EXAMINATION OF FRICTION CONDITIONS AT ORTHOGONAL CUTTING

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1. Introduction

In connection with the investigation of forces arising during the cutting of metals, a great deal of test data on the main cutting force are available. In case of a given cutting speed the work involved in the cutting process depends on the main cutting force. The necessary energy for cutting is used up by the shearing and friction processes. During cutting, shear and friction are in close connection with each other. The better the shear conditions, the more favourable the friction conditions. Shear conditions are improved and friction forces are reduced by a more arduous shear plane angle. The decrease of the friction force influences the decrease of the main cutting force both directly and indirectly. Let us examine first the main cutting force under various friction conditions.

2. Calculation of main cutting force

Metal cutting forces are calculated by force equations which in their majority are fractional exponential power functions or linear relationships.

As an example, for the relationship of the type $F = C_{Fh}\, h^p$, the compilation of Kronenberg [1] is quoted (Table I).

Table I

$F = C_{Fh}\, h^p\, l$	C_{Fh}	p
Taylor	200	0.93
Boston	170	0.76
AWF	140	0.52
ASME	190	0.80
Dawihl	185	0.76

Several $F = C_{FA}\, A^s$ functions are found in the collection of data by RICHTER [2] contained in Table II.

Table II

$F = C_{FA}\, A^s$	C_{FA}	s
Friedrich	198	0.93
Hippler	240	0.75
AWF	160	0.87
Leyensetter	190	0.84
Kronenberg	270	0.80

KASIRIN [3] gives a linear force equation of the form $F = C_F\, h\, l$. The earliest information on linear force equations may be attributed to WIEBE [4], dating back to 1858. Several recently developed linear relationships have been summarized in Table III. Under certain conditions the equations in

Table III

RICHTER [2]	$F = C_1(1 + C_2/h)hl$
THOMSEN [5]	$F = (\tau A_0 + F_0 \sin \varphi)\ \dfrac{1}{\eta}\ \dfrac{2 \cos (\beta-\gamma)}{1-\sin (\beta-\gamma)}$
STREMPEL [6]	$F = (A_F\, h + B)l$
ALBRECHT [4]	$F = C_1 + \zeta h\, (\cos \varrho_Q - \gamma)$
KASIRIN [3]	$F = C_F\, hl$

Table III can be brought to the simple form $F = (A_F\, h + B)l$ (e.g. in connection with the Thomsen—Kobayashy equation. See [7]).

It appears from the tabulated data that the quoted relationships are rather divergent, chiefly because the cutting test conditions lack an international standardisation even today. Without further precisions on the causes of deviation, let us consider the experimental determination of force equations.

3. Method of examination

Force equations are usually plotted from force data for determined and adjusted chip thicknesses, establishing the equation of the regressive straight from the plots. Be h_1 and h_2 the smallest and the largest undeformed chip thicknesses, resp., then the test interval will be $(h_1\, h_2)$. The basic condition of the application of force equations is the determination of the range of validity. This is, however, sometimes omitted in publications.

Analytically the force function is given by determining the intercept value of the ordinate on the basis of measured points belonging to the extrapolated $h = 0$. The force pertaining to this intercept value has no physical content. As regards the range $0 < h < 0.05$ it is also difficult to make a statement, as in a given cutting system the given chip thickness, which can just or still certainly be cut off, usually is within the range $h < 0.05$. This range needs still a more substantial explanation.

According to the method by the author [8] the force belonging to increasing or decreasing chip thicknesses is continually recorded. Thereby the h_{krit} chip thickness can be determined together with the examination of the

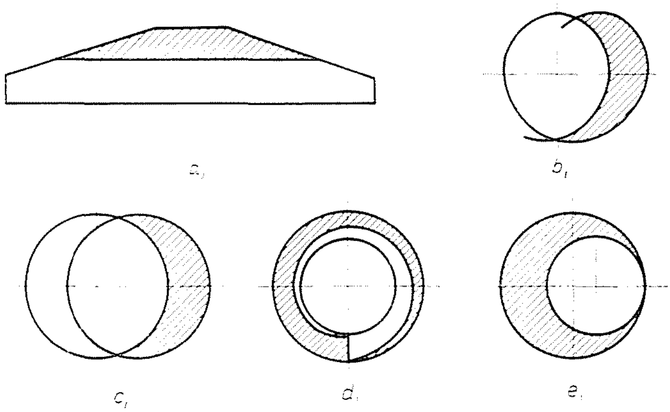

Fig. 1. Various chip models

development of the force at subcritical chip thicknesses. Several models lend themselves to study the cutting off for varying chip thicknesses, the simplest being the shaping of the slope (Fig. 1*a*), when the chip thickness varies linearily. Cykloid arcs confine the milling chips (Fig. 1*b*). Chip forms bounded by circular arcs arise during repeater feeding (Fig. 1*c*). For a feed-in during turning, starting from cylinder jacket surface, at constant feeding, during the first turn the chip thickness increases according to an Archimedean spiral, that is, when switching off the feeding it decreases (Fig. 1*d*). This method can be applied for long turning also. Chips of varying thicknesses can be cut off in case of eccentrically clamped cylinder jacket surfaces, too. (Fig. 1*e*). When turning eccentrically clamped cylinder jacket surfaces supplied with grooves, several consecutive increasing and decreasing sections can be recorded.

