EFFECT OF CHIP BREAKERS ON THE CUTTING FORCE DURING THE MACHINING OF STEEL C45

Jiří Kratochvíl¹, Jana Petrů¹, Marek Pagáč¹, Jozef Holubják², Jozef Mrázík²

¹ VŠB – Technical University of Ostrava, Faculty of Mechanical Engineering, 17. listopadu 15/2172, 708 33 Ostrava-Poruba, Czech Republic, e-mail: jiri.kratochvil@vsb.cz, jana.petru@vsb.cz, marek.pagac@vsb.cz
² University of Žilina, Faculty of Mechanical Engineering, Univerzitna 1, 010 26, Žilina, Slovakia, e-mail: dana.stancekova@fstroj.uniza.sk, jozef.holbjak@fstroj.uniza.sk, jozef.mrazik@fstroj.uniza.sk

ABSTRACT
The paper deals with the dependence of cutting force on the breaker of an indexable cutting insert (ICI). The experiment monitored individual cutting force components for different insert breakers, cutting speeds and feed rates during machining. The cutting depth remained constant. The tool holder, material and coating of the indexable cutting insert was also identical.

Keywords: edge geometry, turning forces, breakers.

INTRODUCTION
The development of machine tools is constantly moving forward. Manufacturers are permanently seeking ways to improve them. Improvements can be achieved by better tool materials, better coatings or innovative tool geometry. Tool geometry affects both the properties of the final product as well as the force acting on the tool, its cutting power and durability. The paper deals with the measurement and comparison of these forces with respect to a change in the micro-geometry of indexable cutting inserts (ICIs) of the turning tool. Indexable cutting inserts have the same shape, the same tool holder, the same basic cemented carbide material and the same type of coating. Indexable cutting inserts only differ in the chip breaker. This paper provides a comparison of cutting forces at different cutting parameters, namely at different cutting speeds and feed rates. Cutting conditions were chosen as the intersection of the recommended values of cutting conditions of individual ICIs.

Conditions of the experiment
The experiment was conducted on lathe model NLX2500MC/700 produced by company DMG MORI. Force components were measured on a piezoelectric dynamometer (produced by Kistler) shown in Figure 1a. Figure 1b shows a dynamometer mounted on the machine. When measuring with a dynamometer, we essentially measure the response to machining forces (i.e. cutting resistances), which are identical to the cutting forces of the opposite direction. In Figure 1b), these cutting resistances are marked $F_c^\prime$, $F_f^\prime$ and $F_p^\prime$ [1, 2, 3].

For this experiment, we used a toolholder DCLNR 2525M-12 with a 95° lead angle ($\kappa_r = 95^\circ$). Into this holder, we inserted Indexable Cutting Inserts (ICI) produced by ISCAR, with the base material of cemented carbide, type IC8250. The material machined during the experiment was steel C45 [4÷7].

Due to the dynamic behaviour of cutting force components, the experiment worked with mean values. These values were evaluated in the software Dyno Ware. This programme is also used to record the values of individual force components from the measuring system. The total cutting force is calculated in accordance with equation (1); for further use, it has been rounded to the nearest whole number.
To present micro-geometry of ICI inserts, contours were marked in the plane parallel to the feed direction and at a distance of 2 mm from the ICI tip. This value was chosen with regard to the cutting depth used. The contours were measured using a contourgraph by Mahr and generated in MarWin 5.00-12 SP1. The contours of individual breakers are shown in Figures 2 to 5 and described below.

ICI CNMG 120408-M3P

ICI CNMG 120408-M3P, see Figure 2: a double-sided 80° rhombic inserts, for medium machining conditions on steel. Low cutting forces due to positive rake, provide smooth cutting [8].

Recommended cutting conditions [8]:

\[ a_p = 0.5 \div 5.5 \text{ [mm]}, \quad f = 0.15 \div 0.5 \text{ [mm]}, \quad v_c = 140 \div 320 \text{ [m/min]} \]

ICI CNMG 120408-PP

ICI CNMG 120408-PP, see Figure 3: Double-sided 80° rhombic inserts with a positive rake angle and sharp, positive-radial edge. Used for machining very ductile materials such as alumin-

\[ F = \sqrt{F_c^2 + F_f^2 + F_p^2} \]  \hspace{1cm} (1)

- \( F \) - resulting cutting force (N),
- \( F_c \) - cutting force component (N),
- \( F_p \) - passive force component (N),
- \( F_f \) - feed force component (N).

