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AN EXPERIMENTAL STUDY OF THE CUTTING FORCES IN THE METAL CUTTING PROCESS

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Abstract: *From the invention of turning machine some engineers are trying to increase the turning productivity. The increase of productivity is following after the breakout in instrumental area, such as the hard alloy instrument and resistance to wear cutting surfaces. The potential of cutting speed has a certain limit. New steel types and cutting tool surfaces types allows significantly increase cutting and turning speeds, but with this increase from the recommended by 20 % the solidity of the instrument decreases by 50 %. For the most operation types the productivity increase begins from the feeding increase. On the average feeding increase by 20 %, the self cost decreases by 15 % when manufacturing the detail in large numbers.*

Key words: Key words: Metal cutting, cutting forces, FEM analysis.

1. INTRODUCTION

From the invention of turning machine some engineers are trying to increase the turning productivity. The increase of productivity is following after the breakout in instrumental area, such as the hard alloy instrument and resistance to wear cutting surfaces [1]. The potential of cutting speed has a certain limit. New steel marks and cutting surfaces types allows significantly increase cutting and turning speeds, but with this increase from the recommended by 20 % the solidity of the instrument decreases by 50 %. For the most operation types the productivity increase begins from the feeding increase. On the average feeding increase by 20 %, the self cost decreases by 15 % when manufacturing the detail in large numbers [2, 3]. Turning with high feeding (or high feed turning), is one of the most actual problems in the increasing of manufacturing volume but there are some problems one of them is the cutting forces increasement and larger metal removal rate, which decrease the cutting tool life significantly. Increasing of manufacturing volume, going together with the cutting instrument technology and material evolution, such as the invention of the carbide cutting materials and wear resistant coatings such as TiC and Ti(C,N) (Figure 1 a, b). Each of these coating has its own properties and functions in the metal cutting process (Figure 2). Together with this evolution of the cutting tool geometry and machining parameters dependencies are researched. Traditionally for the decreasing the machining time of one part, the cutting depth was increased, decreasing by this way the machining procession. Nowadays the wear resistance of the cutting tools increasing and it is mostly used one or two machining operations (medium and fine finishing). Another way to increase the productivity is the increasing of cutting speed. However the potential is not endless. New cutting tool materials allow us to increase the cutting speed by 20%, but the cutting tool stiffness will decrease by 50 %. The cutting process involves the removal of metal in the form of chips from the workpiece by the action of the cutting tool, which later is coupled to the machine structure through different elastic elements. Normally, any small vibration caused by occasional disturbances, such as inhomogeneity of the work material and the runout and misalignment of the workpiece, would be damped out by the structure of the cutting system. Sometimes, however, the disturbances are maintained and the system becomes unstable, so that the relative periodic displacement between the tool and the workpiece may build up to large amplitude. This relative periodic motion between the cutting tool and the workpiece is known as chatter. This chatter depends on the cutting forces in the cutting process. The forces acting on the tool are an important aspect of machining. For those concerned with the manufacture of machine tools, knowledge of the forces is needed for estimation of power requirements and for the design of machine tool elements, toolholders and fixtures, adequately rigid and are free from vibration. Cutting forces vary with the tool angles, and accurate measurement of forces is helpful in optimizing tool design and predicting tool life. Scientific analysis of metal cutting also requires knowledge of the forces, and in the last hundred years, many force measurement devices, known as dynamometers, have been developed, capable of measuring tool forces with increasing accuracy. Early methods were based on strain-gage measurement of the elastic deflection of the tool under load. Today, one of the most commonly used dynamometers is aforce-platform piezo-electric load cells. For a semi-orthogonal cutting operation in lathe turning, the force components can be measured in three directions, and the force relationships are relatively simple [4,5,6,7].

