TOOL LIFE CRITERION OF SINGLE POINT TOOLS WHEN CUTTING WITH NC MACHINE TOOLS

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I. The programing of NC machine tools and the tool life

Up to present, observations on experimental cutting in the laboratory and the technology in the plant were rather contradictory. Tool life equations determined in laboratory conditions were transferred to factory practice with poor results. Most frequently, this has to be attributed to the varying characteristics of material to be cut and of the tool. The situation is somewhat different when automatic machines and machine lines are used. Here, however, possibility of rapid tool wear or cracks mean such a great interruption, that everywhere — instead of optimum cutting conditions — a more or less safety technology is developed. Contrary to these, the commonly known high investment and operating expenses of NC machines, the quick changeability of the tools and the complete exclusion of personal factors influence the whole technology to a degree to approach laboratory conditions. The lathe-type NC machines, dependent on their purpose, produce components of either axial or disk character. In semi-rough turning with NC machines, the tool is demanded not to break off before a certain time. It is known that the economical tool life is directly proportional to the time for changing the tool and the cost of tool for one tool life. The cost of NC cutting tools is high, but the percentage for one tool life is low and involves a high cutting speed. In the case of turning steels and tough materials — independent of the dominant characteristics of condition — crater wear appears at these high speeds. Tests by OSMAN [1] and others prove that among the usual time-dependent characteristics of the crater the most characteristic i.e. linear change is shown by the depth of crater. Indirectly this also causes the cracking of the tool [2], thus in the case of semi-rough turning, depth of crater is regarded as the tool life criterion. As both length and cross turning, that is, both constant and varying speeds may occur, calculation methods must be worked out for both.

II. Crater wear for constant or varying speed. Tool life functions

1. *Theory*

The notation used in connection with the description of tool wear is shown in Fig. 1, schematic picture of a perpendicular section on a worn tool main edge.

The depth of crater linearly depends on the time, the exponent of cutting speed is greater than 1:

$$m = Btv^c \tag{1}$$

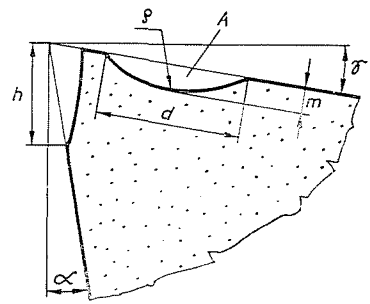

Fig. 1. Characteristic wear of the tool in perpendicular section on main edge (h — flank wear' d — width of crater, m — depth of crater, A — area of crater section, ϱ — radius of crater section, γ — rake angle, α — clearance angle)

where B and c constant
t time
v cutting speed

In the knowledge of B and c for constant cutting speed, the wear can be determined presuming constant feed. Rearranging Eq. (1) presuming tool life criterion values $m = m_0$ yields Eq. (2), i.e. the TAYLOR equation:

$$\frac{m_0}{B} = tv^c \qquad (\text{“}C = Tv^m\text{”}). \tag{2}$$

In cross turning it may be assumed that up to a time Δt the cutting speed is constant and for this time Eq. (1) is true. Thus the direction of the tangent to the curve $m = f(t)$ is:

$$\frac{\Delta m}{\Delta t} = Bv^c \qquad (v = \text{const.}). \tag{3}$$

It follows that the first derivative of curve $m = f(t)$ is:

$$\frac{dm}{dt} = Bv^c \qquad (v = f(t)!). \tag{4}$$

Supposing that cutting is performed in the range d_1 and d_2:

$$m = B \int_{t_1}^{t_2} v \, dt \tag{5}$$

where

$$v = \frac{d \pi n}{1000}, \qquad [v] = m/\text{min}$$

d_1, d_2 diameters, $[d] = \text{mm}$

$d = d_1 - 2\text{net}$

n rpm

e feed

$t_1 = 0$

$$t_2 = \frac{d_1 - d_2}{2en}, \qquad (d_1 > d_2)$$

$$m = \frac{B n^{c-1} \pi^c}{(c+1)\, 2e\, 10^{3c}} \left(d_1^{c+1} - d_2^{c+1}\right). \tag{6}$$

If cross turning is repeated z-times in a given range of diameters, the accumulated wear is obtained by simple multiplication:

$$\Sigma m = zm. \tag{7}$$

The condition of the suitability of Eq. 6 is that between the applied cutting speed limits the radius of the crater can be regarded as independent of the cutting speed and constant in time. The experiment in Fig. 2, as well as the measurements of OSMAN have also proved this assumption.

