EXPERIMENTAL DETERMINATION OF CUTTING FORCE BY LONGITUDINAL TURNING OF C60E STEEL

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Abstract: The effects of cutting conditions on the cutting force in the longitudinal turning of C60E steel were experimentally investigated. During experiments, three components of cutting force were measured, the main cutting force, the feed force and the passive force. The width of cut, the thickness of cut, feed, depth of cut and tool cutting-edge angle are found to be affecting force components. The cutting force is influenced not only by cutting conditions but also the cutting edge geometry and the material of workpiece. The influence of the cutting edge geometry and the material of workpiece is not investigate.

Keywords: Longitudinal turning, cutting tool, cutting force, steel

1. INTRODUCTION

Metal cutting process is a complicated process where the performance depends upon a number of cutting and tooling conditions. Cutting force has a significant influence on cutting process. Information about the expected cutting force components is significant for the following reasons:

- The forces occurring in the metal cutting process provide information about the power requirements of the machine.
- Choosing the right cutting process and the optimum technological parameters results in significant savings of energy during machining.
- For developments in the filed of adaptive control of the cutting process, knowledge of the cutting force is of major importance in defining the performance limit confining the range of optimization.

Of the factors influencing the cutting force, the following are very important:

- Cutting method (constant or varying cross-sectional area of cut).
- Cutting conditions (cutting speed, feed, and depth of cut).
- The material of workpiece (chemical composition, heat treatment)
- The cutting tool (tool material, cutting edge geometry, chip breaker, coating, tool wear).
- Cutting fluid.

There are theoretical models of cutting force that specify the cutting force during machining. In this study is given an explanation of the influence of the cutting condition on cutting force by longitudinal turning.

2. EQUATIONS FOR CALCULATION THE CUTTING FORCE COMPONENTS

The cutting force F acting on the tool during the machining operation. Knowledge about the force acting on the cutting tool may help the manufacture of machining tool to estimate the power requirement. The cutting forces vary with the tool angles, feed and cutting speed. The force components in lathe turning can be measured in three directions, figure 1. The component of the force acting on the rake face of the tool, normal to cutting edge, in the direction of motion of the workpiece is called the main cutting force (tangential force) F_c. This is usually the largest force component, and acts in the direction of the cutting speed. The force component acting on the tool in the direction parallel with the direction of feed, is called the feed force (axial force) F_f. The third component, push the cutting tool away from the work in radial direction, is called the passive force (radial force) F_p. The machining parameters as data depth of cut a_p and feed f_a pass over by way of the cross-sectional area of cut $A_f = b \cdot h = a_p \cdot f_a$. Conditions of the tool's engagement are shown in figure 2.

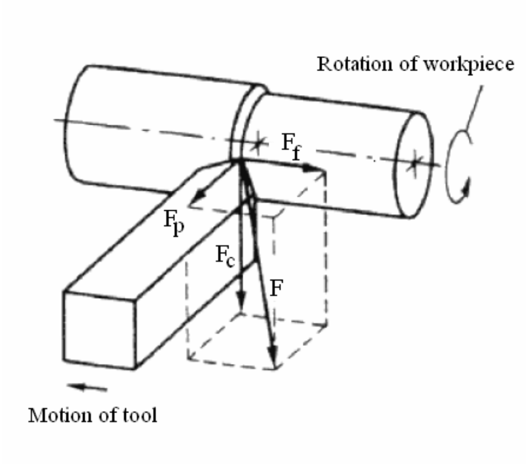

Fig. 1. Cutting force components

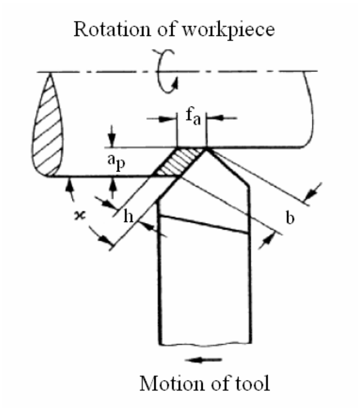

Fig. 2. Conditions of the tool's engagement

If we know the components of cutting force we can determine cutting force by equation:

$$F = \sqrt{F_c^2 + F_f^2 + F_p^2} \tag{1}$$

Main cutting force (tangential force) acts in direction tangential to the revolving workpiece and represents the resistance to the rotation of the workpiece. Kienzle has suggest the equation for determine the main cutting force in form:

$$F_c = k_c \cdot A_f \tag{2}$$

Where is k_c - specific cutting force, and A_f - cross-sectional area of cut.

