The Effect of Cutting Speed on the Ploughing Forces

Alexey Popov (alespopov@yandex.ru)
Technical University of Liberec: Technicka Univerzita v Liberci

Iuliia Krasnikova
Technical University of Liberec: Technicka Univerzita v Liberci

Research Article

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Abstract

The ploughing forces (PFs) are one of the important parameters for calculating the tool life. They directly affect the stress on the tool flank face and are responsible for wear and tear conditions of the cutting tool as well. In this study we attempted to find the impact of cutting speed on PFs, that is, the relation between cutting speed and PFs. In this paper, the ploughing forces were estimated by a new comparison method in which forces at different point of contact areas are added (sum of forces) to get the PFs accurately. The accuracy of PFs estimated with this method will be better than previously used methods. This paper presents the measurement results of the PFs when turning stainless steel, structural steel and aluminum alloy materials. The results of experimental studies showed that an increase in cutting speed ranging from 50 to 200 m/min resulted in increase in PFs by 1.4–3.2 times when turning with different flank wears.

Introduction

Currently, numerous wear models that relate stresses and temperature at the tool flank face to the wear rate are used to calculate the tool life in various technological operations. Several studies focused on the tool wear mechanisms use flank face stress and temperature to predict the tool life in diamond turning [1], to model fretting wear in partial slip regime [2] or to study the computational modelling of 3D turning process [3].

The ploughing forces (PFs) directly affect the stress on the tool flank face and thereby determine the wear and tear conditions of the cutting tool. Because of this reason, wear models created for calculating the tool life cannot be used without determining the PFs [4-7].

An analysis of the scientific literature has revealed the lack of information about the PFs dependence on cutting speed, an important parameter of cutting conditions, which significantly influence the tool life. Moreover, there is no information about this PFs dependence on cutting speed even in the new “comparison method of total forces at different contact areas” (Popov–Dugin’s method) [8,9]. But PFs estimated using this method increased the accuracy by 23%–84% compared with the previously used “comparison method of total forces at different flank wears” (Zorev’s method) [10].

This study is aimed at solving this important and practical problem, by determining the effect of cutting speed, Vc, on the PFs using the Popov–Dugin’s method.

Experimental Procedure

The turning process was conducted on a lathe TOS SU 50/1500. The workpieces with a diameter of 70 mm and thickness of 5 mm from three different materials were used, namely stainless steel 1.4571, structural steel 1.0301, and aluminum alloy AlMgSi. The cutting plate TPUN 160308 of hard alloy ISO P30 was fixed in the PRAMET TOOLS cutter CTCPN 2514 M16. The cutting tool had the front angle of \( \gamma = \)
5° and the flank angle of $\alpha = 6°$. The turning experiments have been performed with the cutting speed $V_c$ ranged from 50 to 200 m/min, and with the uncut chip thickness $a_p$ of 0.05 mm for all experiments.

Measuring the rounding radius of the new cutting insert with the KEYENCE Laser Scanning Confocal Microscope has revealed that the new insert has a radius of 0.03 mm. The flank wear $VB$ was produced artificially by grinding against a diamond grinding wheel in an EBN-2C machine. $VB$ was measured by the KEYENCE Laser Scanning Confocal Microscope with a measuring accuracy of approximately 1 µm.

PFs were measured by a three-component piezo-electric KISTLER dynamometer, model 9265B-9441B using the Popov–Dugin's method described in previous studies [11–14]. The expansion scheme of the total active force $F_a$, which was used to determine the cutting forces (CFs), is shown in Figure 1. The CFs are estimated from the average of the 5 measurements obtained.

**Experimental Results**

3.1 *Measurement results of the effect of $V_c$ on the CFs when turning different materials using a cutting insert with $VB = 0.2$*

Figures 2-4 present the experimental results of the effect of $V_c$ on the CFs when turning stainless steel, structural steel, and aluminum alloy materials using a cutting insert with $VB = 0.2$.