Fig. 1. (a) dynamometer and measured forces, (b) breakdown of the measured forces on the machine

Fig. 2. Contour of ICI breakers CNMG 120408-M3P and CNMG 120408-M3P [8]
ium alloys, soft, low carbon steel, stainless steel, and high temperature alloys [9].

Recommended cutting conditions [9]:

\[
\begin{align*}
    & a_p = 1+4 [\text{mm}], \\
    & f = 0.14+0.3 [\text{mm}], \\
    & v_c = 140+320 [\text{m/min}].
\end{align*}
\]

ICI CNMM 120408-R3P

ICI CNMM 120408-R3P, see Figure 4: a double-sided 80° rhomboid inserts, for rough turning applications of steel [10].

Recommended cutting conditions [10]:

\[
\begin{align*}
    & a_p = 0.7+7.5 [\text{mm}], \\
    & f = 0.2+0.55 [\text{mm}], \\
    & v_c = 140+320 [\text{m/min}].
\end{align*}
\]

ICI CNMM 120408-M4PW

ICI CNMM 120408-M4PW, see figure 5: The insert has a very positive radial, helical cutting edge and a positive rake angle, which reduces the cutting forces. A wiper corner design produces a high surface finish even at high feed rates. Used for heavy machining applications [11].

Recommended conditions [11]:

\[
\begin{align*}
    & a_p = 1.5+5 [\text{mm}], \\
    & f = 0.24+0.59 [\text{mm}], \\
    & v_c = 140+320 [\text{m/min}].
\end{align*}
\]

Table 1 shows mean values of the individual force components as well as the calculated values of the resultant cutting force for the part of the
experiment where the cutting speed was \( v_c = 300 \text{ m/min} \), cutting depth \( a_p = 2 \text{ mm} \) and there was a change in the feed rate \( f \) (mm).

After calculating the resulting force (the green column according to equation 1 in Table 1), a chart was created to compare the different ICI breakers at given conditions (see Figure 6).

The graph clearly shows that the ICI exposed to the highest load was ICI with breaker CNMM 120408-R3P for all selected feed values. Conversely, the breaker CNMG 120408-M3P is exposed to the smallest force load at feed values \( f = 0.2 \) and 0.35 mm. Only at feed \( f = 0.5 \text{ mm} \), the breaker CNMM 120408-M4PW was exposed to the lowest load.

| \( f \) [mm] | \( F_p \) [N] | \( F_c \) [N] | \( F_f \) [N] | \( F_q \) [N] | \( F_r \) [N] | \( F_t \) [N] | \( F_e \) [N] | \( F_s \) [N] | \( F_t \) [N] | \( F_e \) [N] | \( F_s \) [N] | \( F_t \) [N] |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0.25 | 288 | 1108 | 764 | 1376 | 1401 | 385 | 1218 | 914 | 1571 | 368 | 1129 | 802 | 1433 |
| 0.35 | 437 | 1444 | 949 | 1782 | 1848 | 550 | 1510 | 1156 | 1980 | 449 | 1447 | 984 | 1807 |
| 0.5 | 619 | 932 | 1285 | 1704 | 1435 | 1663 | 789 | 677 | 1525 | 1846 | 671 | 1004 | 1326 | 1793 |

Fig. 5. Contour of ICI breaker CNMM 120408-M4PW and CNMM 120408-M4PW [11]

Fig. 6. Dependence of the resulting cutting force on the feed and breaker for \( v_c = 300 \text{ m/min} \) and \( a_p = 2 \text{ mm} \)
The resulting force between the highest and lowest value of cutting force is $\Delta F = 195 \text{ N}$ at feed rate $f = 0.25$ mm. At $f = 0.25$, the difference is $\Delta F = 198 \text{ N}$ and at $f = 0.5$, the difference is $\Delta F = 183 \text{ N}$. This difference may result in a longer life of the ICI, when smaller force presses the abrasive particles against the edge, and even the temperature could be lower at the cutting point.

