



MACHINING WITH ROTARY CUTTING TOOLS – EXPERIMENTAL RESEARCH

МЕХАНИЧЕСКАЯ ОБРАБОТКА С РОТОРНЫМИ ИНСТРУМЕНТАМИ - ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ

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Abstract: The paper presents the results of an experimental research program studying the influence of the rotary motion of the cutting edge upon the cutting process in the case of rotary machining.

KEYWORDS: MACHINING, ROTARY CUTTING TOOL

1. Introduction

Rotary cutting continues to draw the attention mainly due to the interesting and attractive features of the cutting process. High tool life and cinematic rake angle, low temperature of the tool chisel, the possibility to cut low manufacturability materials, etc. are some of these features. Several researches have been performed starting in the early '50, trying to explain the mechanisms behind the absolute and relative cutting processes identified behind of rotary machining, [1, 2, and 3]

In the case of machining with conventional, stationary cutting tools, the whole energy consumed for chip formation is provided by the machine tool. The power used in the cutting process and the removal rates are determined by the cutting speed. The specific power in respect with the removed volume is practically constant. In case of rotary cutting tools, the circular chisel has a supplementary rotary movement. This movement can be obtained from the machine tool or from a supplementary movement source (an electrical engine or a hydraulic engine). When the cutting force has a particular level, the power consumed by driving the rotary tool and introduced within the cutting zone is proportional with the rotary speed v_m . Disregarding the cutting speed v , the rotary speed of the cutting edge v_m do not affect the removal rate, but influences, in a controllable manner, the specific power consumed for cutting the unit of volume.

The supplementary energy, introduced by the supplementary rotary movement of the cutting tool in the process of chip formation, will influence it dramatically. Taking in account that for cutting the unit of volume there is necessary a minimum amount of energy in the case of stationary cutting tools SCT, applying this criterion follows to an evident force reduction. The supplementary energy provided from the rotary movement source will affect the chip formation process, especially at low rotary speeds v_m . In the case of rotary movement with high rotary speeds, from the energy introduced in the cutting zone a part will be dissipated as heat, due to the increased friction between the chip and the tool rake face and between the tool and the workpiece. This aspect will modify the thermal picture of the process and will affect the properties of the chip material. One can then expect a decrease of the energy consumed for the shearing process due to the lower value of the yield limit produced by increasing the temperature of the workpiece in the near region to the chip root.

2. Experimental research with Driven Rotary Tools

In order to emphasize the energetic picture of the cutting process when the tool makes the supplementary rotary movement, a series of experiments have been performed with driven rotary cutting tools. Aluminum alloy test pieces with $l = 100$ mm and $b = 4$ mm were machined with HSS tools having 10° and 30° normal rake angles.

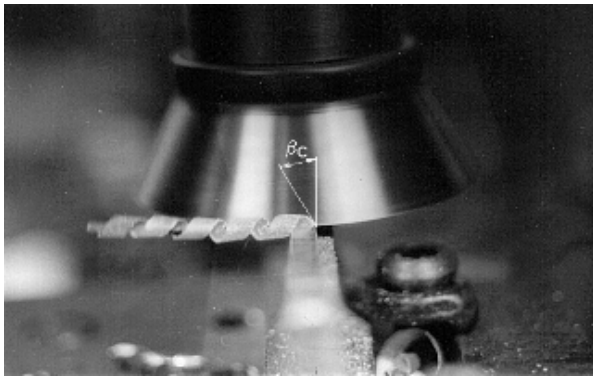
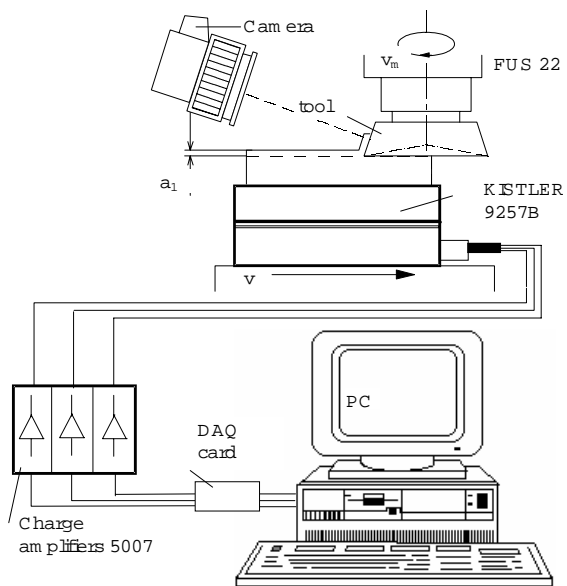


