SHORT RUN LIFE TEST BY COMBINED METHOD TO DETERMINE CUTTING LIFE EQUATION AT MILLING*

By

I. KALÁSZI and PHUNG RAN

Department of Production Engineering, Technical University, Budapest

(Received July 16, 1976)

1. Introduction

The considerable progress in technics and machine industry arises the need of higher quality and quantity requirements for metal cutting.

As a first step to develop machine production improved materials for tools have been applied. This tendency is valid even in our days, moreover, increasing.

The rapid progress of production engineering, including numerically controlled machines and especially tool materials, necessitates the determination of tool life. Tool life test results as data for technological data banks are considered of special importance. It is, however, essential to achieve higher economical efficiency in testing procedures.

Measuring of tool wear is the most common method to determine tool life equation. However, as proved by experiences, this conventional method required materials in too large quantities and long time.

Milling entails more difficulties in measuring than usual cutting. That is why it is imperative to develop a new, time sparing and less expensive method ot determine tool life equation with an accuracy sufficient for workshop conditions.

It is known that among the parameters having influence on tool life there are tool and chip as well as friction of the surfaces between tool and workpiece and the temperature thus arising the most determinative ones.

At high cutting speeds the temperature produced at cutting zone is also high and wear processes are accelerated.

Thus, it is evident that at high cutting speeds cutting temperature acts as most essential parameter affecting tool life, therefore measuring of temperature would provide most adequate means for the determination of tool life equations.

Temperature measuring has already been proved a suitable method for turning (2, 3, 4) but tests for its applicability for discontinuous cutting (such as milling) are still missing.

* Brief review from a C. Sc. work performed at the Dept. of Prod. Eng., Technical University, Budapest (1).

This paper is intended to explain that combined measuring of temperature and wear is expected to result in exact tool life equation not only for turning but also milling.

2. Essence of the combined method

Setting up tool life equation for mill consists of two steps:
Determination of cutting life using
1. single-tooth mill and
2. multi-tooth mill.

These steps for face milling are discussed as follows.

2.1. *Setting up tool life equation for single-tooth mill*

The basic principle is to set up the equation by combining the results obtained by temperature measuring and short life wear measuring. As to be seen from Figure 1, lathe is provided with milling cutter.

Procedure to determine tool life equation:
— temperature at milling may be expressed in equation, provided that among the influencing factors not more than one is considered while all the other factors remain unchanged:

$$\Theta = C_\Theta \cdot v^r e^p f^q B^k D^h \tag{1}$$

where Θ cutting temperature (°C)
v cutting speed (m/min)
e feed per tooth (mm/tooth)
f depth of cut (mm)
B width of milling (mm)
D mill diameter (mm)

Taking into consideration the dimensional analyses of Kronenberg (5) equation (1) may be transformed to

$$v = \frac{C}{e^a f^b B^c D^d} \tag{2}$$

where

$$C = \left[\frac{\Theta}{C_\Theta}\right]^{\frac{1}{r}}; \quad a = \frac{p}{r}; \quad b = \frac{q}{r}; \quad c = \frac{k}{r}; \quad d = \frac{h}{r}.$$

Equation (2) implies tool life. For obtaining tool life explicitely, tool life exponent m has to be defined for which measuring of wear is needed. Thus, this method is considered combined.

Te obtain tool life exponent m the following equation is to be set up by help of crater wear measuring:

