UDK 621.941:004.896
Original scientific article/Izvirni znanstveni članek

ISSN 1580-2949
MTAEC9, 47(2)199(2013)

INCREASING TOOL LIFE DURING TURNING WITH A VARIABLE DEPTH OF CUT

POVEČANJE ZDRŽLJIVOSTI ORODJA PRI STRUŽENJU Z VARIABILNO GLOBINO REZA

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Prejem rokopisa – received: 2012-09-05; sprejem za objavo – accepted for publication: 2012-09-27

The article deals with the improvement of cutting-tool durability by using CAD/CAM systems. It proposes new roughing turning cycles where a variable depth of cut is applied. The experimental part verifies theoretical prerequisites when a flange is being machined with a sintered-carbide cutting tool. It compares the turning where the standard roughing cycle is used and the turning where the proposed roughing cycle with a variable depth of cut is applied.

Keywords: variable depth of cut, durability, CAD-CAM systems, turning

Članek obravnava izboljšanje zdržljivosti orodij za odrezavanje z uporabo sistema CAD/CAM. Predlagani so novi cikli grobega struženja, kjer se uporablja spremenljivo globino rezanja. V eksperimentalnem delu so potrjeni teoretični prvi pogoji pri struženju prirobnice z rezilnim orodjem iz sintranih karbidov. Primerjano je struženje, kjer je uporabljen standarden cikel odrezavanja, s tistim struženjem, kjer je uporabljen predlagan cikel odrezavanja s spremenljivo globino rezanja.

Ključne besede: spremenljiva globina rezanja, zdržljivost, sistem CAD-CAM, struženje

1 SUPPOSED PROCESS OF TOOL WEAR

Tool wear depends on numerous factors, for example: workpiece material, tool material and geometry, cutting parameters (cutting speed, feed, cutting depth), used process liquid, cutting machine and many others[1].

It is proved that cutting the depth does not have the greatest influence. Since it has its share in the intensity of tool wear (a growing cutting depth increases the tool wear as well) it makes sense to deal with cutting depth and we can consider it as a significant factor of tool wear.

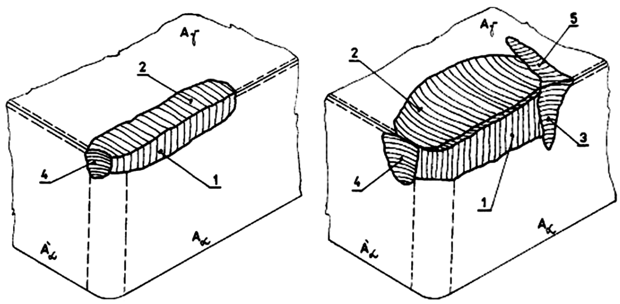
1.1 Tool wear of a selected type of cutting tools

The most used cutting materials in the area of CNC machining are sintered carbide and cutting ceramics[2,3]. As seen in **Figure 1**, the tool-wear method depends on the applied tool materials. The tool wear of the cutting ceramics is rather linear without any marked stepped increases. The tool wear will therefore grow with an increasing depth of cut. It is, thus, not advisable to apply a variable depth of cut to the ceramics with such behavior. The types of cutting ceramics, such as the nitride ceramics, in which a more pronounced notch on the back is formed during the machining may be used exceptionally[4,5].

Sintered carbide tends to form a pronounced notch on the face and main back. This notch could be very advantageously used in the roughing cycles with a variable depth of cut. Efforts will be made to distribute this pronounced notch over the maximum possible length of the tool's cutting edge.

Figure 2 below describes the used marking of the tool wear according to ISO 3685.[6]

In applying a variable depth of cut (in the sintered carbide) the durability-improvement effect is expected to occur in the cutting edge provided the wear shaped as a notch on the back is distributed over the longer part of the cutting edge. These prerequisites were verified with the experiments during the practical machining of the concerned part – the flange.