Figure 2(a) shows that, when processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in the ploughing-force component in direction of cutting $F_{pl,c}$ by 2.6 times, but at the same time the chip-forming force component in direction of cutting $F_{ch,c}$ is reduced by 17%, and the active force component in direction of cutting $F_c$ is reduced by 11%.

When processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has resulted in twofold increase in the ploughing-force component in the feed direction $F_{pl,f}$, but at the same time a decrease by 21% in the chip-forming force component in the feed direction $F_{ch,f}$ and by 13% in the active force component in the feed direction $F_f$ [Figure 2(b)] is observed.

When processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has resulted in an increase in the PF $F_{pl}$ by 2.2 times, but at the same time a decrease by 18% in the chip-forming force $F_{ch}$ and by 12% in the active force $F_a$ [Figure 2(c)] is observed.

Notably, when analyzing the experimental results, it is necessary to pay attention to the increase in the absolute values of the PFs and decrease in values of the CFs on the front surface. Figure 2(c) shows that when processing stainless steel, an increase in $V_c$ from 50 to 200 m/min has led to an increase in the $F_{pl}$ by 124 N, but the $F_{ch}$ is decreased by 383 N which explains the decrease in the $F_a$ by 259 N.
Figure 3(a) shows that, when processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in the $F_{pl,c}$ by 2.4 times, but at the same time the $F_{ch,c}$ is reduced by 16%, and the $F_c$ is reduced by 11%.

When processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has resulted in an increase in the $F_{pl,f}$ by 2.7 times, but at the same time a decrease by 30% in the $F_{ch,f}$ and by 20% in the $F_f$ [Figure 3(b)] is observed.

When processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has resulted in an increase in the $F_{pl}$ by 2.6 times, but at the same time a decrease by 20% in the $F_{ch}$ and by the 13% in the $F_a$ [Figure 3(c)] is observed.

Notably, Figure 3(c) shows that when processing structural steel, an increase in $V_c$ from 50 to 200 m/min has led to an increase in the $F_{pl}$ by 138 N, but the $F_{ch}$ is decreased by 410 N which explains the decrease in the $F_a$ by 272 N.

Figure 4(a) shows that, when processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in the $F_{pl,c}$ by 1.3 times, but at the same time the $F_{ch,c}$ is reduced by 15% and the $F_c$ is reduced by 14%.

When processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has resulted in an increase in the $F_{pl,f}$ by 1.8 times, but at the same time a decrease by 23% in the $F_{ch,f}$ and by 18% in the $F_f$ [Figure 4(b)] is observed.

When processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has resulted in an increase in the $F_{pl}$ by 1.4 times, but at the same time a decrease by 16% in the $F_{ch}$ and by the 16% in the $F_a$ [Figure 4(c)] is observed.

Figure 4(c) shows that when processing aluminum alloy, an increase in $V_c$ from 50 to 200 m/min has led to an increase in the $F_{pl}$ by 19 N, but the $F_{ch}$ is decreased by 202 N which explains the decrease in $F_a$ by 183 N.

It is a well-known fact that $F_a$ decreases as $V_c$ increases in the process of cutting with different materials and is reflected in a large number of studies [11–15]. At the same time, an increase in PFs with an increase in $V_c$ was established for the first time.

3.2 Measurement results of the effect of $V_c$ on the PFs when turning different materials using a cutting insert with different VB

The measurement results of the effect of $V_c$ on the PFs when turning stainless steel, structural steel, and aluminum alloy using a cutting insert with different VB are shown in Figures 5-7.
Figure 5(a) shows that, when processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,c}$ by 2.4 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.8 times when using a cutting insert with $VB = 0.1$ mm and by 2.6 times when using a cutting insert with $VB = 0.2$ mm.

When processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,f}$ by 1.6 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.7 times when using a cutting insert with $VB = 0.1$ mm and by 2 times when using a cutting insert with $VB = 0.2$ mm [Figure 5(b)].

When processing stainless steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl}$ by 1.9 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.8 times when using a cutting insert with $VB = 0.1$ mm and by 2.2 times when using a cutting insert with $VB = 0.2$ mm [Figure 5(c)].