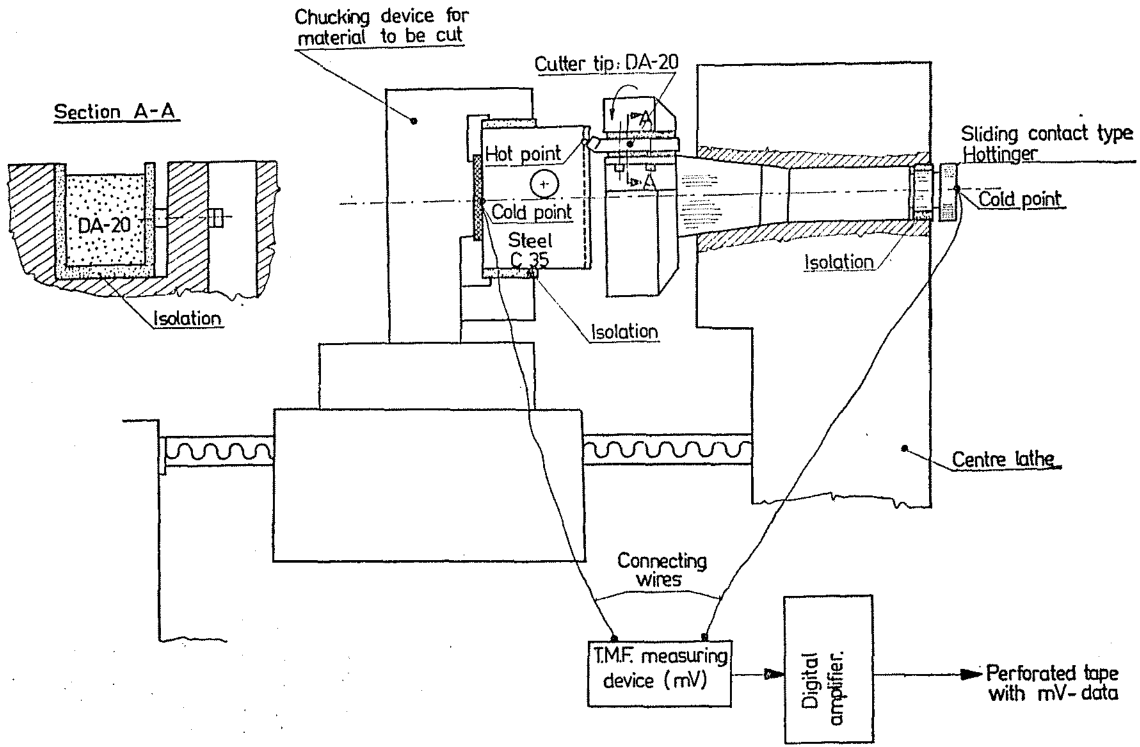

Fig. 1. **Model of single-tooth face milling for combined method**

$$A_{kr} = At^n v^x \ [\mathrm{mm}^2] \tag{3}$$

where A_{kr} area of crater wear (mm^2)

t cutting time (min)

From equation (3) it follows that

$$v = \frac{C^*}{T^m} \tag{4}$$

In this equation

$$C^* = \left[\frac{A_{kr}}{A}\right]^{\frac{1}{x}}$$

where

T tool life (min)

$$m = \frac{n}{x}$$

A crater area to be determined at one point for given t, v, e, f values (mm^2)

Considering equations (2) and (4):

$$v = \frac{C}{T_1^m e^a f^b B^c D^d} \tag{5}$$

This present the so-called extended tool life equation in which subindex "1" for T refers to the single-tooth mill.

2.2. *Determination of wheel life equation for multi-tooth mill*

Single-tooth mills are not often used in practice. For this reason prectice requires tests to disclose to which extent tool life depends on tooth-number of mill.

Therefore the relationship between the tool life of mill with tooth-number $z(T_z)$ and tooth-number of mill (z) is to be determined and expressed in the following form, assuming that increasing of tooth-number is accompanied by higher temperature at the contact zone of cutting edges:

$$T_z = T_1 z^{-l} \tag{6}$$

where T_z tool life belonging to the mill with tooth-number z (min)

T_1 tool life belonging to the mill with tooth-number 1 (min)

Z tooth-number of mill

l constant to be determined by measuring

Introducing the expression $l \times m = g$ and using equations (5) and (6) the result will be

$$v = \frac{C}{T_z^m e^a f^b B^c D^d z^g} \tag{7}$$

3. Test conditions and results

3.1 *Test conditions*

Test materials

For workpiece we used steel C35 according to MSZ 61—68 and through-away positive tip DA—20 as per MSZ 1968/2T in the milling cutter.