1 – surface of wear on the back
2 – crater wear
3 – notch wear on the main back
4 – notch wear on the minor back
5 – notch on the face

Aα – main back
Aα´ – minor back
Aγ – face

Figure 1: Cutting-ceramics wear process and the tool-wear process of sintered carbides[4,5]

Slika 1: Proces obrabe rezilne keramike in obrabe orodja iz sintranih karbidov[4,5]

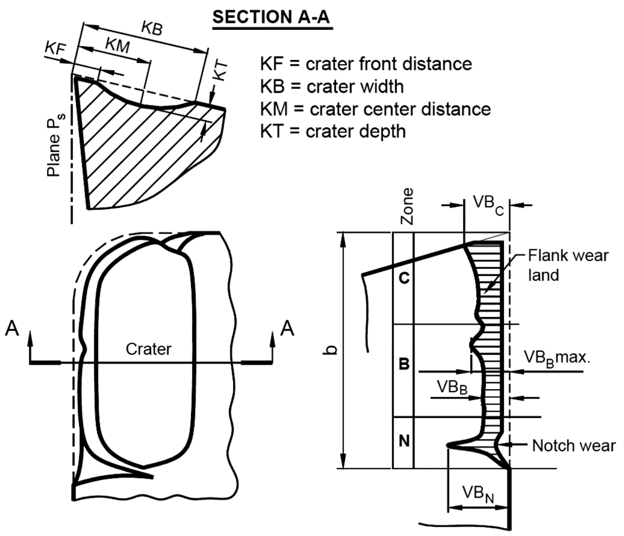


Figure 2: Tool wear according to ISO 3685:1993 [6]
Slika 2: Obraba orodja skladno z ISO 3685:1993 [6]

Both types of the cutting material were tested in practice by experimental machining of the selected turning parts. The theoretical assumption that the cutting ceramic does not tend to form a notch on the back was proven and it is essential for this tool-life improvement method. That is why only the experimental works where sintered carbide is used are stated below.

2 POSSIBILITIES OF A ROUGHING TOOL PATH IN CAM SYSTEMS

The basic types of the used machining cycles and operating stages for the 2-axis turning are as follows:

- straight (rectangle) turning,
- face turning,
- rough turning,
- finish turning,
- profile turning,
- groove turning,
- pocket turning,
- thread turning,
- hole machining,
- parting off (cutting off),
- rest cycle (residual turning),
- hand setting of tool motion.

The conventional roughing cycles in turning, where a cutting tool performs a constant depth of cut can be adapted and extended with the cycles when the tool cuts with a variable depth of cut. The proposed roughing cycles are as follows:

- rough cycle "decreasing of engagement" (**Figure 3**),
- roughing by creating a conical surface,
- roughing with the use of nonlinear methods, etc.

Figure 4 depicts a commonly used roughing cycle. A constant depth of cut is used in this roughing cycle. The machining process results in the wear that prevails in one point of the cutting edge only.

During the roughing strategy – the cut decrement – each chip removal is performed with a different depth of cut so a different cutting part of the tool is under stress during each cutting operation. This method of machining can be time-consuming due to several passes. This is compensated for by an increased tool life, a lower loading of the machine spindle and a reduced machine noise. The depth of cut is reduced when the final diameter is being approached. The maximum wear point is therefore moved outwards from the cut, prolonging the cutting-tool durability. This type of roughing cycle is already contained in the advanced CAM systems (EdgeCAM,

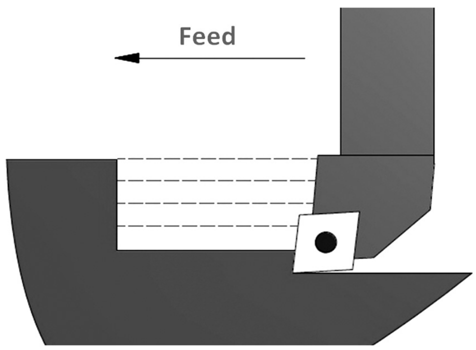


Figure 4: Roughing cycle with a constant depth of cut
Slika 4: Cikel odvzemanja s konstantno globino reza

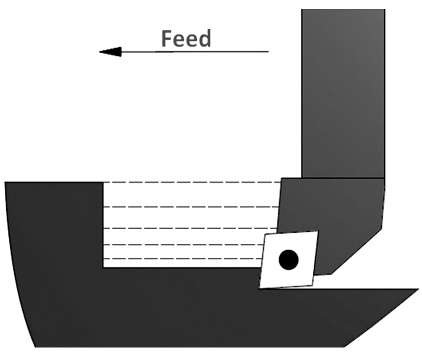


Figure 3: Roughing cycle – a decreased cut
Slika 3: Cikel odvzemanja – zmanjševanje odvzema

