THE PREDICTION OF THE CUTTING EFFICIENCY FOR TURNING OPERATIONS

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ABSTRACT

A series of machining experiments were conducted on steel specimens, and the effect of various machining parameters on cutting forces are presented. Empirical formulae for the estimation of the cutting forces, as functions of the cutting conditions, were deriven.

The term "Cutting Efficiency" is introduced, and could be considered as a measure of the performance of the cutting system. An empirical formula for the prediction of the cutting efficiency was established, and it could be used in optimization techniques.

KEYWORDS

Metal cutting, machining, cutting forces, specific cutting energy, cutting efficiency.

INTRODUCTION

The effect of the various parameters on the cutting process is the governing factor in determining the optimum cutting conditions to be applied, in order that better quality, minimum cost, maximum tool life, or maximum production rate could be attained. Therefore, the prediction of the generated forces during cutting has a great importance, not only for proper designing of cutting tools and clamping devices, but also for accurate estimation of cutting economy.

There have been many efforts to study the cutting process theoritically and to derive mathematical expressions relating the behavicur of the process to the different machining parameters [1-14].

Most of the theories did not give practical solutions due to

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the complexity of the cutting process and the numerous assumptions involved.

The deriviation of empirical formulae based on experimental data may help in solving such a problem, and better estimation of the cutting variables could be achieved.

EXPERIMENTAL WORK

Turning experiments were conducted, under dry cuttting condition, on hot rolled bars of steel 37 by means of H.S.S. tools having 60 deg. approach angle and 8 deg. back and side rake angles.The range of cutting speeds used was from 8 to 50 m/min., while that for feeds was from 0.1 to 0.31 mm/rev. The depth of cut also varied from 1.0 to 2.5 mm.

The cutting forces were measured by means of an inductive three components force dynamometer and its accessories. The dynamometer has 6 KN maximum load capacity, 1.0 N sensitivity, and 2 KHZ natural frequency.

RESULTS AND DISCUSSION

A-FORCE:

The effect of cutting velocity (V) on the tangential component (Fz) of the resultant force is shown in Fig. 1. The increase of the force at low cutting velocity was due to the formation of the built-up-edge, which was clearly observed during the machining. At higher range (above 20 m/min.), the force decreased with the increase of the velocity due to the decrease of the coefficient of friction and the reduction in the volume of the deformed zone.

Fig.2 illustrates the effect of feed (f) on Fz for different speeds and at 1.0 mm depth of cut. The relationship is almost linear, and the extensions of the straight lines intersect with the ordinate at a value which represent the component of the ploughing force (Fp)in the direction of cutting velocity. The ploughing force was found to be independent of both the cutting velocity and the feed, and dependent on the depth of cut. The relation between ploughing force (Fp) and depth of cut (d), Fig.3, was found to be,

$$Fp=160\ d^{0.85} \tag{1}$$

On plotting the effect of cutting velocity on tangential force for constant depth of cut of 1.0 mm on a logarithmic scale, Fig.4, the following formula was obtained,

$$Fz=K_1\ V^{-0.25} \tag{2}$$

The proprtionality constant was found to vary with feed according to the following formula, Fig.5,

$$K_1=4300\ f^{0.70} \tag{3}$$

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The relation between tangential force (Fz) and depth of cut (d) for constant feed of 0.10 mm/rev. was obtained by means of the following two equations, Fig.6 and Fig.7,

$$Fz=K_2\ V^{-0.25} \quad (4)$$

$$K_2=850\ d^{0.97} \quad (5)$$

Thus, by applying the four equations (2-5), the effect of the machining parameters (speed, feed, and depth of cut) on the tangential force could be represented by the following empirical formula,

$$Fz=4300\ V^{-0.25}\ f^{0.7}\ d^{0.97} \quad (6)$$

where Fz: tangential force, N
V :cutting velocity , m/min.
f :feed , mm/rev.
d :depth of cut , mm

The tangential force (Fz) is the sum of two forces,

a-Cutting force (Fc), which is the force required to perform the actual cutting operation.

b-Ploughing force (Fp), which is the force required to overcome the resistance of the work material to the penetration of the cutting edge.

