MODIFIED QUATION $T=f(v_c)$ AND IST IDENTIFICATION

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Abstract: Recent development of the application of new kinds of material in transport and production technology places higher requirements on the technologist at the determination of cutting conditions. The assortment of recent kinds of cutting material enables to intensify cutting conditions while maintaining acceptable tool durability. The dependence of tool durability on cutting speed, or „basic law of machining“, is the basic means to determine tool durability at selected cutting conditions. The paper contains a suggestion to modify the original Taylor equation on recent conditions of productive machining.

Key words: machining, tool life, tool wear, sintered carbide

Modifikovana jednačina $T=f(v_c)$ i njena identifikacija. Nedavni razvoj primene novih vrsta materijala u transportu i proizvodnim tehnologijama stavlja sve veće zahteve tehnologi pri određivanju režima rezanja. Asortiman novih vrsta materijala za rezanje omogućava da se intenziviraju režimi rezanja uz održavanje prihvatljive postojanosti alata. Zavisnost postojanosti alata od brzine rezanja ili "osnovni zakon obrade", je osnovno sredstvo za utvrđivanje postojanosti alata za izabrane uslove rezanja. U radu se nalazi predlog za izmenu originalne Tailorove jednačine za nove uslove produktivne obrade.

Ključne reči: mašinska obrada, postojanost, habanja alata, sinterovani karbida

1. HISTORY OF THE DESCRIPTION OF EQUATION $T = f(v_c)$

In 1906, after the invention of high-speed cutting steel, Taylor [1] constructed graphic dependences $VB = f(\tau_s)$ at different cutting speeds (Fig. 1). He selected the criterion of blunting, equal for all curves VB_k .

Fig. 1. Curves of tool wear at different cutting speeds $v_5 > v_4 > \dots > v_1$

For this criterion, the values of durability $VB_1 - VB_5$ are subtracted and a graph of dependence $T = f(v_c)$ is constructed (Fig. 2). In the Figure, an actual diagramme, which has been obtained in an experiment, is shown.

As it is difficult to describe a curve mathematically, after its transformation into double logarithmic network, a straight line is obtained (Fig.3).

The dependence presents a visually precise straight line, which confirms Taylor's theory.

The straight line equation in double algorithmic system will have the following form:

$$\log T = \log C_T - m \cdot \log v_c \quad (1)$$

where $m = \arctg \varphi$ is slope of the straight line.

After de-taking a logarithm of the equation, a well-known Taylor equation appears [2-5]:

$$T = \frac{C_T}{v_c^m} \quad (2)$$

Fig. 2. Theoretical (a) and experimental (b) dependence of tool durability on cutting speed

Fig. 3. Theoretical and actual dependence $T = f(v_c)$ in double logarithmic system

2. MODIFICATION OF DEPENDENCE $T-v_c$

In the course of the century, a development of high-performance cutting materials on the base of sintered carbids, ceramics, complemented with wear resistance coats has realised [6-9]. Therefore it is necessary to modify the original Taylor equation.

When machining with a tool made of sintered carbid, $T-v_c$ dependence has much more complex course. At selected criterion of blunting $VB_k = 0.3\text{mm}$, values of relative durabilities have been subtracted and a graph in Fig. 4 has been constructed. The conditions which have been used correspond with finishing turning.

Fig. 4. Experimental dependence of tool durability on cutting speed when machining with a tool made of sintered carbid in a linear coordinate system

It can be seen that at minimal values of cutting speeds, there occurs the increase of durability as a result of a small area of contact of the chip with the tool face. Cut material is firm but brittle. A segmented

chip, which does not adhere with cutting material, is created. At higher cutting speed, the durability decreases (local minimum is probably at $v_c \approx 20\text{ m.min}^{-1}$). Further increase of cutting speed leads to the creation of a built-up edge and its protective effect on cutting wedge shows. Durability increases sharply and reaches its maximum at approximately $v_c = 90\text{ m.min}^{-1}$. Then it decreases continually and at cutting speeds above 200 m.min^{-1} it reaches several min.

It can be seen that the course of the curve is rather complex. There exist two areas of high durability – at minimal cutting speed and, in presented case, at cutting speed of approximately 100 m.min^{-1} . At cutting speed about 20 m.min^{-1} the durability is minimal, similar phenomenon occurs after crossing the cutting speed 140 m.min^{-1} . If the dependence is transformed into double logarithmic system (Fig. 5), one can get a graph which can be interpolated by abscisses. As in practice cutting speeds of over 80 m.min^{-1} are usually used, Taylor equation (2) can be used to describe decreasing branches of the curve. However, it is necessary to realise that there exist cases when whole range of cutting speeds are used (cutting off, drilling, turning with combination tools, etc.) and where tool durability changes considerably and it is necessary to know them.