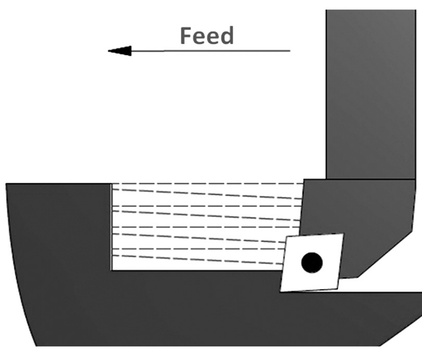


Figure 5: Roughing cycle creating a conical surface
Slika 5: Cikel odvzemanja, pri katerem nastaja konična površina

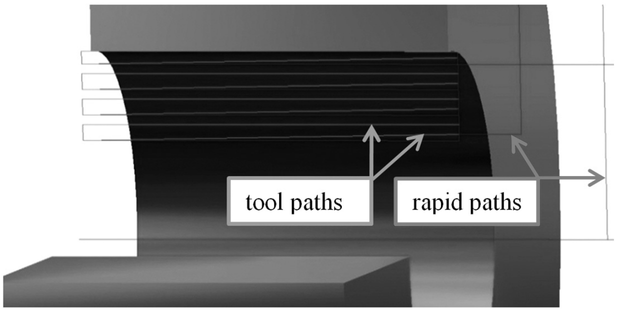


Figure 6: Roughing-cycle simulation when a conical surface is made during an internal turning
Slika 6: Simulacija cikla odvzemanja, pri katerem nastaja konična površina pri notranjem struženju

turning to profile). An application of this feature, when longer parts are turned, is advantageous for the elimination of the ever-decreasing workpiece stiffness.

The cutting, with which a conical surface is formed, starts with the deepest depth of cut which decreases in the feeding direction, as shown in **Figure 5**. The second cut is programmed to be parallel with the workpiece axis. This provides for an efficient removal of the conical surface formed in the previous cut. Thanks to this strategy, the tool wear moves along the cutting edge from the maximum to the minimum depth of cut (a_{pmax} to a_{pmin}). **Figure 6** shows a simulation of the machining (a programmed tool path) when turning the flanges, for which the experimental part was done.

The non-linear roughing-cycle method also ensures a variable depth of cut. For example, a tool path's wavy profile (**Figure 7**) will achieve the same effect as the previous methods. During both the first and the second cut, the machined material is on a gradual increase and decrease and a variable depth of cut is thereby achieved. It is also possible to shift the machined surface and, in doing so, change the depth of cut. However, this requires an advanced CAD/CAM system joined with the CNC cutting machines.

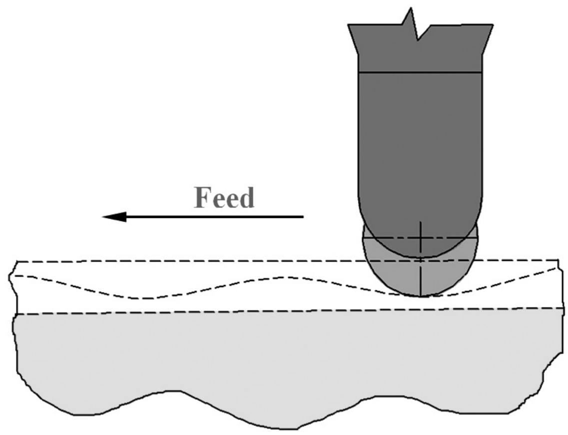


Figure 7: Roughing cycle – the nonlinear method
Slika 7: Cikel odvzemanja – nelinearna metoda

3 EXPERIMENTAL WORK

Two strategies were used during turning: the conventional method with a constant depth of cut and the cone-forming machining.