4. The determination of the main cutting force equation on the basis of chip shapes bound by circular arcs

The geometries of chips bound by circular arcs are shown in Fig. 2. During the test the rotating main moving tool separates the chips of varying thickness (Fig. 3). The main cutting force is determined by a torquemeter.

and recorded on a circular plate, the deviation being the distance between the basic circle of the intercepting point of the arcs and diagram plotted in the indicated angle position (Fig. 4). The axis of the recording disc was directly driven at a 2 : 1 acceleration by the rotating tool axis. In such a way the cutting arc of 180° was transformed to 360°, as can be seen in the diagram.

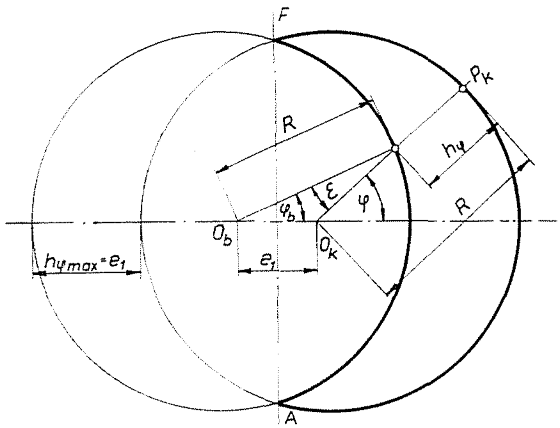

Fig. 2. Geometry of chip bound by circular arcs

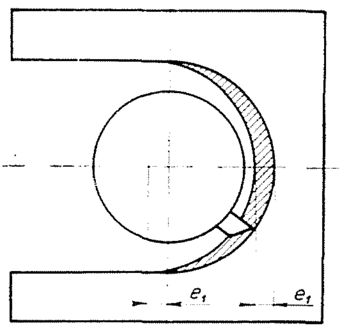

Fig. 3. The scheme of the cutting apparatus

The specimen cut was prepared from a material type C 35 lead alloyed, normalized, with perlite-ferrite structure a ground sheet 3 mm thick perpendicularly cut ot the axis. Its composition was: C 0.32, Mn 0.53, Si 0.28, Pb 0.23, S 0.038, P 0.036. Material characteristics: $HB = 159$ kp/mm^2, $\sigma_B = 51$ kp/mm^2, $\sigma_F = 25$ kp/mm^2, $\delta_5 = 13.6$.

Further data: the intermittent feed $h_{max} = 0.3$, diameter of tool $D = 100$ mm, cutting speed $v = 0.45$ m/min, the inserted tip R3 (18—4—1) high-speed steel, $\gamma = 15°$, $\alpha = 6°$.

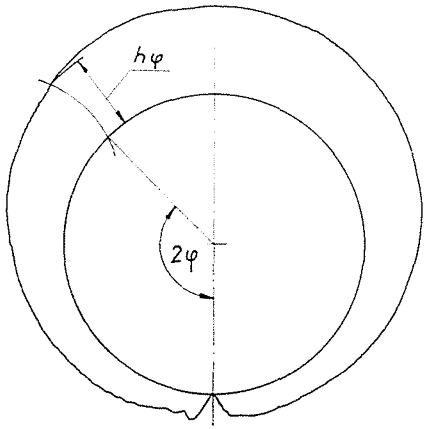

Fig. 4. Diagram of the $F = F(\varphi)$ function

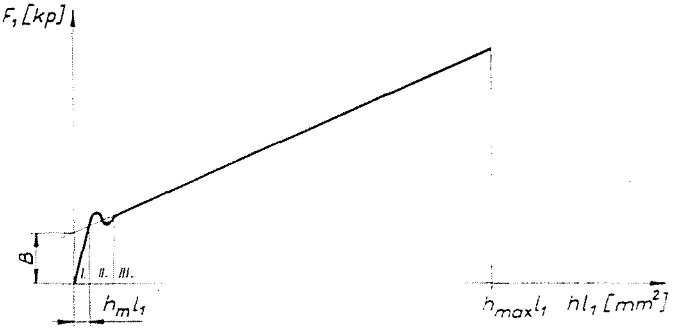

Fig. 5. Linear force equation $F_1 = F_1(hl_1)$ plotted from recorded values shown in Fig. 4

The diagram of the force equation can be plotted from values read off the recorded diagram, with $F_1 = Fl_1/l$ values in the ordinate and undeformed chip cross section hl_1 in the abscissa (Fig. 5). On the basis of the plotted diagram, the force values belong to three regions. The first, evenly increasing section lasts until cutting begins. The second section is characterized by decreasing force. In the third section the force increases evenly again, according to the increasing chip thickness. Now, omitting the analysis of the inner cracking, on the basis of h_m values at intersections of linear sections, the development of the force simplified to two sections can be described as follows:

For $h < h_m$ $\quad F_1 = C(hl_1)$, furthermore

for $h > h_m$ $\quad F_1 = C(h_m l_1) + A_F(h - h_m)l_1$

where C is a physically interpretable characteristic value.