By subtracting the ploughing force from tangential force, the cutting force was calculated, and the effect of the machining parameters on the cutting force were plotted on logarithmic scale, Fig. (8-11). The following set of equations was obtained,

For constant depth of cut of 1.0 mm:

$$Fc=K_3\ V^{-0.35} \quad (7)$$

$$K_3=6400\ f^{0.95} \quad (8)$$

For constant feed of 0.1 mm/rev.:

$$Fc=K_4\ V^{-0.35} \quad (9)$$

$$K_4=720\ d^{0.97} \quad (10)$$

Thus, the general empirical formula relating the cutting force to the machining parameters could be derived from eq^s.(7-10) to take the following form,

$$Fc=6400\ V^{-0.35}\ f^{0.95}\ d^{0.97} \quad (11)$$

B-ENERGY:

The total power (U), in watts, required to perform the cutting operation is the rate of energy change and equales the product of tangential force Fz, in newtons, and cutting velocity V, in m/sec. By applying equ.(6), the total power velocity V, in m/sec. By applying equ.(6), the total power could be estimated as :

$$U=71.7\ V^{+0.75}\ f^{0.7}\ d^{0.97} \qquad (12)$$

The apparent specific cutting energy (Psa), which is the total energy consumed per unit volume of metal removed, could be obtained by dividing the tangential force by the undeformed chip cross-section area (f.d),

$$Psa=4300\ V^{-0.25}\ f^{-0.3}\ d^{-0.03} \qquad (13)$$

It is clear that the apparent specific cutting energy varies inversely with both the feed, due to size effect, and the cutting velocity, due to strain rate effect. The depth of cut has a minor or rather a negligiable effect on (Psa).

The real specific cutting energy (Psr), which is the actual energy consumed per unit volume of metal removed [15], could be obtained by dividing the cutting force by the undeformed chip cross-section area,

$$Psr=6400\ V^{-0.35}\ f^{-0.05}\ d^{-0.03} \qquad (14)$$

As can be seen, the real specific cutting energy varies inversly with cutting velocity; and is not affected by either feed or depth of cut. Thus, the real specific cutting energy could be considered as a constant parameter for the machined material at constant cutting velocity, as mentioned before by Riad [15].

C-EFFICIENCY:

The ratio between the actual energy and the total energy consumed in cutting, could be used as a measure for the evaluation of the efficiency of the cutting process. Thus, by dividing the real specific cutting energy, eq.(14), by the apparent one, eq.(13), or dividing the cutting force, eq. (11), by the tangential one, eq. (6), the cutting efficiency could have the following form,

$$\eta=1.49\ V^{-0.1}\ f^{0.25} \qquad (15)$$

This shows that the cutting efficiency is a function of cutting speed and feed, and cutting conditions should be selected so as to maximize this parameter taking into considrations other constraints.

CONCLUSIONS

From above results and discussions, the following conclusions may be drawen:

1. The plouging force increases with the depth of cut, and is not affected by the change in cutting velocity and feed.
2. The cutting force decreases with the increase of cutting velocity (outside the built-up-edge range), and increases with feed and depth of cut.

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from cutting conditions, according to an empirical formula.

4. The total energy consumed per unit volume of metal removed decreases with the increase of either cutting velocity or feed.
5. The actual energy consumed per unit volume of metal removed is a constant parameter for the material, and decreases with the increase of cutting velocity.
6. The cutting efficiency evaluates the performance of the cutting process, and could be used in optimization techniques to find the optimum cutting conditions.

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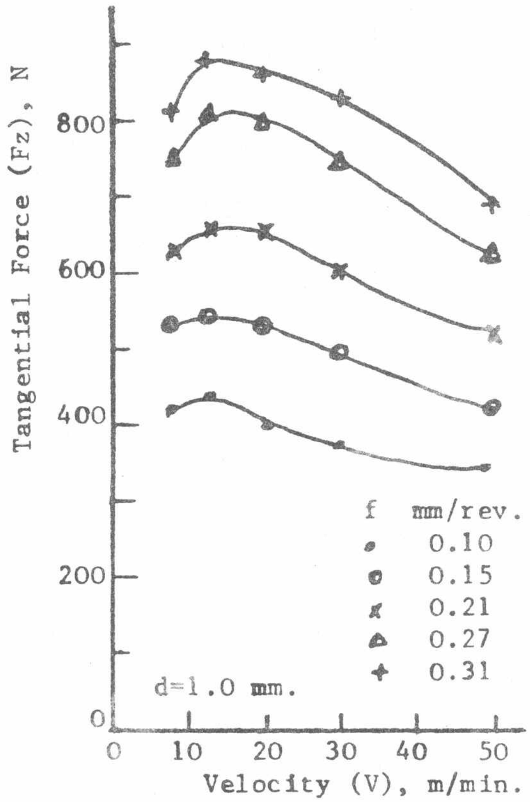

Fig.1 The effect of cutting speed on tangential force (Fz).