3.1 Experimental characterization

The verification of theoretical presumptions was carried out in practice. For this purpose we used the following cutting machine: Mori Seiki SL – 65 B with the drive system Fanuc and the spindle power of P = 71 kW. The worpiece material was the austenitic stainless steel 1.4401 that corresponds to DIN X5CrNiMo17-2-2 with a hardness of 180 HB. This material is mainly used in chemical industry, apparatus engineering, pulp industry and food industry. The dimensions of the worpiece (the flange) were as follows: its external diameter D = 350 mm, internal diameter d_1 = 56 mm, length L = 73 mm and the internal diameter of the semi-product before finishing d_2 = 157 mm. The cutting tool was an internal radius turning tool (the Sandvik company) with the cutting inserts: CNMG 12 04 12 – MR 2025 with the CVD coating. This tool is suitable for longitudinal medium roughing and roughing. During the cutting the cutting fluid was used. The cutting conditions differed only in the cut size and depth shape, as shown in **Table1**.

The different depths of cut (stock removals) in the internal roughing cycle are shown in **Figure 8**.

Here a gradual removal of the material from the first tool path to the last one (n^{th}) is shown. The total number of tool paths (n) depends on the size of the workpiece and the technological possibilities of the insert as well.

A representative sample of the tool wear has been selected from all of the performed experiments focusing

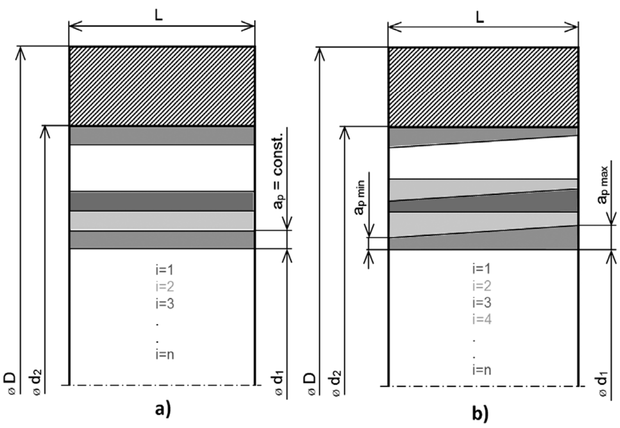


Figure 8: Tool paths: a) a constant depth of cut, b) a variable depth of cut (i <1,n> = number of tool paths; n = total number of tool paths; L, D, d_1 = dimensions of the workpiece; L, D, d_2 = dimensions of the semi-product before finishing)
Slika 8: Poti orodja: a) konstantna globina reza, b) spremenljiva globina reza (i <1,n> = število poti orodja, n = celotno število poti orodja, L, D, d_1 = dimenzije obdelovanca, L, D, d_2 = dimenzije nedokončanega polproizvoda)

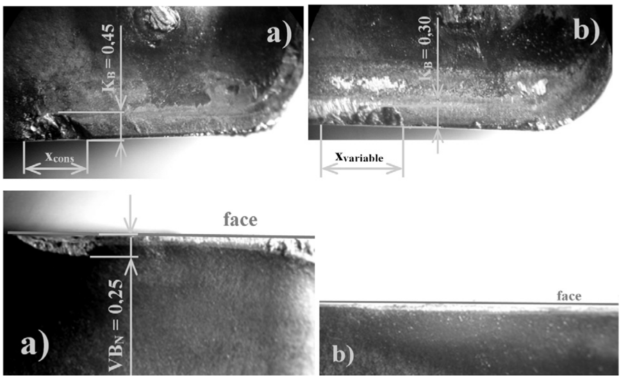


Figure 9: Comparison of the tool-face and back wear: a) a constant depth of cut, b) a variable depth of cut

Slika 9: Primerjava obrabe čela in začelja orodja: a) konstantna globina reza, b) spremenljiva globina reza

Table 1: Cutting conditions: the constant-depth-of-cut strategy and the conical-surface strategy

Tabela 1: Pogoji rezanja: strategija s konstantno globino rezanja in strategija s konično površino

Cutting conditions			rough turning		
			constant depth of cut	variable depth of cut	
cutting speed	v_c	m min^{-1}	180	180	
feed	f	mm r^{-1}	0.3	0.3	
depth of cut	a_p	mm	4	$a_{pmin} = 3$	$a_{pmin} = 5$

on the wear in the form of a notch on the face and on the back.

With regard to the measurement during the production, the tool wear was measured with a microscope with an installed digital camera. To read the wear values the Micrometrics SE Premium software, version 7.2, was used.