Fig. 5. Dependence from Fig. 4 in double logarithmic coordinate system

3. ANALYTIC DESCRIPTION

In an attempt to describe such a dependence mathematically it has been found out that it is a non-linear function [2]:

$$T = C \cdot \exp(-v) \cdot ((v^4) + (v^{-1})) \quad (3)$$

where

$$v_c = (\ln v_c); v \in (0, \infty); v_c \in (1, \infty); C = C(a_p, f, r_e); C = 50$$

The non-linear function $T = f(v_c)$ depends on non-linear parameters. It is possible to statistically analyse the dependence from n -realised experimental dependences of tool durability $T_1, T_2, \dots, T_n$ on cutting speed:

$$T_i = T(v_c, \theta) + \varepsilon_i, \quad (4)$$

where $\theta = (\theta_1, \dots, \theta_p)^T$; $\theta \in R^p$ is the vector of suggested parameters.

Cutting speed v_c is expressed by a single-column vector;

ε_1 is required preciseness: $\varepsilon_t = N(0, \sigma^2)$.

$t = 1, \dots, n$, partial derivations $\frac{\partial^2 \theta}{\partial \theta_i \partial \theta_j}$, $t = 1, \dots, n$

are continuous functions.

The original equation is expressed in the following form:

$$T = \frac{\ln v_c^4 + \frac{1}{\ln v_c}}{e^{\ln v_c}} \quad (5)$$

Its graphic description can be found in Fig. 6.

Fig. 6. Diagramme $T = f(v_c)$ from analytic expression (conditions equal to those in Fig. 5)

Optimal cutting speed can be determined by a derivation of the equation (5) according to v_c or its adjustment respectively (6) and setting a derivation equalling -1, i.e. constructing a tangent line to the curve under the angle -45° [10, 11].

$$T = \frac{50}{e^{\ln v_c}} \left((\ln v_c)^4 + (\ln v_c)^{-1} \right) \quad (6)$$

$$\frac{dT}{dv_c} = -1$$

There are two solutions. The first corresponds to maximum, the second to minimum (uninteresting) durability. After adjustment an equation is being solved:

$$50 \cdot \ln(v_c) + 50 \cdot v_c \cdot \ln(v_c) - 200 \cdot \ln(v_c) + 50 + v_c \cdot \ln(v_c) = 0 \quad (7)$$

The equation has two solutions: $v_{c \text{ opt}} = 100 \text{ m.min}^{-1}$ and $v_{c \text{ min}} = 22 \text{ m.min}^{-1}$. It is in interaction with Fig. 4.

4. SOME ESSENTIAL DEPENDENCES

In another experiment, the influence of the cut depth on the course of observed dependence has been followed. The diagramme is shown in Fig. 7.

Fig. 7. Experimental curves of dependence $T-v_c$, obtained at different shifts

It can be seen that with increased shift the curves move towards lower cutting speeds. At minimal cutting speeds they merge. Maximum values T do not differ, they increase minimally with the increase of shift.

In Fig. 8 there is an experimental course of dependence obtained when turning with ceramic tools.

Fig. 8. Experimental dependence $T-v_c$, obtained when turning with coated ceramic tool

In comparison with machining made by sintered carbide, the values are shifted towards higher cutting speeds.

It is interesting to observe the course of $T-v_c$ dependence at super high cutting speeds. Corresponding diagramme in double logarithmic system is shown in Fig. 9.

Fig. 9. Experimental dependence $T-v_c$ in maximum obtainable range of cutting speeds

In comparison with previous dependences, a considerable decrease of durability at high cutting speeds can be seen. At $v_c \geq 100$ m.min tool durability reaches values of few seconds.

5. SUGGESTION OF RATIONAL EXPERIMENT

Finding out $T-v_c$ dependence in wide range of cutting speeds requires a lot of time and material. A hypothesis can be formed that the same function can be fulfilled also by dependence $VB - v_c$, constructed after some machining time $\tau_s = \text{const}$.

Such a dependence is shown in Fig. 10. It corresponds with continuous machining during the time of 20 min.

Fig. 10. Experimental course of dependence of wear on the back on cutting speed

As it can be seen, this dependence is in fact an inverse function of $T - v_c$ dependence from Fig. 4. Equally, as $T - v_c$ dependence enables to determine optimal cutting speed which provides the smallest intensity of tool wear.

6. CONCLUSION

Identification of dependence of tool durability on cutting speed for given pair cut – cutting material is of special importance in determination of cutting conditions, mainly cutting speed. Taylor solved this problem in a genius way as early as the beginning of the last century when high-speed cutting steel was invented. The development of new tool and cut materials requires modification of Taylor equation of constant durability as one of the conditions for effective material machining.

7. REFERENCES

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