Similar statements can be made on the radial component force as on the main cutting force.

5. The development of force equations during application of cutting fluids

The purpose of the application of cutting fluids is to improve accuracy of dimension, surface quality and tool wear. In this case, the evaluation is based on marks and traces left by the cutting process both on the workpiece

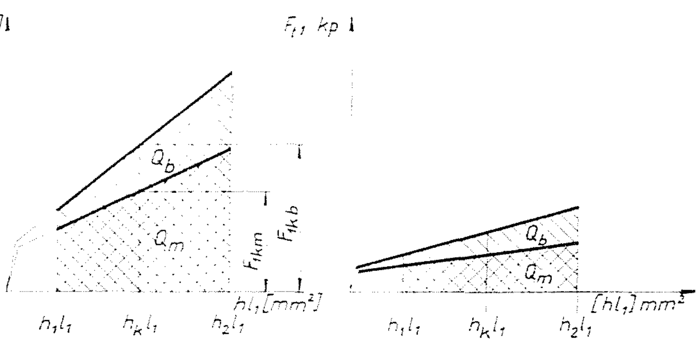

Fig. 6. Efficiency of cutting fluids in terms of areas Q_b and Q_m

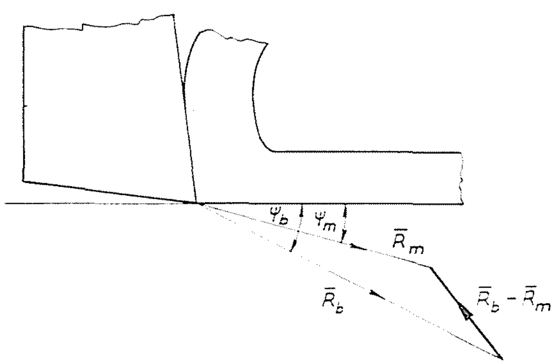

Fig. 7. The deviation vector of cutting forces R_b and R_m. b = basic condition; m = tested wet condition

and on the tool. Thereby indices are obtained on the accuracy, on the deformed surface layer, on surface roughness and tool wear.

The cutting fluids affect the cutting process in an extraordinarily complicated and many-sided way. It is expedient to examine primarily effects decisive for the mentioned aim and largely characteristic to the cutting process itself. No doubt, in this respect the cutting force is primarily of interest.

With the improvement of friction conditions, hence upon using cutting fluids, characteristics A_F and B of the force straights vary. Thus, the changing of the linear force equations permits to examine the effects of the lubricating materials. In the determined interval (h_1 h_2), the ratio of shaded areas (Fig. 6) can be used expediently as the measure of efficiency. Denote efficiencies of basic fluid and of the fluid to be qualified by Q_b and Q_m, resp., then the ratio Q_m/Q_b will be the quality index. The same is true for the radial component. In the case of linear force equation, the ratio of the ordinates belonging to h_k medium chip thickness can be applied.

As a result of complex investigations on the forces belonging to the medium chip thickness the effect of the cutting fluids is expressed by a deviation vector shown in Fig. 7. It can be stated that cutting fluids reducing the friction are of importance by decreasing the value of the radial component.

Summary

The improvement of friction conditions decreases the cutting force. The influence of cutting fluids can be evaluated expediently from the work area calculable from linear force equations. The difference of the cutting force vectors offers a method for further evaluation.

References

1. KRONENBERG, M.: Grundzüge der Zerspanungslehre. Springer-Verlag Berlin 1954.
2. RICHTER, A.: Die Zerspanungskräfte beim Drehen im Bereich des Fliesspans. Wissenschaftliche Zeitschrift der Technischen Hochschule Dresden. **4/5**, 2 (1952/53).
3. KASIRIN, A. I.: Metal cutting by high-speed steel. (In Hungarian). Nehézipari Könyvkiadó, Budapest, 1952.
4. DOHMEN, H. G.: Zusammenfassung und Vergleich der zerspanungsmechanischen Theorien. Industrie Anzeiger **87**, (1965).
5. THOMSEN, et al.: Deformation work absorbed by the workpiece during metal cutting. Trans. of the ASME. May (1953).
6. STREMPEL, H.: Schnitt- und Drangkraftverhalten beim Gegenlauffräsen. Fertigungstechnik und Betrieb **11**, 675 (1964).
7. KALÁSZI, I.—REZEK, Ö.: A new method of evaluation of cutting fluids by means of Kobayashy—Thomsen's cutting force equation for a low cutting speed range. Acta Technica, Acad. Sc. Hung. **66**, 417—426 (1969).
8. LETTNER, F. J.—REZEK, Ö.: Cutting force investigation by a new model. Annals of the C.I.R.P. **16**, 179—181 (1968).

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