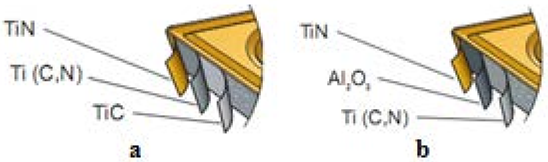


Fig. 1. Turning insert coating combinations

2. METAL CUTTING PROCESS AND CUTTING TOOL DESCRIPTION

In metal cutting the force component is acting on the tool in the direction OX, parallel with the direction of feed, is referred to as the feed force, Ff. This force acts tangential to the main cutting forces Fc. To maintain consistency within all machining processes the symbol for this tangential force is frequently written as Ft rather than Ff. The third component, acting in the direction OZ, tending to push the tool away from the work in a radial direction, is the smallest of the force components in semi-orthogonal cutting and, for purposes of analysis of cutting forces in simple turning, it is usually ignored. It is of interest that the forces involved in machining are relatively low compared with those in other metal working operations such as forging. For the experimental study of the cutting forces in the metal cutting on the lathe are chosen two types of stainless steel: 420 and 304, also modern cutting tools from SECO, Sumitomo , Kennametal with CVD and PVD coatings, with different type of the chip-breaker geometry, because the chip forming process is also actual question which is necessary to solve in the middle-finish machining operation, because of high chrome and nickel contents in this machined part, what in fact cause problems of the good chip forming process. (Here will be represented only first variant of the cutting forces experimental study using 420 stainless steel and TM4000-coated cutting insert from SECO). These coatings are high wear-resistant, decrease cutting forces and as a result - vibrations in the cutting process (this process was also widely studied [8]). On the figure 2 is shown the modern cutting tool (the toolholder and the cutting insert) and the scheme of the metal cutting process. Each of the metal cutting operations have different grades- chipbreaker and coating combinations for the each machining operation- rough machining, middle machining and fine finishing machining . Cutting inserts for the middle-finishing operations are also called negative inserts because they are places in the cutting tool under the negative angle (Figure 3). One more important value is the main cutting edge angle „ ϕ ”, which using in different machining operations gives us different values of the cutting forces (Figure 4) [9,10].

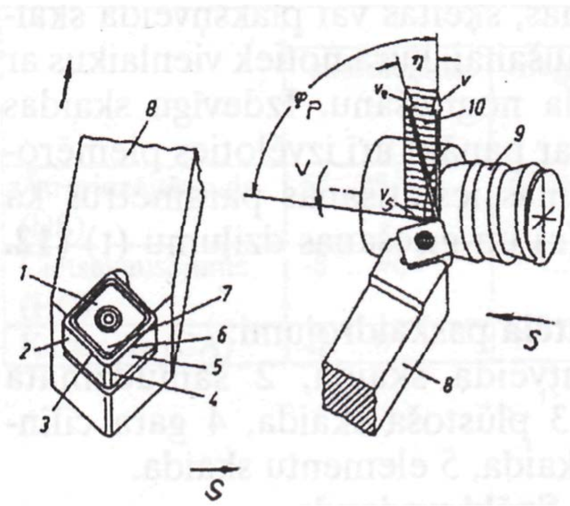


Fig. 2. Cutting tool (1 - cutting insert, 2 – secondary plane, 3 - auxiliary cutting edge, 4 - cutting edge nose, 5 - main back surface, 6 - main cutting edge, 7 - chip breaker, 8 - cutting insert holder, 9- machined part, 10 - work plane, *v* - cutting speed, v_e - effective cutting speed, ϕ_p – feeding movement angle, η - machining speed angle).

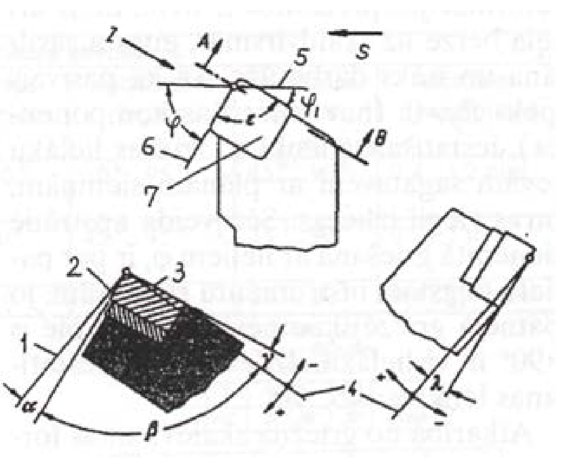


Fig. 3. Negative cutting insert geometry (1- tool cutting edge plane, 2- back plane, 3- chip breaker plane, 5- work plane, 6- cutting edge plane, 7- cutting insert, λ- chip breaker plane, α- back plane angle, β- cutting insert base angle, ϕ- main cutting edge angle, λ- cutting edge angle).

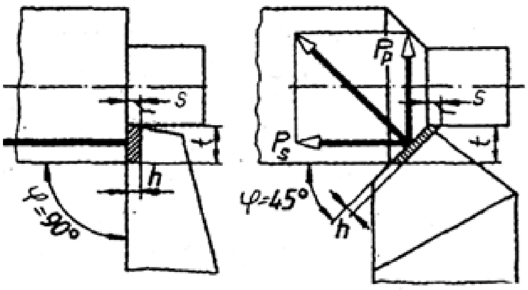


Fig. 4. The dependence of the feeding force P_s and passive force P_p from the the main cutting edge angle ϕ .

