Cutting Speed Sensitivity of Tool Life

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Introduction

Taylor equation is one of the important topics in mechanical engineering technology courses of manufacturing processes, machining and tool design. It is important because it deals with cutter life in machining. Cutter life affects manufacturing in two ways. First, a longer cutter life means lower cutter cost per workpiece. Secondly, a longer cutter life means less frequent change of the tool and hence a smaller amount of tool change time per workpiece machined. Tool life is affected by the workpiece conditions, the tool conditions and the machining parameters. Of the machining parameters, which include the depth of cut, the feed, the surface cutting velocity and the cutting fluid, the cutting velocity affects the tool life the most. The basic Talor equation shows the mathematical relation between the tool life and the cutting speed though its generalized forms cover more machining variables. This paper will explore the basic Taylor equation on the physical meaning of one of its variables so that students can better understand and apply the equation.

The basic Taylor equation has the simple mathematical form:

$$V \cdot T^n = C \qquad (1)$$

in which T is the tool life (min), V is the surface cutting speed (ft/min), and *n* and *C* are constants. Do parameters *n* and *C* have notable physical meanings?

This equation appears in many textbook [1-4]. In all the books, the authors always explain the physical relation presented by the equation because understanding the physical relation by students is as important as their ability to manipulate numbers with the equation. Students need to know that any equation, theoretically derived or empirically derived, is nothing but a mathematical expression of physical relations.

In fact, the physical meaning of constant *C* has been well discussed in some textbooks such as [1]. It says that if we let T = 1 (min) in equation (1) then it becomes

$$V \cdot (1)^n = C$$

or

$$V = C \tag{2}$$

Therefore C equals to the cutting speed corresponding to one-minute tool life.

However, available explanations of constant n in equation (1) are less clearer. In [4], logarithm operations are applied onto equation (1) for two cases 1 and 2:

$$\log V_1 + n \log T_1 = \log C$$

$$\log V_2 + n \log T_2 = \log C$$

which lead to

$$n = (\log V_1 - \log V_2)/(\log T_2 - \log T_1) \tag{3}$$

Equation (3) states that constant n in Taylor equation is the slope of the straight line representing the equation in a log-log scale. However, it is more of a mathematical explanation than of a physical explanation.

Also it is known that in general n is more a function of the cutting tool material [4]:

n ˜ 0.1 – 0.15 for cutting tools of high speed steels
n ˜ 0.2 – 0.25 for cutting tools of carbides
n ˜ 0.6 – 1.0 for cutting tools of ceramics

But there is not much explanation for the facts.

It appears to the author of this paper that an exploration of the physical meaning of constant n in Taylor equation could be desirable and helpful to students as well as instructors. Some work to the end has been performed as shown below.

Exploration of physical meaning of constant *n* in Taylor equation

Some mathematical work will be performed below to reveal the physical meaning of constant n in Taylor Equation (1).

Differentiating Equation (1), we have

$$d(V \cdot T^n) = d(C)$$

Because C is a constant,

$$d(V \cdot T^n) = 0 \tag{4}$$

Expanding the left-hand side,

$$V \cdot d(T^n) + dV \cdot T^n = 0$$

or

$$V \cdot n \cdot T^{n-1} \cdot d(T) + dV \cdot T^n = 0$$

Canceling T^{n-1} from both terms,

$$V \cdot n \cdot dT + dV \cdot T = 0$$

from which

$$-\frac{dT}{dV} = \frac{T}{V \cdot n} \tag{5}$$

Please take a look at the above equation. The left-hand side – *dT/dV* is the change in tool life over the change in cutting speed. **Let us define the term – *dT/dV* as the cutting speed sensitivity of tool life**. The negative sign is to make the sensitivity value positive. The term sensitivity is used similarly in many subjects.

Equation (5) does not clearly reveal the relation between the sensitivity – *dT/dV* and the parameters on its right-hand side because variables *T* and *V* are interrelated.

(A) To see the relation between the sensitivity – *dT/dV* and the cutting speed *V*, we use Taylor equation (1) to eliminate *T* in Equation (5),

$$-\frac{dT}{dV} = \frac{C^{\frac{1}{n}}}{V^{(1+\frac{1}{n})} \cdot n} \tag{6}$$

The three parameters on the right-hand side of Equation (6) are constant *n*, constant *C* and cutting velocity *V*, which are independent of one another. We can see from the equation that –

Cutting speed sensitivity of tool life – *dT/dV* is higher when cutting speed *V* is smaller. In other words, tool life is more sensitive to cutting speed at lower cutting speeds than at higher cutting speeds. This can be verified by Fig. 1 from [1].