Figure 6(a) shows that, when processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,c}$ by 2.9 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.9 times when using a cutting insert with $VB = 0.1$ mm and by 1.8 times when using a cutting insert with $VB = 0.2$ mm.

When processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,f}$ by 3.6 times when turning using a cutting insert with $VB = 0.03$ mm, by 2.3 times when using a cutting insert with $VB = 0.1$ mm and by 2.7 times when using a cutting insert with $VB = 0.2$ mm [Figure 6(b)].

When processing structural steel, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl}$ by 3.2 times when turning using a cutting insert with $VB = 0.03$ mm, by 2.1 times when using a cutting insert with $VB = 0.1$ mm and by 2.6 times when using a cutting insert with $VB = 0.2$ mm [Figure 6(c)].

Figure 7(a) shows that, when processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,c}$ by 1.4 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.3 times when using a cutting insert with $VB = 0.1$ mm and by 1.3 times when using a cutting insert with $VB = 0.2$ mm.

When processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl,f}$ by 1.8 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.7 times when using a cutting insert with $VB = 0.1$ mm and by 1.8 times when using a cutting insert with $VB = 0.2$ mm [Figure 7(b)].

When processing aluminum alloy, an increase in the $V_c$ from 50 to 200 m/min has led to an increase in $F_{pl}$ by 1.5 times when turning using a cutting insert with $VB = 0.03$ mm, by 1.4 times when turning using a cutting insert with $VB = 0.1$ mm and by 1.4 times when using a cutting insert with $VB = 0.2$ mm [Figure 7(c)].
Conclusion

It was established for the first time that an increase in cutting speed leads to an increase in PFs – when turning with VB from 0.03 mm to 0.2 mm and with an increase in cutting speed ranging from 50 to 200 m/min, an increase in. In the operations performed in this article, it is observed PFs were increased (1) 2.1–3.2 times when turning structural steel, (2) 1.9–2.2 times when turning stainless steel, and (3) 1.4–1.5 times when turning aluminum alloy.

Such an increase in PFs in the studied range does not contradict the well-known fact of a decrease in the active force $F_a$ decreases with an increase in cutting speed in the studied range. This phenomenon is explained by the fact that with an increase in the cutting speed, the forces on the front surface, which significantly exceed the forces on the rear surface, and decrease simultaneously. The decrease in CFs on the front surface in absolute value exceeds the increase in forces on the rear surface, which ultimately leads to a decrease in the active force $F_a$.

Declarations

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**Figures**
Figure 1

The scheme of the active force $F_a$, expanded into the chip-forming force $F_{Ch}$ and PF FPI and into the components in feed and cutting directions
Figure 2

The effect of $V_c$ on the (a) $F_c, F_{ch,c}, F_{pl,c}$, (b) $F_f, F_{ch,f}, F_{pl,f}$ and (c) $F_a, F_{ch}, F_{pl}$ when turning stainless steel using a cutting insert with $VB = 0.2$
Figure 3

The effect of Vc on the (a) Fc, Fch,c, Fpl,c, (b) Ff, Fch,f, Fpl,f and (c) Fa, Fch, Fpl when turning structural steel using a cutting insert with VB = 0.2
Figure 4

The effect of $V_c$ on the CFs when turning aluminum alloy using a cutting insert with $VB = 0.2$
Figure 5

The effect of $V_c$ on the PFs when turning stainless steel using a cutting insert with different VB: (a) the effect of $V_c$ on $F_{pl,c}$; (b) the effect of $V_c$ on $F_{pl,f}$; (c) the effect of $V_c$ on $F_{pl}$. 
Figure 6

The effect of $V_c$ on the PFs when turning structural steel using a cutting insert with different $V_B$: (a) the effect of $V_c$ on $F_{pl,c}$; (b) the effect of $V_c$ on $F_{pl,f}$; (c) the effect of $V_c$ on $F_{pl}$. 
Figure 7

The effect of Vc on the PFs when turning aluminum alloy using a cutting insert with different VB: (a) the effect of Vc on Fpl,c; (b) the effect of Vc on Fpl,f; (c) the effect of Vc on Fpl.