3. EXPERIMENTAL PART AND RESULTS

The aim of the experiment is to study the machining parameters, especially cutting force values and machined surface roughness results and also the tool wear. For our tree factor experiment was chosen the 420 stainless steel (12 % Chromium), modern Duratomic coated negative turning insert TNMG 160412-MF4 , TM4000 with cutting edge radius 1,2 mm, lathe 16K20. Experimental machine is shown on figure 5. Machining parameters combinations (table 1) are: feeding - 0,1 mm/Rpm and 0,35 mm/Rpm; cutting depth is 0,5mm; cutting speed 90 m/min., and 112 m/min. The chosen chipbreaker MF4, for medium/finishing turning with TM4000 coating, two holders with cutting angle φ = 90º and φ = 60º. The main advantage of the MF4 chipbreaker is that the open and highly positive design (up to 25° rake angle) reduces cutting forces. This, in turn gives: low cutting forces - higher cutting speed; increased speed capability - higher productivity; traditional medium - finishing inserts perform well at ordinary speeds, but fail early when the speed is increased. During metal cutting on the lathe three cutting forces take place in this progress. They may vary with tool angles, feed and cutting speed. Figure 6 shows us the component of the force acting in the rake face of the tool, normal to cutting edge, in the direction OY is so called the cutting force Fc (P_p). This is usually the largest component, and acts at the direction of cutting velocity. The force component acting in the tool in the direction OX, parallel with the direction of feed, is referred to as the feed force Ff (P_S).The third component, acting in OZ direction (P_c), pushes the cutting tool away from the work in the radial direction. This is the smallest of the force components. Cutting forces in metal cutting is one of the most actual problems, especially in dry (without cooling) machining process. To study this process we are using dynamometer UDM-600 and computer FEM analysis. The result of the measured cutting force P_z is shown on the figure 7. Measured mean values of the surface roughness results are shown in the table 2 and best surface roughness result diagram (Fig.8). In our days the computer modelling programs which use Finite Element Method (FEM) analysis, such as ABAQUS, Third Wave Advantage can solve this problem. What in fact was done in cooperation with Helsinki University of technology [11]. The computer modelling metal cutting parameters combination are the same as in the table 1, FEM cutting forces graphics are shown on the figure 9.

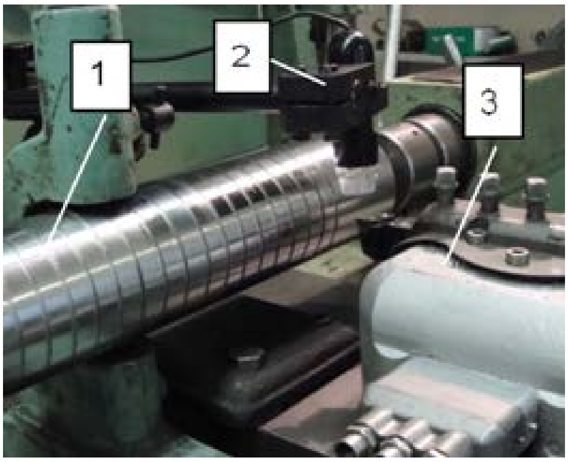


Fig.5 Experimental scheme: 1- machined part; 2 – digital microscope; 3 – UDM – 600 dynamometer

Parameter comb. Nr.	**1**	**2**	**3**	**4**
Feeding, mm/Rpm	0,1	0,35	0,1	0,35
Cutting depth, mm	0,5	0,5	0,5	0,5
Cutting speed, m/min	90	90	112	112
Cutting edge angle	60°	60°	60°	60°
Parameter comb. Nr.	**5**	**6**	**7**	**8**
Feeding, mm/Rpm	0,1	0,35	0,1	0,35
Cutting depth, mm	0,5	0,5	0,5	0,5
Cutting speed, m/min	90	90	112	112
Cutting edge angle	90°	90°	90°	90°