Measuring devices

For measuring of temperature we applied digital voltmeter Type RFT 4041 No. 1698 and photorecorder Type MOM MF 1—1, No. 914027 to measure the voltage of the natural thermocouple workpiece-tool.

When measuring wear, the method developed by the Dept. of Prod. Eng., Technical University Budapest, was observed [7].

3.2 *Test results*

After repeating measurings five times for each point we took average of the values obtained.

Figure 2 shows an example of temperature data, while Figure 3 refers to wear measuring results.

The extended equation of temperature was obtained by graphical analysis in the next form (see Figure 3):

$$\Theta = 184\, v^{0,31}\, e^{0,5} f^{0,02}\, B^{0,23}\, D^{-0,23} \qquad (8$$

The next equation is also set up by graphical analysis:

$$A_{kr} = A\, t^{1,04}\, v^{3,23} \tag{9}$$

Both measurings were within the following technological range:

$v = 59.6 \div 380$ m/min
$e = 0.1 \div 0,25$ mm/tooth
$f = 1 \div 4$ mm
$B/D = 0.5 \div 0.9$

Rearranging equations (8) and (9) and calculating value C as per equation (5) for any optional relating temperature within the given technological range, it may be written that

$$v = \frac{417\, D^{0,74}}{T_1^{0,32}\, e^{0,17} f^{0,07}\, B^{0,74}} \tag{10}$$

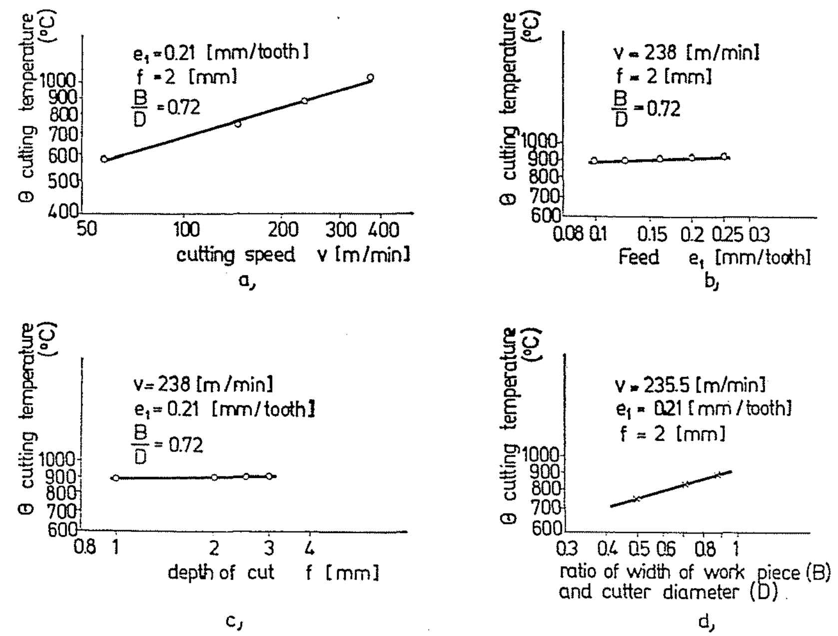

Fig. 2. Cutting temperature measured by the method shown in Fig. 1 at various cutting conditions