Cross-sectional area of the cut A_f we can determine by equation:

$$A_f = b \cdot h = a_p \cdot f_a \tag{3}$$

Where is b - the width of cut, h - the thickness of cut, a_p - depth of cut, and f_a - axial feed.

Width of cut b, and thickness of cut h, figure 2, can determine by equations:

$$b = \frac{a_p}{\sin\chi} \quad ; \quad h = f_a \cdot \sin\chi \tag{4}$$

Where is κ - tool cutting-edge angle (entering angle).

Specific cutting force k_c is given as a function of the thickness of cut h in form:

$$k_c = k_{c1.1} \cdot h^{-m_c} \quad (5)$$

Where is $k_{c1.1}$ - specific main cutting force unit, and m_c - coefficient of main cutting force.

From equations (2), (3) and (5) we have the Kienzle equation for main cutting force in form:

$$F_c = k_{c1.1} \cdot b \cdot h^{1-m_c} \quad (6)$$

The specific cutting force unit $k_{c1.1}$ related to the cross-sectional area of the cut $b \cdot h = 1mm^2$, and the coefficient of main cutting force are included into the equation as characteristic data. The specific cutting force unit $k_{c1.1}$ is, in this case, largely dependent on the material of workpiece, the cutting conditions, the tool and the procedural influences. The coefficient of main cutting force m_c characterizes the cutting force behaviour of the workpiece material - tool material combination for different thicknesses of cut.

From figure 3 we can determine the specific cutting force. In the figure 3 is shown the representation of the experimentally determined quotient of the main cutting force F_c and the width of cut b as a function of the thickness of the cut h in the system of log-log coordinates, in a straight line that is described by the equation:

$$\log \frac{F_c}{b} = \log k_{c1.1} + (1 - m_c) \cdot \log h \quad (7)$$

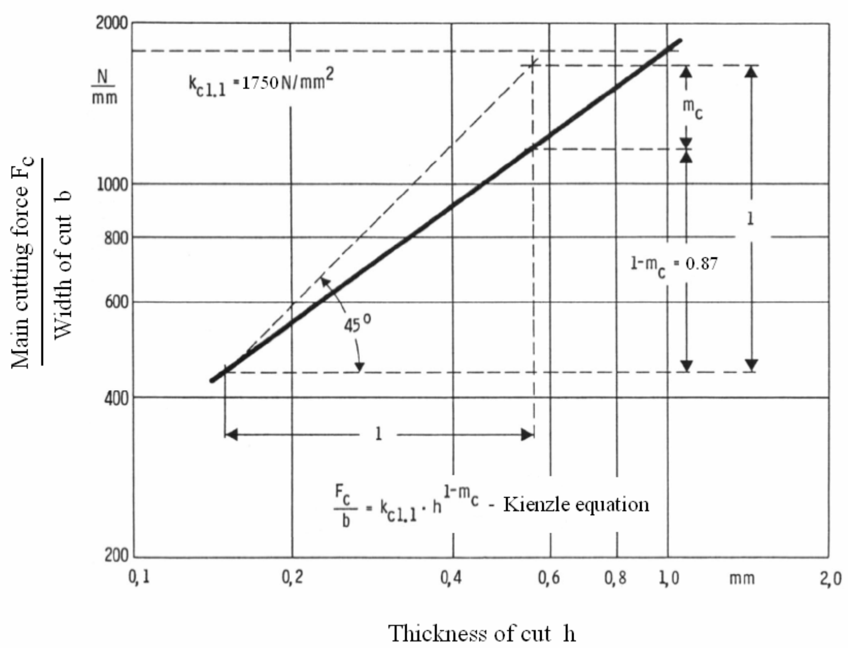

Fig. 3. Quotient of the main cutting force and the width of cut versus the thickness of cut

Feed force (axial force) acts in the direction parallel to the axis of the work and represents the resistance to the axial (longitudinal) feed of tool. For the calculation of feed force F_f a relationship can be established that is similar to that used for the main cutting force F_c as:

$$F_f = k_{f1.1} \cdot b \cdot h^{1-m_f} \tag{8}$$

Where is $k_{f1.1}$ - specific feed force unit, and m_f - coefficient of feed force.

As characteristic data, the specific feed force unit $k_{f1.1}$ related to a cross sectional area of cut of $b \cdot h = 1mm^2$ and the coefficient of feed force m_f are included in the equation. Unlike to the cutting force equation, this equation to calculate the feed force must be regarded as an approximate solution as the scatter of the test values in the representation $F_f / b = f(h)$ is larger than with the cutting force.