Table 1. Machining process parameters

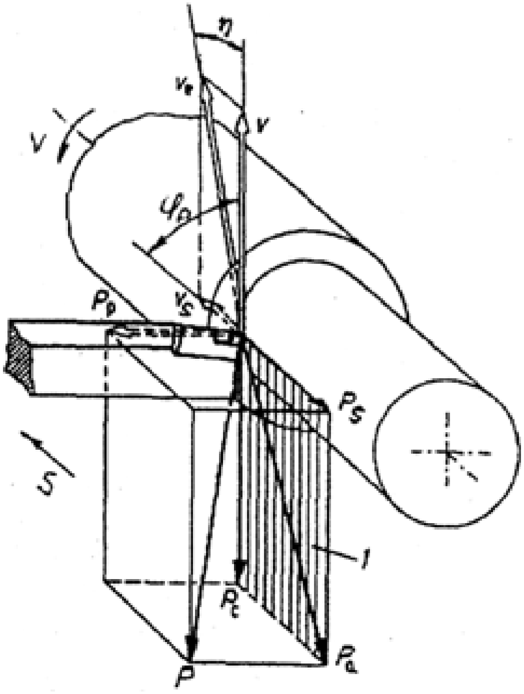


Fig. 6. Cutting forces in the metal cutting process

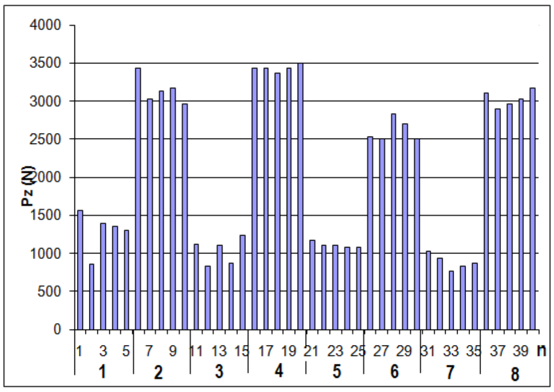


Fig. 7. The result of measured cutting force P_z during the experiment

Machining block number	Ra, µm	Rt, µm	Hardness, HB
1	5,92	44,82	262
2	4,57	29,41	275
3	5,04	39	272
4	5,72	40,88	264
5	5,56	47,2	250
6	3,46	21,55	273
7	5,4	41,7	277
8	3,68	35,4	278

Table 2. Machined surface results

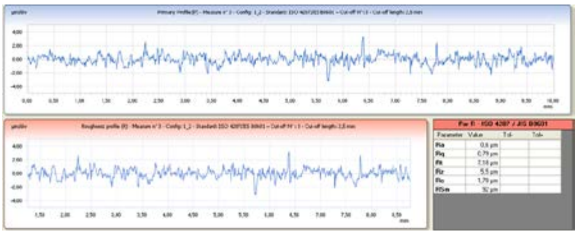
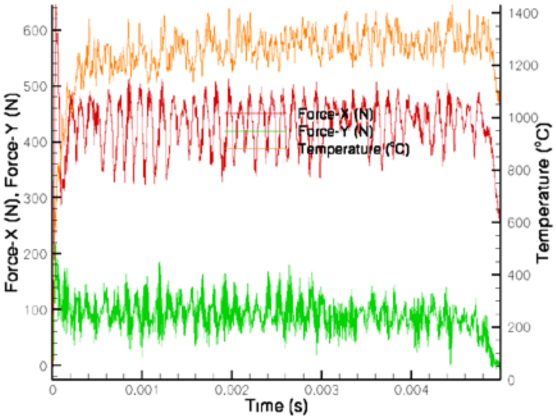


Fig.8. Best surface roughness result diagram.



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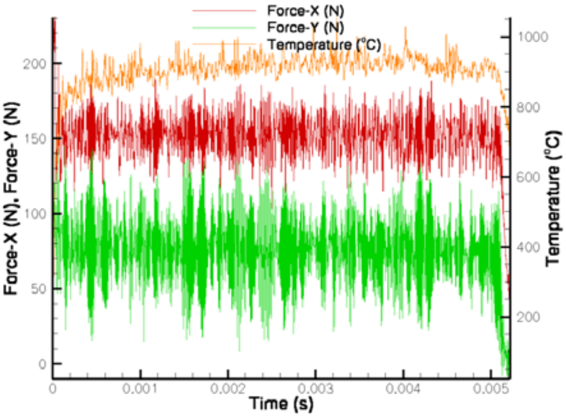

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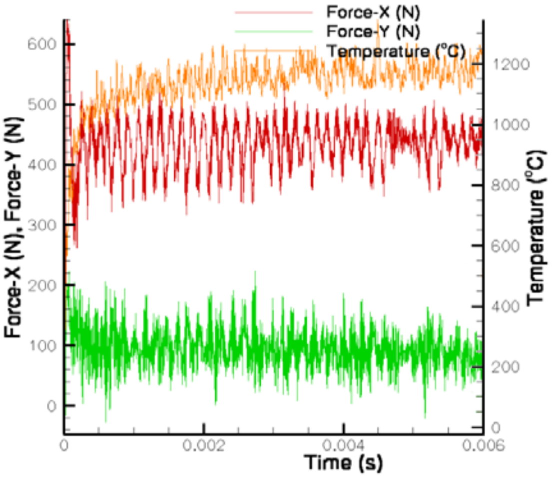

c

Fig. 9. Metal cutting forces values results using FEM modelling

5. CONCLUSIONS

The experimental results show how machining parameters and technological regimes combinations change machined surface results.

Main conclusion is that in order to obtain better result it is necessary to change the cutting edge angle. However it is not so handy when the different profile surfaces are machined.

In the same time increased cutting speed and decreased feeding are not so important factors because they do not effect seriously machined surface result.

This cutting tool was produced dirrectly for the machining of the stainless steel and in the rezult we did not see any tool wear.

6. ACKNOWLEDGEMENT

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