

I. Sztankovics, Miskolc, Hungary

COMPONENTS OF THE CUTTING FORCE AND THEIR SPECIFIC VALUES AT DIFFERENT FEEDS IN ROTATIONAL TURNING

Abstract. The alteration of the cutting force is studied by the increase of the feed in rotational turning. The time course of the cutting force components is analysed by experiments done with different edge-geometrical tools, and the specific cutting forces are calculated. One of the findings is the possibility to effectively lower the passive force acting on the cutting tool by the application of rotational turning.

Keywords: cutting force; rotational turning; feed; passive force; axial load.

4. INTRODUCTION

The different applied relative motions and edge geometries of the cutting tools significantly alter the values and ratios of the cutting force and its components. An edge with helical geometry and a tangential circular feed are applied in rotational turning [1], with the geometrical and kinematical relations shown in Figure 1 (n_t : revolutions per minute of the tool; n_w : revolutions per minute of the workpiece; v_a : additional axial feed rate; r_t : radius of the helical cutting edge; λ_s : inclination angle; r_w : radius of the machined surface; R_w : radius of the to be machined surface; a_p : depth of cut; a_w : distance of the symmetry axes).

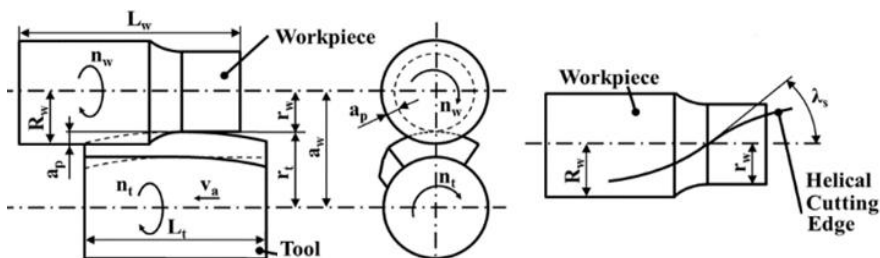


Figure 1 – Geometrical and kinematical relations of rotational turning

In the research of cutting forces the analysis of their specific values is appropriate. Karpuschewski et al. [2] showed that the alteration of the chip ratio by the application of high-feed is a possibility to lower the specific cutting force. Kundrák et al. revealed in their experimental work [3] that the ratio of the force components also varies by the alteration of the feed among the decrease of

the cutting edge specific load. Among the different cutting force components, the tangential component is dominant, according to Denkena et al. [4]. In the work of Tarag et al. [5] we can see that we can achieve stable chip removal by the increase of the feed (among others) due to the decrease of the specific cutting forces and the alteration of the cutting force angle. It can be seen that the value of the feed plays a significant role from the viewpoint of the cutting force. Therefore, the aim of my experiments is to study the specific cutting forces during the increase of the feed in turning with different cutting conditions (rotational and longitudinal turning).

5. EXPERIMENTAL CONDITIONS

The aim of my experiments was the measurement and analysis of the cutting force during chip removal by rotational turning.

The characteristic movement conditions of the procedure are realised on a Perfect-Jet MCV-M8 machining centre during the experiments. The experimental workpiece was clamped in the spindle of the milling machine, whose rotation assured the typical rotational movement of turning. The cutting tool is fixed in the force measurement device (Kistler 9257A) which was clamped on the machine table. The interpolated circular motion of the cutting tool with the machine table realised the relative circular feed around the workpiece. I chose a normalized C45 steel grade with a cylindrical surface of Ø40 mm diameter and 12 mm length. Two rotational turning tools were applied with different inclination angles: R1 – $\lambda_s = 30^\circ$ (Fraisa P5300682) and R2 – $\lambda_s = 45^\circ$ (Sandvik Coromant 1P341-1600-XB 1630). For the comparison of the measured values a standard turning tool (S) was also applied (CNMG 120412-PM insert in DCLNL 2525 M 12 holder). I carried out the experiments with 200 m/min cutting speed, 0.1 mm depth of cut and six values of feed for each cutting tool ($f = 0.1$ mm, 0.2 mm, 0.4 mm, 0.6 mm, 0.8 mm, 1.0 mm).