Passive force (radial force) acts in a radial direction from the center line of the workpiece. In accordance with the rules of calculating the feed force F_f, the passive force F_p can be expressed as:

$$F_p = k_{p1.1} \cdot b \cdot h^{1-m_p} \tag{9}$$

Where is $k_{p1.1}$ - specific passive force unit, and m_p - coefficient of passive force.

As characteristic data, the specific passive force unit $k_{p1.1}$ related to a cross sectional area of cut of $b \cdot h = 1mm^2$ and the coefficient of passive force m_p are included in the equation.

3. EXPERIMENTAL RESEARCH

Longitudinal turning was conducted on a rigid, high-precision lathe "Potisje" PA-C 30, with power of 11 kW.

The cylindrical bar of workpiece were held in the machine with a collet to minimize run-out and maximize rigidity. The workpiece material used in this experiment was C60E steel (EN10027-1), R_m=700-1000 N/mm^2, hardness value of HB=220. The cylindrical bar specimen that is utilized in this experiments had a diameter of 62 mm and length of 500 mm. Cutting tool was toolholder PCLNR 3225P12 with insert CCMT 09T304UR415, rake angle γ=-6, angle of inclination λ=-6, corner radius r_ε=0.8 mm. Cutting condition was: number of revolution n=500 o/min, axial feed f_a=0.249-0.392 mm/o, depth of cut a_p=2.5-4 mm, tool cutting-edge angle (entering angle) κ=45°-90°. Sectional area of cut $A_f = b \cdot h = a_p \cdot f_a$ was constant.

The cutting forces were measured with a three-component force dynamometer Kistler type 9441, mount on the lathe via a custom designed adapter for the toolholder creating a very rigid tooling fixture. The charge signal generated at the dynamometer was amplified using charge amplifier Kistler type 5007A. The amplified signal is acquired and sampled by using computer Hewlett Packard HP 9000/300. Experimental equipment is shown in figure 4 and graph of cutting force components is shown in figure 5.

Fig. 4. Experimental equipment

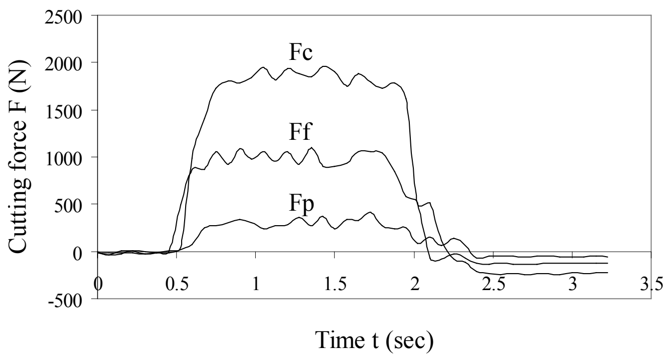

Fig. 5. Graph of cutting force components

Experimental results are shown in Table 1. The table 1 shows that the main cutting force is the largest, the feed force is the middle and the passive force is the smallest in longitudinal turning. It is evident that the cutting force changes with variation of the tool cutting-edge angle (entering angle) κ.

Using the specific methodology, according Kienzle equation (6) and figure 3, it is determined equations for each component of the cutting force i.e. main cutting force (tangential force), feed force (axial force) and passive force (radial force). It is determined equations for various tool cutting-edge angle (entering angle) κ, and than equations for cutting force components with middle values of specific main cutting force unit and coefficient of main cutting force.

Table 1. Experimental results

Axial feed and depth of cut	Cutting force components				
	κ	45°	60°	75°	90°
f_a=0.249 mm/o, a_p=4 mm	F_c (N)	2048	2060	2001	2146
	F_f (N)	1362	1267	1228	1206
	F_p (N)	253	256	339	495
f_a=0.321 mm/o, a_p=3 mm	F_c (N)	2111	1896	1895	2134
	F_f (N)	1189	1113	1032	1098
	F_p (N)	253	302	405	534
f_a=0.392 mm/o, a_p=2.5 mm	F_c (N)	1983	1918	2034	2084
	F_f (N)	1145	1050	993	976
	F_p (N)	231	339	442	586

In table 2 are shown equations for cutting force components with middle values of parameters $k_{c1.1}$ - specific main cutting force unit and m_c - coefficient of main cutting force.