Fig. 1 Rotary Driven Tool cutting process setup

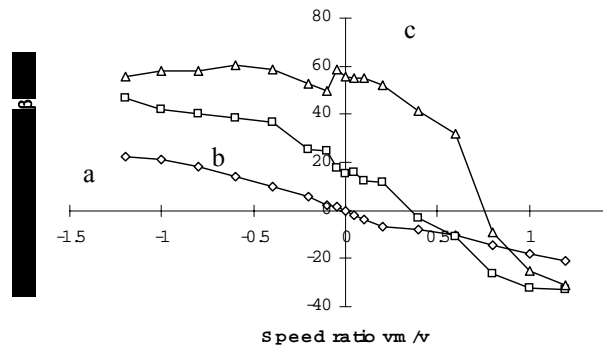


Fig. 2 Influence of the rotary motion on the absolute flow angle β_c (a - $\lambda_T=15^\circ$, b - $\lambda_T=0^\circ$, c - $\lambda_T=45^\circ$)

In order to avoid interference with the natural friction condition on the tool rake face dry machining has been used for all the experimental runs. During the tests, the cutting forces have been measured using a Kistler dynamometer (fig. 1). The chip dimensions were measured using a thickness measuring apparatus Hoepler Oditest (0,01mm resolution) and the chip flowing angle was investigated via photographic technique. The preliminary experimental runs proved that the cutting speed having values between 0.125 m/min and 10 m/min do not affect considerably the chip formation in comparison with the rotary movement speed that has the main effect on chip formation. The following simplifying consideration has been adopted:

- Chip section was considered rectangular;
- Variation of edge inclination angle λ_T has been neglected;
- Cutting forces have been considered oriented as in a conventional oblique cutting: F_p – the principal component, F_l – the lateral component and F_p the passive component.

3. Chip forms

During the experimental runs the following observations has been recorded:

- When the ratio v_m/v had values approximately equal with $\sin\lambda$, the chip section was almost triangle like the chip sections obtained when machining with self propelled rotary cutting tools;
- When the speed ratio has been increased, the rake face tends to move the chip producing an increase in the chip flow angle. The value of the chip flow angle remains between 40° - 50° and the sign has been adopted as the sign for v_m taking in account the direction of rotary movement;
- When the speed ratio was high enough the slip between the chip and the rake face increased so the floe angle decreased. This has been also visualized by measuring the pitch of the chip helix, because this was mainly the chip type produced.

4. Components of the cutting forces

In figures, 3 and 4 examples of the force components variation with the speed ratio are presented. Analyzing these diagrams one can observe that:

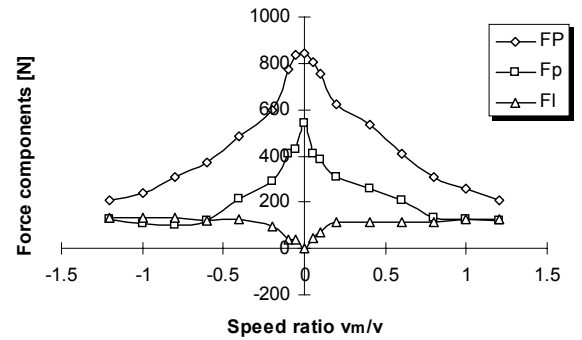


Fig. 3 Force components versus speed ratio v_m/v ($\gamma_n=10^\circ$, $\lambda_T=0^\circ$, $a_1=0,1$ mm, $b=4$ mm)

- There is a continuous decrease in the level of the cutting components F_p and F_r with the increasing of v_m neither the less of the direction of rotary movement;
- In the region where v_m/v approaches $\sin\lambda_T$ there are local disturbances in the variation of the cutting components;
- The value of the normal rake angle do not affect the trend of the variation of cutting components

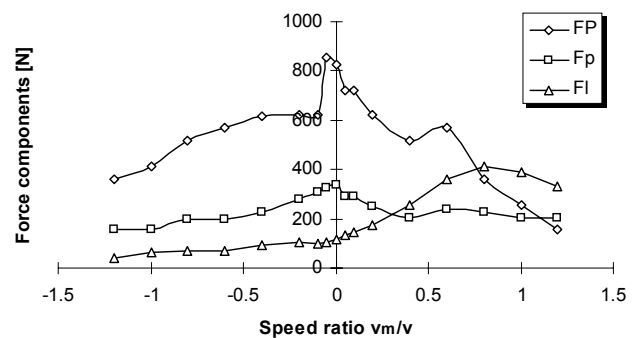


Fig. 4 Force components versus speed ratio v_m/v ($\gamma_n=10^\circ$, $\lambda_T=45^\circ$, $a_1=0,1$ mm, $b=4$ mm)

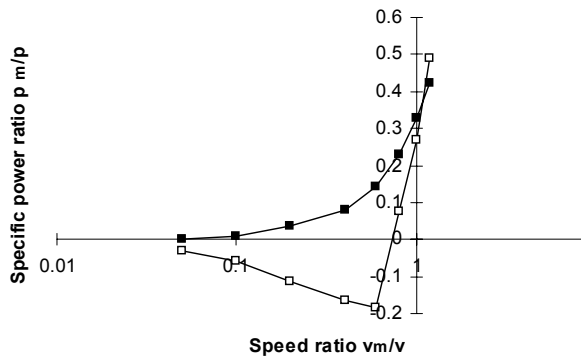
5. Aspects regarding energy consumption due the supplementary rotary movement of the cutting edge

The variation of calculated specific power (in respect with the cross section of the uncut chip) versus the speed ratio revealed that:

- The specific power decreases when the rotary movement is performed in the natural direction even

after the value favorable for self-propelling the rotary tool is achieved. The same trend was observed when the movement had a negative direction;

- When rotary movement was present the specific power was 40 ...70% lower than in case of stationary tool;
- The specific power is not considerably affected by the inclination angle λ_T which instead influences considerably the cutting components;
- The specific power decreases with the increase of the rake angle, but this is not as remarkable as in case of stationary tools.