6. EXPERIMENTAL RESULTS

The X, Y and Z directional forces (linked to the machine table) are measured by the device at a 1000 Hz sampling rate. From the measured values and the momentary position of the workpiece-tool, I calculated for each case the main cutting force (F_c), passive force (F_p) and feed directional force (F_f) in the coordinate system linked to the rotating workpiece. From the completed results of the three cutting tools Figure 2 shows the diagrams of the R1 tool. I also determined the maximal values for the 18 experimental setups (Table 1).

Table 1 – Maximal values of F_c , F_p and F_f

f [mm]		0.1	0.2	0.4	0.6	0.8	1
F_c [N]	R1	51.63	82.50	136.49	180.23	204.30	276.17
	R2	56.06	78.80	130.43	182.38	228.27	268.85
	S	55.56	82.13	130.09	178.06	230.90	280.72
F_p [N]	R1	33.17	49.97	74.83	96.29	102.17	145.16
	R2	36.39	48.84	72.18	90.86	107.26	127.34
	S	73.60	93.60	130.82	171.80	212.16	251.97
F_f [N]	R1	13.52	21.28	38.62	53.15	59.51	83.93
	R2	21.67	30.93	53.53	74.96	96.36	114.84
	S	11.61	8.25	17.84	24.29	25.01	27.69

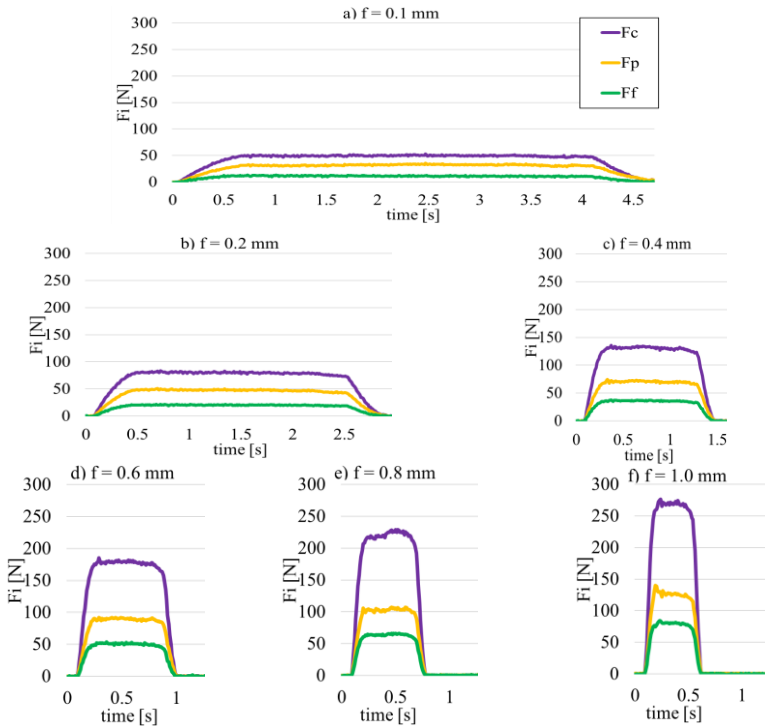


Figure 2 – Cutting force measurements during machining with R1 tool ($\lambda_s = 30^\circ$)

7. DISCUSSION

Several conclusions can be drawn from the force measurement results in Figure 2. In the experiments with different feeds the highest force component was the main cutting force (F_c), which was followed by the passive force (F_p) and feed directional force (F_f). The constant section of the cutting forces shows the removal of constant cross-sectional area of the chip (A_c), where the rotational turning shows traditional turning-like characteristics. The run-in and run-out phases [6] can be seen clearly in the figures, which is specified by the increase and decrease of each cutting force component. These sections have a significantly longer part than in traditional turning due to the high inclination angle of the helical cutting edge. For the cases in Figure 2.a-b the passive force is nearly 60%, the feed directional force is nearly 25% of the main cutting force. For the cases in Figure 2.d-f (where the feed was much higher) the F_p is nearly 50%, the F_f is nearly 30% of F_c . Therefore, I conclude that the ratio of the cutting force components alters with the increase of the feed, and moreover with the direction of the resultant cutting force. From the values of Table 1 the specific cutting forces (k_i) of F_c , F_p and F_f were also calculated according to Equation 1. The calculation results are shown in Table 2.