The upper part of **Figure 9** shows the tool wear on the face. The lower part of the same figure shows the tool wear on the back. The strategy with a constant depth of cut reports, for the same period of time (machining time t = 18.6 min), a greater tool wear than the strategy with a variable depth of cut.

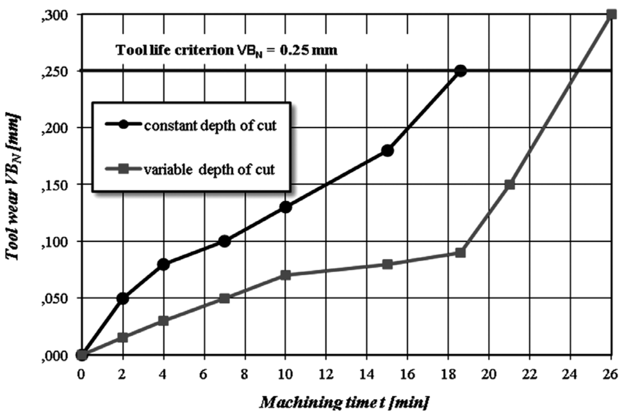


Figure 10: Dependence of the VB_N tool wear on time under the roughing strategy – a constant depth of cut and a variable depth of cut

Slika 10: Odvisnost obrabe VB_N orodja od časa odrezavanja – konstantna globina reza in spremenljiva globina reza

Figure 9 reveals a visible notch on the face (with the length x_{cons} of 1.03 mm) and on the back formed while using the constant depth of cut. The notch wear on the face is greater than in the case of the strategy with a variable a_p. There is also a visible notch on the back, VB_N = 0.25 mm. The strategy using a variable depth of cut causes no notch on the back, as shown in **Figure 9**, the bottom b part).

With the variable depth of cut, the notches are distributed over the tool's longer cutting edge corresponding to the variable depth of cut. The notches shift in relation to the changing depth of cut (from 3 mm to 5 mm depth of cut), $x_{variable}$ = 1.49 mm.

The dependence of the tool wear on time was recorded and entered into the "Dependence of VB_N tool wear on time" chart, as shown in **Figure 10.** The cutting process was interrupted in order to measure the tool wear after the tool path (between the cuts) so as not to disturb the cutting process by starting a cut and getting out of a cut and the measuring interval was kept to last for about 2 min.

This chart clearly implies that the roughing method with a variable depth of cut causes a lower wear VB_N in the same time and under the same cutting conditions. The wear has a slighter inclination in the second area of the chart (in this area the tool wear increases uniformly). The tool wear criterion was set to be VB_N = 0.25 mm.

The durability of the cutting edge in the roughing cycle with a constant depth of cut was, on average, 18 min. In the newly designed cycle with a variable depth of cut, the durability of the cutting edge was 26 min, i.e., the durability increased by 44 %.

4 DISCUSSION AND CONCLUSIONS

The proposed manufacturing technology of the flange and shaft components ensures a reduced tool wear, i.e., an increased turning-tool durability and life. There is a more favorable distribution of wear on the replaceable tool insert when employing the proposed turning technology.

An application of the new roughing cycle resulted in a decrease in the spindle load by 10 %. This reduction was monitored directly on the cutting machine – it was displayed on the indicator of the spindle load.

This change caused a reduction in the energy demand of the machine tool. The roughing cycle with a variable depth of cut was applied in the company of JohnCrane a.s. It gave excellent results in the form of an increased durability of the cutting edge by 44 % in the maintained machining time.

The increased durability of the tool significantly reduces the total costs for the cutting tools. These costs are also reduced by less frequent downtimes when a worn tool is replaced. However, the disadvantage of this technology is a more complicated tool-path programming for the roughing cycle with a variable depth of cut.

The suggested roughing cycles may not have a positive influence on the machining process. It is necessary to carefully consider all the aspects associated with the proposed cycles. These can include a reduced rigidity of the machine tool caused by both the tool's simultaneous movement in the directions of the two axes and the requirements of the software (CAM system) and the CNC programmer.

Acknowledgement

We would like to thank the company of JohnCrane a.s. for allowing us to perform our experiments. This paper was supported by the Czech Science Foundation, Student Grant Competition (SP2011/23), VSB-Technical University of Ostrava.

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