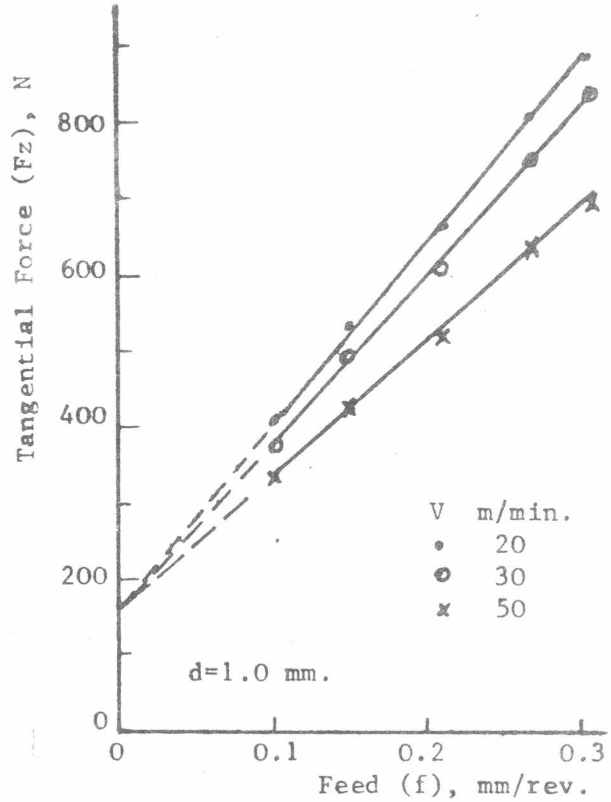

Fig.2 The effect of feed on tangential force (Fz).

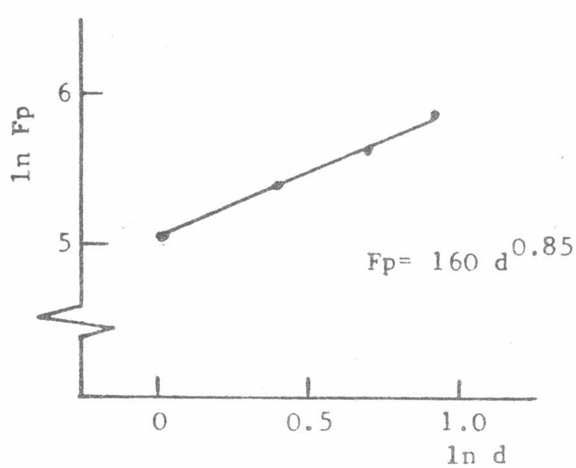

Fig.3 Logarithmic relationship between ploughing force (Fp) and depth of cut (d).

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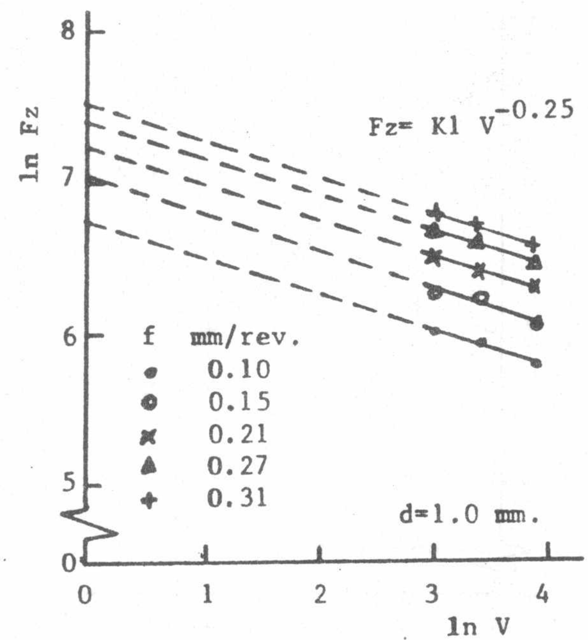

Fig.4 Logarithmic relationship between tangential force (Fz) and cutting speed V. at constant depth of cut.