$$F_i = k_i \cdot A_c \rightarrow k_i = F_i / A_c \quad (i = c, p, f \ ; A_c = a \cdot f) \quad (1)$$

Table 2 – Values of the specific cutting forces

f [mm]		0.1	0.2	0.4	0.6	0.8	1
k_c [N/mm ²]	R1	5163.36	4124.76	3412.35	3003.83	2553.77	2761.74
	R2	5605.99	3940.18	3260.72	3039.72	2853.43	2688.51
	S	5556.39	4106.48	3252.35	2967.67	2886.28	2807.17
k_p [N/mm ²]	R1	3316.67	2498.67	1870.78	1604.87	1277.17	1451.63
	R2	3639.15	2442.00	1804.48	1514.27	1340.72	1273.39
	S	7359.85	4680.19	3270.60	2863.32	2651.95	2519.72
k_f [N/mm ²]	R1	1352.19	1063.82	965.56	885.80	743.90	839.28
	R2	2166.64	1546.47	1338.32	1249.27	1204.45	1148.43
	S	1161.45	412.38	445.96	404.75	312.64	276.88

It can be seen in Figure 3 that I obtained nearly the same specific main cutting forces (k_c) with the three cutting tools in different feeds. Also, the load on the specific cross section decreases with the increase of the feed due to the increase in

the chip height. The load reduction is higher in low feeds (0.1 mm-0.4 mm) than in high feeds (0.6 mm – 1.0 mm). Figure 4 shows the specific values of the passive force, which decreases with the feed increasement, similarly to the k_c . The k_p values become nearly constant after reaching 0.4 mm feed. The specific load of the traditional turning tool (S) was nearly twice as that as of the machining with rotational tools (R1, R2). Thus, I can conclude that the shape error can be lowered by the application of rotational turning, due to the decrease in the radial force. The lowest values of the specific feed-directional force were yielded with S, while the highest values were obtained with R2. The k_f can be considered constant after 0.2 feed.