Table 2. Equations for cutting force by longitudinal turning

Main cutting force (Tangential force)	Feed force (Axial force)	Passive force (Radial force)	Cutting force (Resultant force)
$F_c = 1750 \cdot b \cdot h^{0.87}$	$F_f = 671 \cdot b \cdot h^{0.51}$	$F_p = 570 \cdot b \cdot h^{1.26}$	$F = \sqrt{F_c^2 + F_f^2 + F_p^2}$
$b = \frac{a_p}{\sin\chi}$; $h = f_a \cdot \sin\chi$			

In figure 6 is shown dependence between quotient of the main cutting force and the width of cut and the thickness of cut. It is approximately linear dependence.

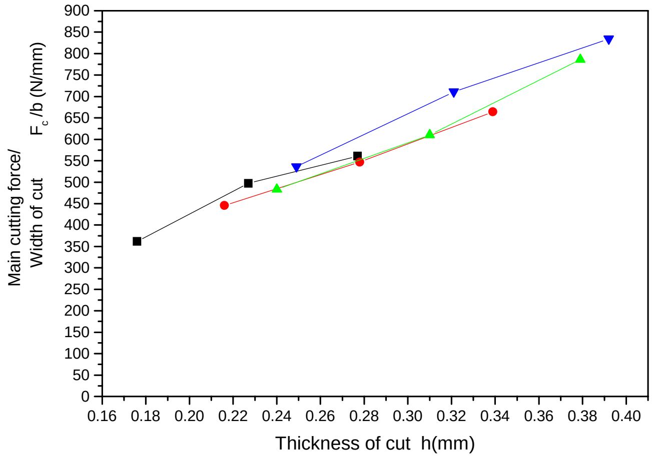

Fig. 6. Quotient of the main cutting force and the width of cut versus the thickness of cut

In figure 7 is shown dependence between the specific main cutting force unit $k_{c1.1}$ and the tool cutting-edge angle (entering angle) κ. It is approximately linear dependence. In figure 8 is shown dependence between the coefficient of main cutting force m_c and the tool cutting-edge angle (entering angle) κ. It is approximately linear dependence.

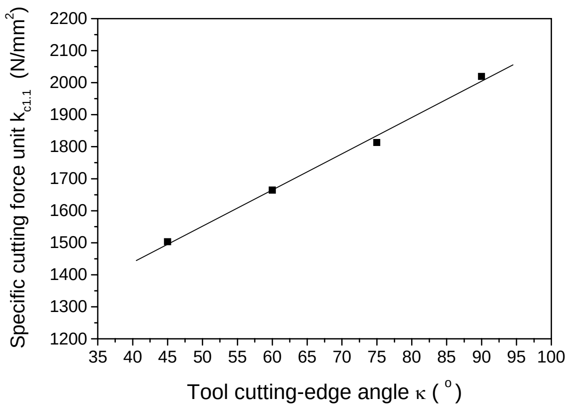

Fig. 7. Specific main cutting force unit $k_{c1.1}$

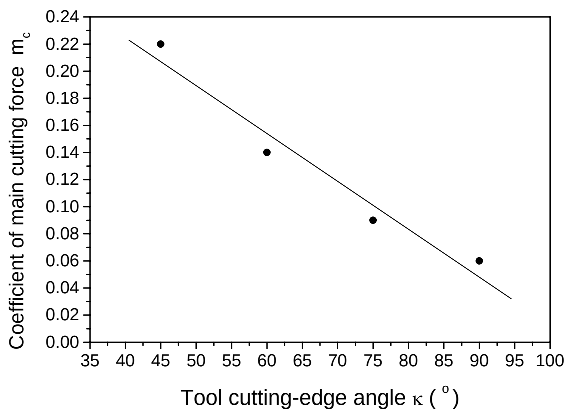

Fig. 8. Coefficient of main cutting force m_c

4. CONCLUSION

Using the specific methodology, according Kienzle equation, it is determined equation for each component of the cutting force. The main cutting force is the largest, the feed force is the middle and the passive force is the smallest in longitudinal turning. The cutting force change with variation of the tool cutting-edge angle κ.

Dependence between quotient of the main cutting force and the width of cut and the thickness of cut show that is approximately an linear dependence. Dependence between the specific main cutting force unit $k_{c1.1}$ and the tool cutting-edge angle κ is approximately linear. Dependence between the coefficient of main cutting force m_c and the tool cutting-edge angle κ is also approximately linear.

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