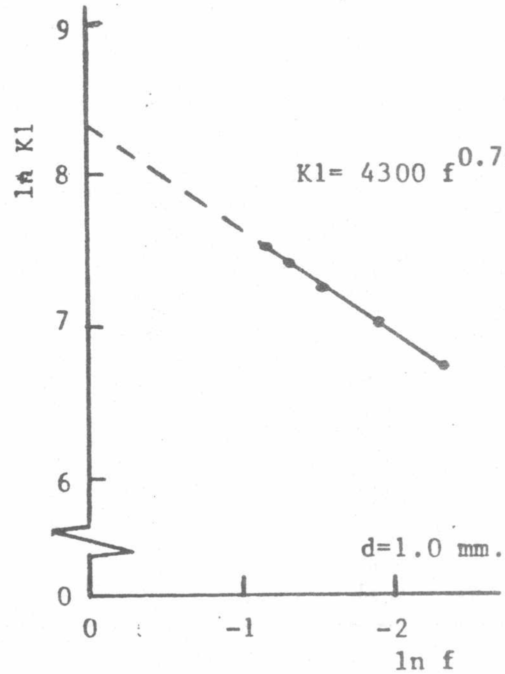

Fig.5 Logarithmic relationship between feed and proportionality constant of Fz and V. at constant depth of cut.

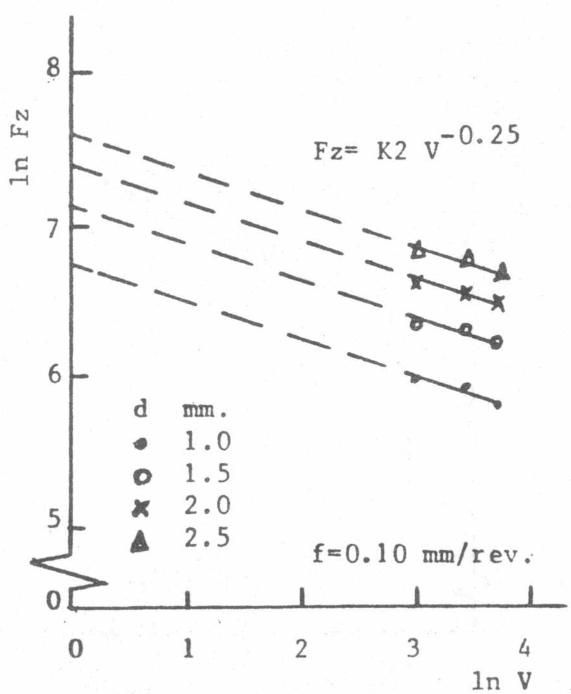

Fig.6 Logarithmic relationship between tangential force (Fz) and cutting speed V at constant feed.

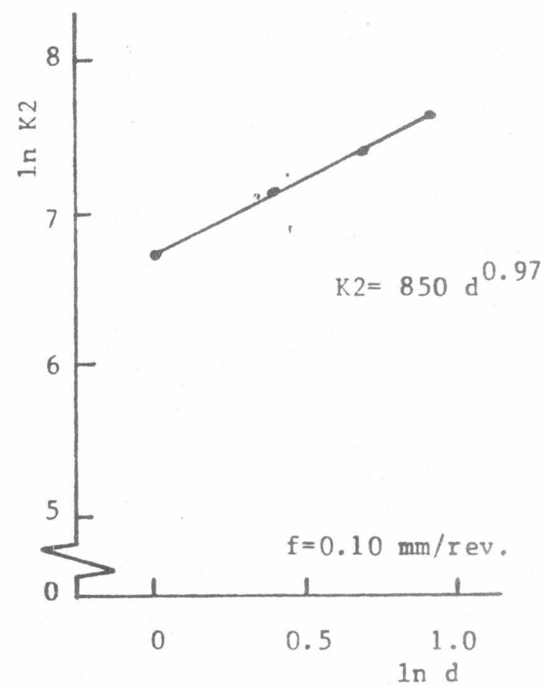

Fig.7 Logarithmic relationship between depth of cut and proportionality constant of Fz and V at constant feed.

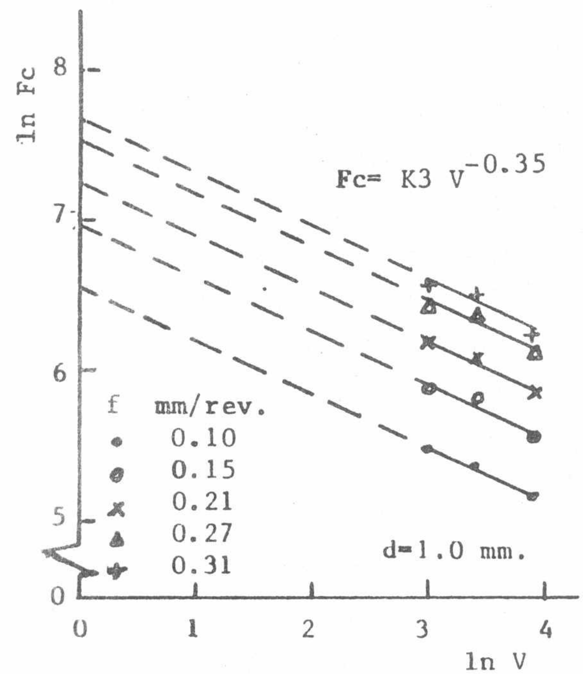

Fig.8 Logarithmic relationship between cutting force (Fc) and cutting speed V at constant depth of cut.