2. *Equivalent cutting speed*

What is the constant cutting speed which causes the same wear as the varying cutting speed of cross turning, if cutting times are equal? Analytically speaking:

$$B t v_{\text{equ}}^c = m = \frac{B n^{c-1} \pi^c}{(c+1)\, 2e\, 10^{3c}} \left(d_1^{c+1} - d_2^{c+1}\right)$$

where

$$t = \frac{d_1 - d_2}{2en}$$

hence

$$\text{i) for } d_2 \approx 0 \text{ and } v_{\max} = \frac{d_1 \pi n}{1000} \qquad v_{\text{equ}} = v_{\max} \left(\frac{1}{c+1} \right)^{\frac{1}{c}} \tag{8}$$

$$\text{ii) and for } d_2/d_1 = k \text{ and } v_{\max} = \frac{d_1 \pi n}{1000}$$

$$v_{\text{equ}} = v_{\max} \left(\frac{1}{c+1} \frac{1 - k^{c+1}}{1-k} \right)^{\frac{1}{c}} . \tag{9}$$

Thus v_{equ} depends on the exponent of the TAYLOR equation, if the tool life criterion is the depth of crater.

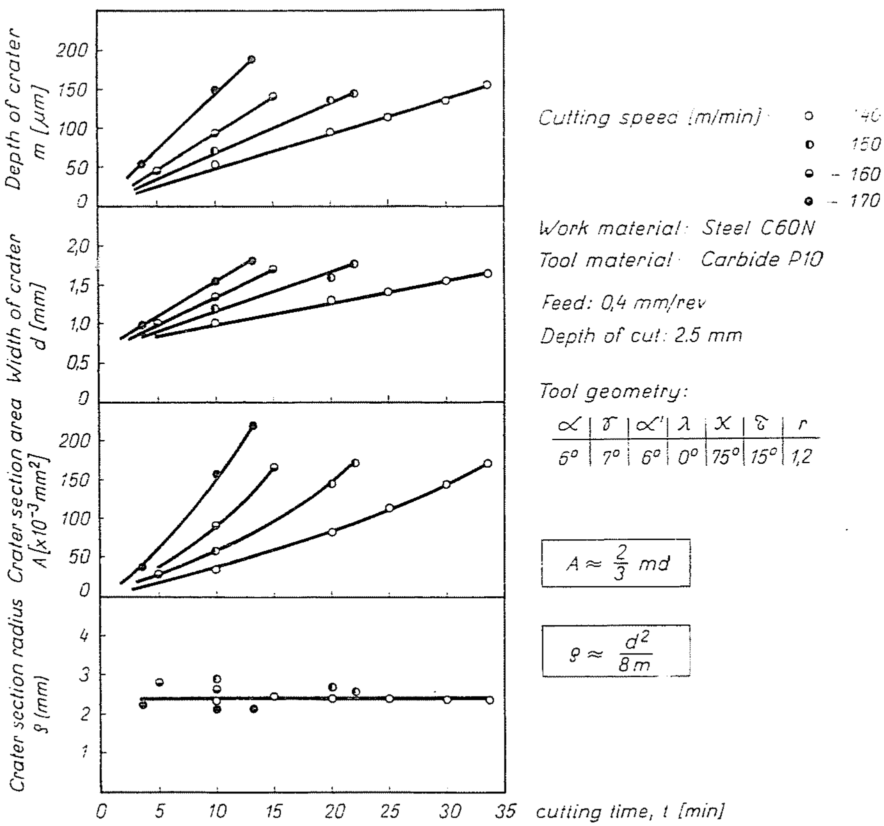

Fig. 2. Crater wear test

3. *The determination of the Taylor equation with cross turning*

The application of Eqs (1) and (2) depends on the knowledge of constants B and c, obtained by plotting wear curves during length turning. Naturally, this required blocks of large dimensions, for easy experiments, especially since no stepless speed variation was available. In NC relation further complications are caused by unfinished product such as a few disks. In determining the B and c constants described in this connection for this material and the carbide we had in stock, we developed a method.