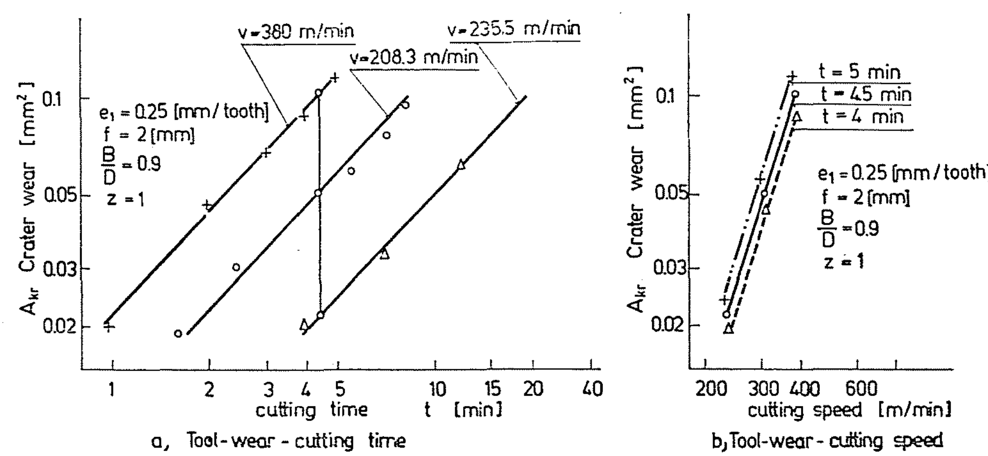

Fig. 3. Dependence of crater wear on cutting time and cutting speed when milling with single-toogh mill.

The above results concern single-tooth mill.

When performing tool life tests of multi-tooth mill for various tooth-numbers we made use of literature data, too (8). See Figure 4.

By averaging we obtained

$$T_z = T_1 \cdot z^{-0,41} \text{ [min]} \tag{11}$$

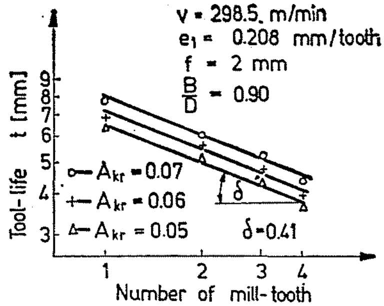

Fig. 4. Dependence of tool life on the number of mill tooth

Thus, tool life equation of mill with tooth-number z:

$$v = \frac{417\, D^{0,74}}{T^{0,32}\, e^{0,17} f^{0,07}\, B^{0,74}\, z^{0,13}} \qquad 12)$$

4. Comparison of methods to determine tool life equations of mill

To justify this new method, for comparison we determined tool life equation of mill by conventional measuring of wear, using the same workpiece, tool materials and tool as described in Chapter 3. For this test we used a vertical milling machine with the same stiffness as that of the lathe applied for single-tooth mill. The usual graphical analyses yielded:

$$v = \frac{395{,}4\, D^{0,7}}{T^{0,31}\, e^{0,24} f^{0,09}\, B^{0,7}\, z^{0,13}} \qquad (13)$$

Tool life measurings of mills were carried out at cutting speeds $v = 235.5$; 298.3; 376.8 and 471.2 m/min, while keeping e, f, B, D and tooth-number $z = 1$ constant, to supervise equations (12) and (13). Tool life of mill was calculated for the test conditions indicated above, in accordance with equations (12) and (13), too.

Table 1 is for the measured and calculated values and Figure 5 shows the equations thus obtained.

Table 1

Calculated and measured tool lives of mills

Constant cutting conditions: $e = 0{,}21$ mm/tooth; $f = 2$ mm; $B = 180$ mm; $D = 250$ mm; $Z = 1$

Cutting speed, v (m/min)	Calculated and measured tool lives T (min)		
	T_m	$T_{(12)}$	$T_{(13)}$
233.5	20	16	15.1
298.3	9	7.56	7.32
376.8	5	3.53	3.51
471.2	2.1	1.72	1.75

T_m tool life measured during test
$T_{(12)}$ tool life calculated as per equation (12)
$T_{(13)}$ tool ilfe calculated as per equation (13)

Table 1 proves that the difference between the tool life values obtained by our combined method and those by conventional wear measuring varies between 3 and 20%. That is, the difference lies within the accuracy range acceptable in workshops.

