that this technique provides a method for predicting the power consumption for various levels of machining parameters from experimental information, and is not time consuming compared with other techniques.

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طريقة احصائية لتوقع القدرة المستخدمة في عمليات الخراطة

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يقدم هذا البحث وسيلة إحصائية لتعيين القدرة المستخدمة في عمليات الخراطة والتي تعتمد على التمثيل الرياضي لتغيرات القطع المختارة عشوائيا. وقد قيست القدرة المستخدمة عمليا مع تغيير كل من سرعة القطع ومعدل التغذية وعمق القطع ومعدن الشغلة وزاوية الجرف لأداة القطع وسائل التبريد.

وقد تم الحصول على علاقة عامة للقدرة المستخدمة كدالة لمتغيرات القطع. كذلك تم الحصول على مجموعة من العلاقات لتعيين القدرة المستخدمة بالنسبة لكل متغير.

ويمكن استخدام هذه الطريقة الإحصائية المقترحة في عمليات التشغيل الأخرى كما أن تطبيقها يقلل الزمن اللازم لإجراء التجارب.