The wear is obtained from cross turning at two different rpm. between identical diameters d_1 and d_2 as in Eqs (10) and (11):

$$m_1 = \frac{B n_1^{c-1} \pi^c}{(c+1)\, 2e\, 10^{3c}} (d_1^{c+1} - d_2^{c+1}) \tag{10}$$

$$m_2 = \frac{B n_2^{c-1} \pi^c}{(c+1)\, 2e\, 10^{3c}} (d_1^{c+1} - d_2^{c+1}) \,. \tag{11}$$

Substituting $m_1/m_2 = M$ and $n_1/n_2 = N$ we obtain:

$$M = N^{c-1}. \tag{12}$$

hence

$$c = \frac{\log M}{\log N} + 1 \,. \tag{13}$$

Knowing c, B can be determined from Eq. (10) or Eq. (11).

4. *Experimental result*

In principle Eq. (6) is equally valid when cutting from the centre or toward the centre. However, it is evident without experiment that a reliable result is only possible by turning from the centre, that is only in this case may the external greatest cutting speed exert a similar influence as length turning on the pre-heated face. Inversely, the cold tool wears less, which gives a false result. This was proved by measurement (Fig. 3).

The following experimental method was chosen for the proof. Cross turning was carried out on identical diameters with various rpm. from the centre. The results are shown in Table 1.

B and c values were calculated by Eqs (7), (10), (11), (13):

$$B = 7{,}87 \cdot 10^{-10}$$

$$c = 4{,}74.$$

Length turning was performed according to the data shown in Table 2.

The suitability of the calculating procedure for practical purposes is shown in Table 2, exhibiting a fair agreement between measured and calculated values. Deviations of the two methods will be investigated in a large series of length and cross turning tests.

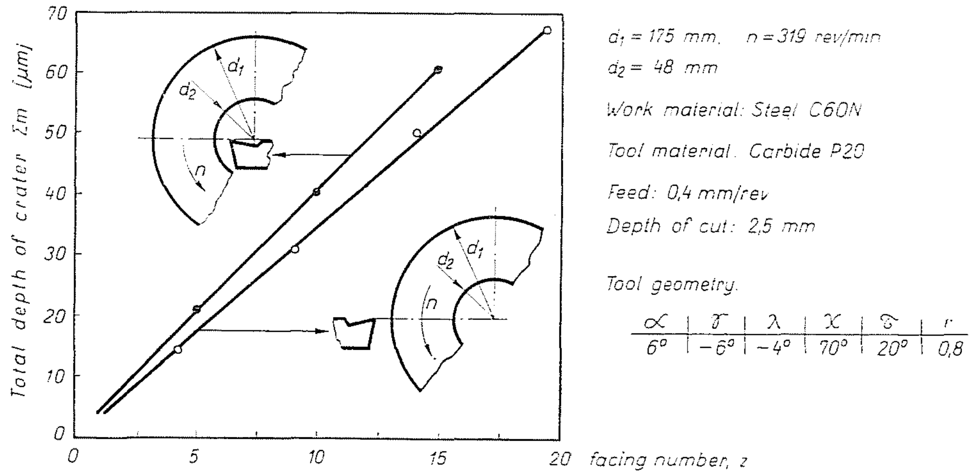

Fig. 3. Determination of the effect of direction of cross turning

Table 1

n [rev/min]	v [m/min]	z [num]	m [μm]
317	175	10	40.5
254	140	7	12

$d_1 = 175.5$ mm, $d_2 = 50$ mm, depth of cut = 2.5 mm, feed = 0.4 mm/rev, carbide: P 20, material: C 60N (Hungarian Standard) carbon steel 0.6% C, HB = 200 kp/mm^2

Table 2

n [rev/min]	d [mm]	v [m/min]	t [min]	m (measured) [μm]	m (calculated) [μm]
319	175.5	175	2	54	67
254	175.5	139.5	6	64	69.7
198	170.5	106	10.9	32	33.4

The specification agrees with data in Table 1

Summary

From financial causes the operation of NC machine tools requires safe technological data based on tool life criterion. Its relationship to the technological data for a given tool — workpiece material couple is simple and inexpensive to determine even for the user of the machine tool. The study deals with the calculation of tool life for semi-rough turning. The tool life criterion is the depth of crater. Its change is calculated for length and cross turning. The

analytical method valid for cross turning offers a direct possibility for the continuous plotting of the Taylor curve, for the determination of its constants. After the solution of still uncleared questions, the procedure offers possibility to decrease by an order the cost and time demand of tool life tests.

References

1. OSMAN, M. O. M.: Crater wear on carbide cutting tools. The Tool and Manufacturing Engineer, March 1969, p. 67—71.
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