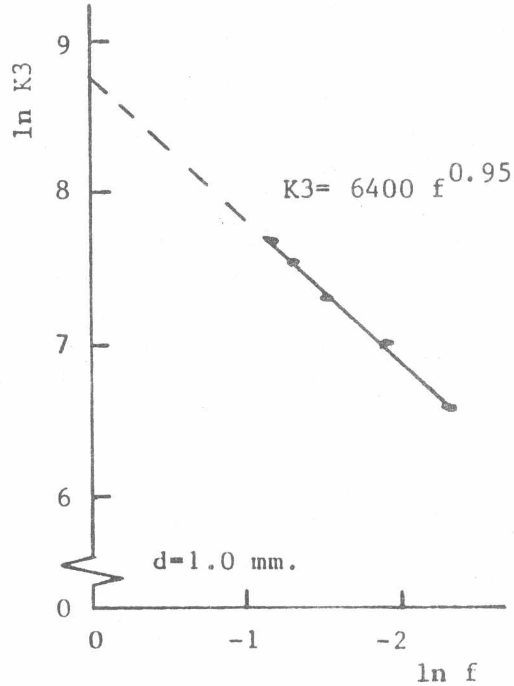

Fig.9 Logarithmic relationship between feed and proportionality constant of Fc and V at constant depth of cut.

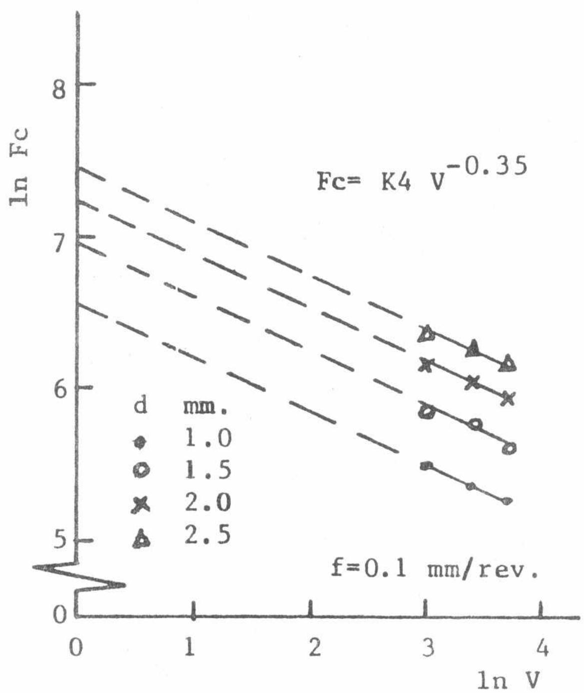

Fig.10 Logarithmic relationship between cutting force (Fc) and cutting speed V at constant feed.

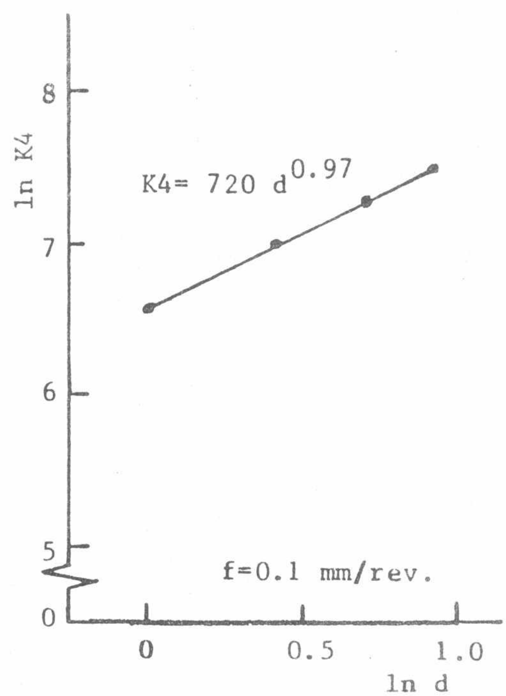

Fig.11 Logarithmic relationship between depth of cut and proportionality constant of Fc and V at constant feed.