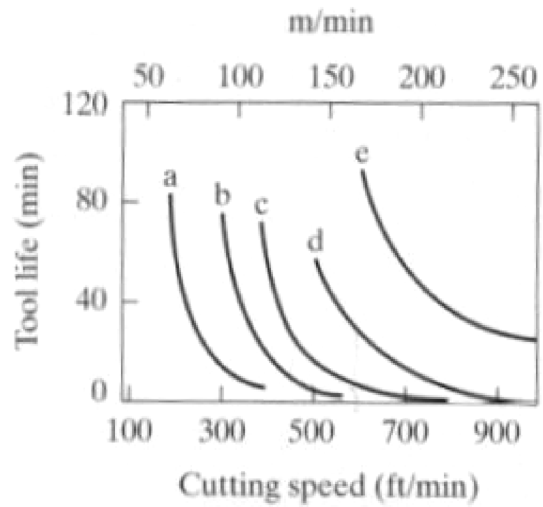

Figure 1 Cutting speed sensitivity of tool life vs cutting speed

(B) To see the relation between the sensitivity dT/dV and the constant n,

(a) We use Taylor equation (1) to eliminate V in Equation (5),

$$-\frac{dT}{dV} = \frac{T^{n+1}}{C \cdot n} \tag{7}$$

(b) We perform differentiation $\frac{d}{dn}(\frac{T^{n+1}}{n})$,

$$\frac{d}{dn}(\frac{T^{n+1}}{n}) = \frac{T^n}{n^2}(n^2 + n - T)$$

Since constant n = 1 and tool life T > 10 minutes,

$$(n^2 + n - T) < 0$$

and

$$\frac{d}{dn}(\frac{T^{n+1}}{n}) < 0 \tag{8}$$

Combining equations (7) and (8),

$$\frac{d}{dn}\left(-\frac{dT}{dV}\right) < 0 \tag{9}$$

Equation (9) shows that –

Cutting speed sensitivity of tool life – *dT/dV* is higher when the value of constant *n* in Taylor equation is smaller. In other words, tool life is more sensitive to cutting speed when the value of constant *n* is smaller than when *n* is larger. This can be verified by Fig. 2 from [1]. Please keep in mind that ceramic tools have the highest values of *n* as shown earlier.

We now see a physical meaning of constant *n* in Taylor equation: it is an inverse indicator of the cutting speed sensitivity of tool life.

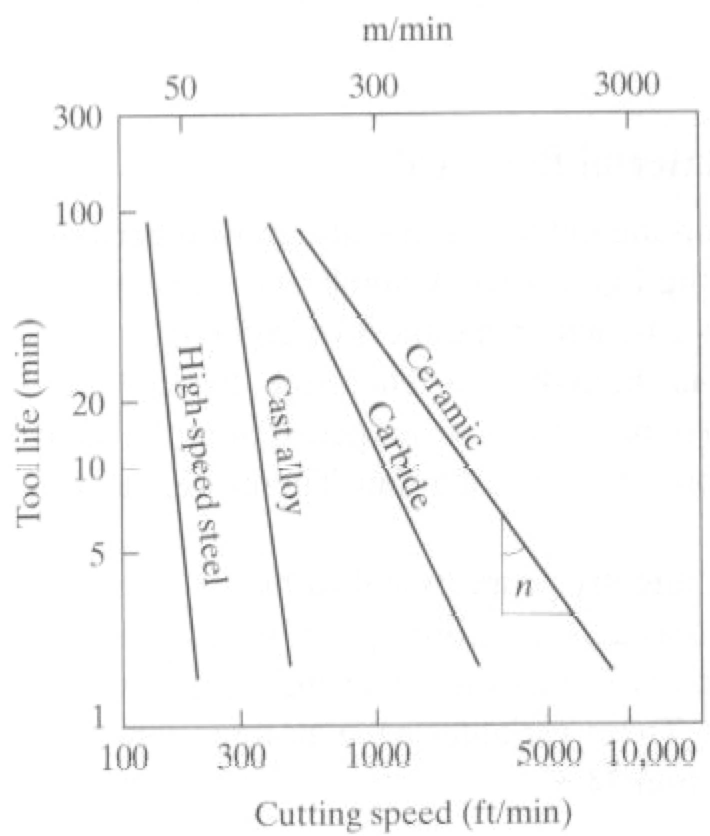

Figure 2 Cutting speed sensitivity of tool life vs constant n in Taylor equation

Conclusion

Study has been performed to explore the physical meaning of constant *n* in Taylor equation. A term called cutting speed sensitivity of tool life has been defined. The study has analyzed the relation between the sensitivity and the cutting speed and the relation between the sensitivy and the constant *n* and has arrived at conclusions that are consistent with experiment results reported in references. The study has shown that constant n in Taylor equation is an inverse indicator of the cutting speed sensitivity of tool life.

It is hope that the study in this paper would be of some use to instructors, students as well as practicing engineers who use Taylor equation.

References

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