In figure 5, the ratio between the specific power used for driving the rotary tool and the total specific power is presented. One can observe that under the limit of the value favorable for self-propelling ($v_m/v = \sin \lambda_T$) the driving of the tool has the characteristics of a brake (p_m being negative) and conducting to instability of the process.

When the speed ratio is higher than this particular value, the amount of energy introduced in the cutting zone will be increased and also the influence on chip formation. In the case of rotary cutting with driven rotary tools (DRT) when $v_m/v = 1$ then the driven power for the tool makes about 30% of the specific power consumed in the process.

6. Friction coefficient between the chip and the tool rake face

In figure 6, the values of the calculated friction coefficients are displayed. One can observe as the main characteristic that the values are lower than those produced with stationary tools ($v_m=0$).

The minimum values correspond to the region favorable for self-propelling of the rotary tool confirming that in this case the minimum friction between chip and tool is produced.

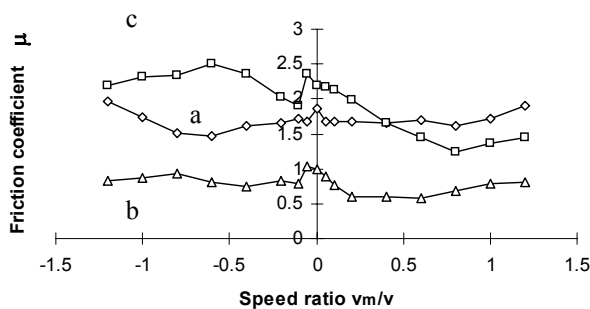


Fig. 6 Calculated friction coefficients μ versus speed ratio v_m/v (a - $\lambda_T = 0^\circ$, b - $\lambda_T = 15^\circ$, c - $\lambda_T = 45^\circ$)

7. Cutting with high rotary speed

When the rotary movement of the tool is produced with very high rotary speeds, the following observation has been achieved:

- The components of the resultant cutting force continue to decrease but not very spectacular (fig. 7). Other researches are need to investigate the actual causes: the rotary movement, the deformation speed or the influence of cutting temperature;

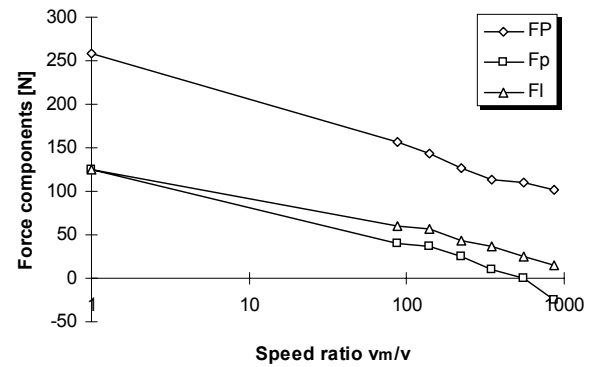


Fig. 7 Force components versus speed ratio v_m/v ($\gamma_n = 10^\circ$, $\lambda_T = 0^\circ$)

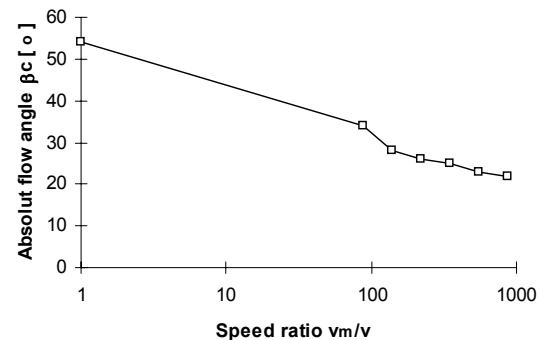


Fig. 8 Flow angle β_c versus speed ratio v_m/v

The chip flow is unable to follow the moving rake face so there is an increase in the slip of the chip upon the tool directly influenced by the value of the rotary speed v_m . This is why the chip flow angle does not increase dramatically but contrary decreases to values of 20° - 25° (fig. 8).

8. Conclusions

Due to the experimental program, some interesting aspects of rotary machining have been revealed. The main aspects investigated were the influence of rotary movement and its speed v_m on chip formation, on cutting components and on the consumed specific power. The results indicates that this unconventional machining procedure can be attractive for practical applications as machining of continuous surfaces on workpieces made from difficult to machine materials, performing increased tool lives and low energy consumptions.

9. Literature

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