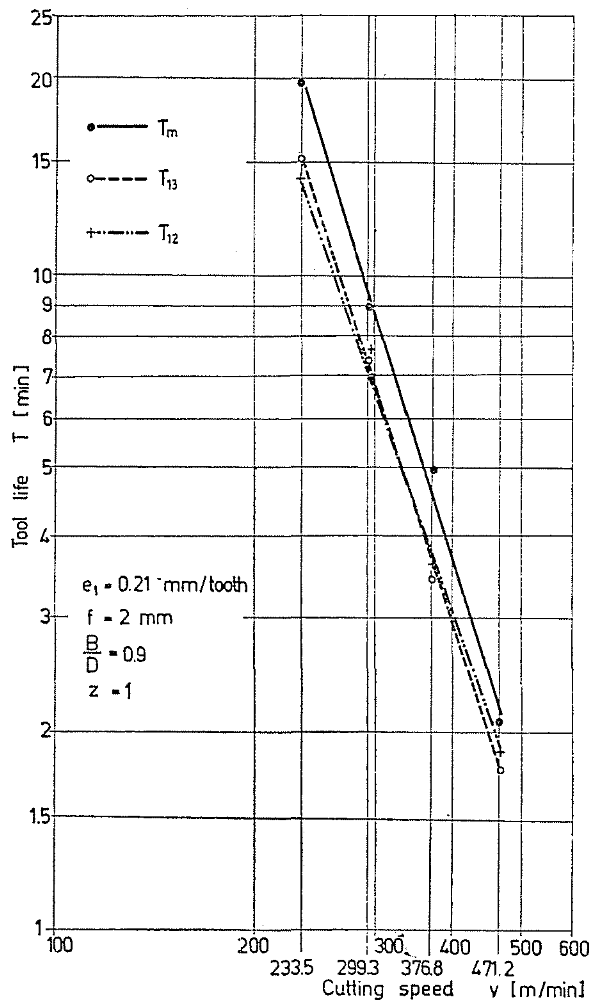

Fig. 5. Tool life and cutting speed relation (see Table 1)

Conclusion

It is clear from the above that the method which combines experimental temperature equation and short run wear measuring enables the determination of tool life equation of mill in a rapid and economical way with an accuracy sufficient for practice.

Summary

Establishment of data banks urgently requires tool life equations for various mills. The authors describe a short run method combining extended temperature equation and wear measuring to determine tool life of face mills. This method is based on single-tooth mill, but its application for multi-tooth mill is also discussed. Comparison of the results obtained by the new method and the conventional one proves the applicability of the new method for use in workshops.

References

1. PHUNG, R.: Investigation of carbid-tip milling tools by single-tooth model with special regard to tool life. C. Sc. Dissertation, Hungarian Academy of Science, 1975 (in Hungarian)
2. DANIELJAN, A. M.: Rezanie metallov i instrument. Mashgiz, Moskow, 1950.
3. Dr. KARDOS, Á.: Comparison of various short run cutting tests to determine tool life. Gép, XVII (1965) November, pp. 417—421. (in Hungarian).
4. KALÁSZI, I.: Measuring method of cutting temperature available for shop practice. Gép, XVI (1964) October, pp. 373—378 (in Hungarian)
5. KRONENBERG, M.: Ultra high speed and other metal cutting phenomena explored by dimensional analysis. ASTME paper, No. 331, Michigan, 1961.
6. KALÁSZI, I.: New methods for evaluation of cutting fluids efficiency. Int. J. Prod. Res. 1971, Vol. 9. No. I. pp. 37—51, London.
7. KALÁSZI, I.: Investigation of wear phenomena when cutting metals. C. Sc. Dissertation. Hungarian Academy of Science, 1963 (in Hungarian).
8. KULJANIC, E.: An investigation of wear in single-tooth and multi-tooth milling. Int. J. Mach. Tool Des. Res. Vol. 14 (1974) Pergamon Press, pp. 95—109.

Prof. Dr. István KALÁSZI
PHUNG RAN
H-1521 Budapest