According to the manufacturer’s recommended conditions, it is clear that the inserts which can be used for larger cutting depths were subjected to greater cutting force than inserts intended for smaller cutting depths. Here, we can see the effect of micro-geometry, especially a negative breaker facet. The larger the facet, the greater the cutting force, but also greater rigidity of the cutting edge for greater material removal.

Table 2 shows mean values of the individual force components as well as the calculated values of the resulting cutting force for the part of the experiment where feed $f = 0.2$ mm, cutting depth $a_p = 2$ mm and where changes occurred in the cutting speed $v_c$ (m.min$^{-1}$).

After calculating the resultant force (the green column according to equation 1 in Table 2), a chart was created to compare the different ICI breakers at given conditions (see Figure 7).

The graph clearly shows that the ICI exposed to the highest load was again the ICI with breaker CNMM 120408-R3P for all selected cutting speeds $v_c$ (m.min$^{-1}$). The breaker CNMG 120408-M3P is in this case the best for all cutting speeds $v_c$ (m.min$^{-1}$).

The difference between the highest and the lowest cutting force is $\Delta F = 153 \text{ N}$ at a cutting speed $v_c = 150$ m.min$^{-1}$, and $\Delta F = 210 \text{ N}$ at a cutting speed $v_c = 250$ m.min$^{-1}$. At a cutting speed $v_c = 300$ m.min$^{-1}$ the difference $\Delta F = 195 \text{ N}$. Identically to the different feed rates, also here it was confirmed that the inserts which can be used for larger cutting depths were subjected to greater cutting force than inserts intended for smaller cutting depths.

**CONCLUSION**

The paper compares forces acting on four types of chip breakers, using the same shape, material and coating of indexable cutting inserts (ICIs). The experiment was divided into two parts. The first part focused on comparing the forces acting on ICIs at different feed rates. The second part focuses on the experiment at different cutting speeds.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>269</td>
<td>1125</td>
<td>1395</td>
<td>196</td>
<td>1119</td>
<td>853</td>
<td>1478</td>
<td>350</td>
<td>1206</td>
<td>905</td>
<td>1548</td>
<td>346</td>
</tr>
<tr>
<td>250</td>
<td>353</td>
<td>1061</td>
<td>1335</td>
<td>198</td>
<td>1168</td>
<td>820</td>
<td>1441</td>
<td>362</td>
<td>1205</td>
<td>897</td>
<td>1545</td>
<td>362</td>
</tr>
<tr>
<td>300</td>
<td>288</td>
<td>1108</td>
<td>1376</td>
<td>186</td>
<td>1143</td>
<td>789</td>
<td>1401</td>
<td>385</td>
<td>1218</td>
<td>914</td>
<td>1571</td>
<td>368</td>
</tr>
</tbody>
</table>

**Table 2.** Experimental values at different $v_c$ and constant $f = 0.25$ mm and $a_p = 2$ mm

Fig. 7. Dependence of the resulting cutting force on the cutting speed and breaker for $f = 0.25$ mm and $a_p = 2$ mm.
The results of the experiment clearly show the effect of geometry on cutting force. In most of the tests, the lowest force was acting on the ICI breaker CNMG 120408-M3P, while the breaker CNMM 120408-R3P was exposed to the highest force in all experiments.

The evaluation of the experiment also showed that it will be necessary to extend the experiment to include ICI testing at different cutting depths, where better results could be shown for ICIs with a greater recommended cutting depth (where a larger breaker facet would not pose a problem), which corresponds to the breaker CNMM 120408-R3P.

Acknowledgement

This Article has been done in connection with the project Education system for personal resource of development and research in field of modern trend of surface engineering – surface integrity, reg. no. CZ.1.07/2.3.00/20.0037 financed by Structural Funds of Europe Union and from the means of state budget of the Czech Republic and by project Students Grant Competition SP2016/172 and SP2016/174 financed by the Ministry of Education, Youth and Sports and Faculty of Mechanical Engineering VŠB-TUO.

REFERENCES