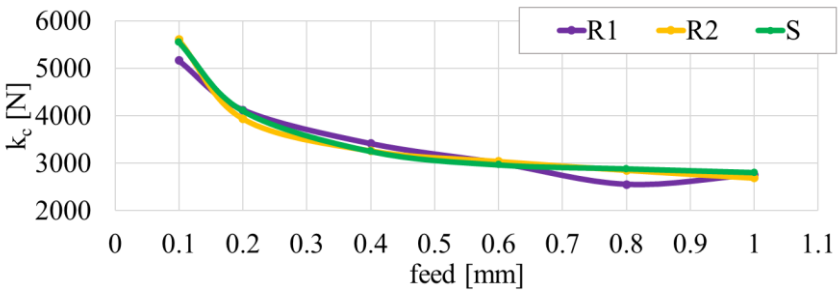


Figure 3 – Alteration of the specific main cutting force

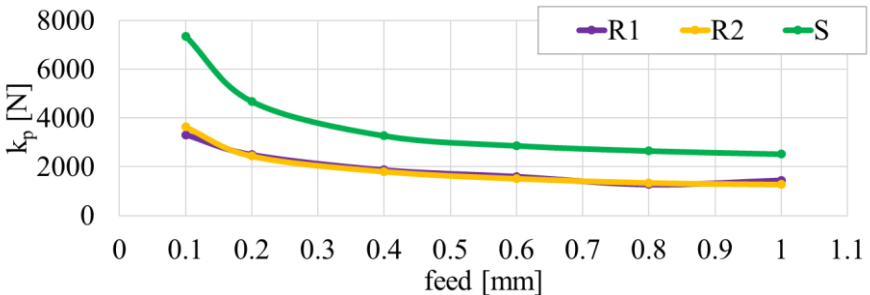


Figure 4 – Alteration of the specific passive force

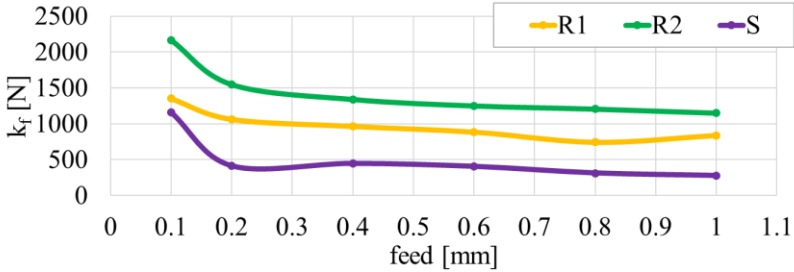


Figure 5 – Alteration of the specific feed-directional force

SUMMARY

The effect of the feed rate on the specific cutting forces was analysed in different turning procedures during experiments. I carried out the experiments at 6 feeds with 2 rotational turning tools with different inclination angles and 1 traditional turning tool. Calculation of the specific cutting forces showed that the specific main cutting force is nearly the same in rotational and traditional turning. However, the specific passive forces are significantly lower in the rotational procedure (nearly half as much as the traditional), while higher values were found during rotational turning (2-4-fold increase) for the specific feed-directional forces than the results of traditional turning. Accordingly, with the same cutting power requirement the force trying to move a workpiece away from a tool will be lower and the axial load on the spindle and tool holder will be higher in rotational turning than in traditional procedure. Hence, we can expect a decrease in workpiece-deflection related errors because the elastic deformation of the dynamical system will be lower. The different axial force must be taken into account during the construction or selection of the tool holder.

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Іштван Станкович, Мішкольц, Угорщина

КОМПОНЕНТИ СИЛИ РІЗАННЯ І ЇХ ПИТОМІ ЗНАЧЕННЯ ПРИ РІЗНИХ ПОДАЧАХ В УМОВАХ РОТАЦІЙНОГО ТОЧІННЯ

Анотація. У статті досліджується зміна сили різання при збільшенні подачі в процесі ротаційного точіння. Динаміка зміни складових сили різання аналізується за допомогою експериментів, проведених різними інструментами з різною геометрією різальних крайок і розраховуються питомі сили різання. Одним з відкриттів є можливість ефективного зниження пасивної сили, що діє на ріжучий інструмент, за допомогою ротаційного точіння. В ході експериментів на обробному центрі Perfect-Jet MCV-M8 були реалізовані характерні для даного процесу руху. Експериментальна заготовка зажималась в шпинделі фрезерного верстата, обертання якого забезпечувало типове обертальний рух токарного оброблення. Ріжучий інструмент був закріплений в пристрої вимірювання сили (Kistler 9257A), яке розміщувалося на столі верстата. Інтерпольований круговий рух ріжучого інструменту зі столом верстата забезпечувало відносну кругову подачу навколо заготовки. В експериментах з різними подачами найвищої складової сили була основна сила різання (F_c), за якою слідували пасивна сила (F_p) і спрямована сила подачі (F_f). Розрахунок питомих сил різання показав, що питомі основні сили різання майже однакові при ротаційному і традиційному точенні. Однак питомі пасивні сили значно нижче при ротаційній процедурі (майже вдвічі менше, ніж при традиційній), в той час як при ротаційному точінні були виявлені більш високі значення (збільшення в 2-4 рази) для питомих сил напрямку подачі, ніж при традиційній токарній обробці. Відповідно, при однакових вимогах до потужності різання зусилля, що намагається відсунути заготовку від інструменту, буде нижче, а осьова навантаження на шпиндель і державка інструменту буде вище при обертанні, ніж при традиційній процедурі. Отже, можна очікувати зменшення помилок, пов'язаних з прогином деталі, оскільки пружна деформація динамічної системи буде менше. Різна осьове зусилля необхідно враховувати при виготовленні або виборі держателя інструменту.

Ключові слова: сила різання; ротаційне точіння; подача; пасивна складова сили різання; осьове зусилля.