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MACHINING OF HARD STEEL ALLOYS WITH NEW PROTOYPES OF CUTTING TOOLS

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Abstract: *This paper presents a comparison between market accessible milling tools and milling tools from a new producer. Cutting into hard material (60 < HRC < 64) requires good, reliable and long life existence of the cutting tool. Cutting of deep pockets represents a difficult challenge – maximum life existence of the cutting tools and also a good end finishing quality has to be assured. Because the market producers can not produce the required tools in a decent time, the producer decided to manufacture his own tools, specially adapted to each and every work piece (length, width, depth of cut, number of teeth…). This paper presents an analysis of cutting forces in hard machining in the same material with the same machining parameters with different prototypes of cutting tools. At the end a comparison of the forces, the tool wear and the surface quality is given.*
Key words: *Milling, hard steel, cutting tools, cutting force*

1. INTRODUCTION

Nowadays there are plenty of manufacturers which develop and produce cutting tools. Their tools are unique, each with its geometry settings and material. The manufacturers don't always give the cutting data recommendation. Usually incomplete data is given with which the desired NC program can not be carried out. When the cutting tools are put into operation and the cutting parameters are wrong, almost immediately the consequences are seen and heard. Either the machine centre is vibrating or making some noise. The cutting parameters need to be changed immediately or the tool will suffer severe damage.

In our tests, one end user of cutting tools decided to try out his own constructed and produced tools, prototypes, and compare them with the market tools. The machining parameters were taken from existing market tools. All other tools were tested with the same parameters into the same work piece material.

Tree different milling tools, prototypes were made and prepared for tests. Two are ball nose end mills and one is a regular end mill. All tools are brand new (not yet used). The diameter of the cutting tools is always the same, 16 mm.

The material for the work piece is a hard steel alloy (designation 1.2379 - OCR) and a grey alloy (designation GGG 70). An NC program is written for 2D and a 3D machining. To determine which tool is in certain cutting conditions the best choice, the decision was made to measure:

- cutting forces,
- surface roughness of the end product.

On behalf of these gathered data, the end results will be given and evaluated. At the end, a recommendation for further work will be given.

Table 1 shows the cutting parameters for ball nose end mill tools (3D). Table 2 shows the cutting parameters for end mills (2D). Only these parameters were used in the tests.

Tests were carried out to determine the machining quality, the tool quality and the economical justification of self developed cutting tools.

Number of revelations per minute	Depth of cut (a_p) [mm]	Feed rate (f) [mm]
3000	0,3	800
3000	0,3	1000
3000	0,3	1500
3000	0,3	2000
3600	0,3	2000
3600	0,5	2000
4000	0,5	2000
4000	1	2000
4500*	1*	2000*

Tab. 1. Cutting parameters for 3D path

Number of revelations per minute	Depth of cut (a_p) [mm]	Feed rate (f) [mm]
2000	0,4	50
2000	0,5	50
2000	0,75	50
2000	0,75	100
2000	1,5	100
1300*	2*	75*

* The last row represents the cutting recommendations from the manufacturer.

Tab. 2. Cutting parameters for 2D path

2. PROBLEM DEFINITION

Market available tools are affordable but their range of use is too wide. For certain problems in machining, specially developed tools are needed. For milling into hard materials (HRC>60), the protective cutting coat has to be wear resistant and must have a longer life span. There has been a lot of work done on optimizing cutting parameters (Milfelner et al. 2006, Totis et al. 2010), measuring forces and suggestions for general improvements of cutting conditions (Wardany et al. 2000, Liu & Mittal 1996). But in real situations, real, experimental data is needed to evaluate the cutting tool and the cutting conditions (Kopac 2004). Because the production of transfer and progressive tools is in small series, sometimes unique, the test can not be accomplished on real work pieces. That is why the decision was mad, to construct a model of cutting paths, which were then tested.

To determine the quality of a cutting tool, two parameters were chosen to be monitored, cutting forces and in the end the surface roughness of the finished part.

Tests were carried out with 3D as well as 2D milling tolls to determine the quality of the new prototypes.

3. PREPARATIONS

The tools used are market available milling tools and selfdeveloped tools which were made on a 5 – axis grinding machine and afterwards coated with a wear resistant coating. The parameters used in the milling process were chosen from the manufacturer tools data sheet. Table 1 and table 2 are showing which parameters were changed during the process. The NC program was always finished, meaning that all the work pieces were machined in the same way and the same depth.

The measurements were always taken at the same spot as the previous one in consequence a direct comparison of the forces acting on the work piece and cutting tool is made.

All together 11 cutting tools were tested and two work piece materials. Five milling tools were end mills and six were ball end nose mills.

For one whole machining cycle the 3D program ran approximately 3000 s (50 min), the 2D program ran approximately 1500 s (25 min).

The cooling of the work piece and cutting tool was only with air (also needed to remove the cut off material).

4. TESTING

Figure 1 shows the work piece during machining and the cutting forces at that time.

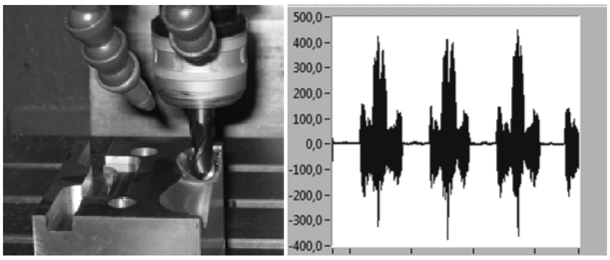

Fig. 1. Work piece fixed on the machine working table

The work piece was positioned on the middle of the working table of the machine. On top and the bottom of the work piece, two counterbore holes were drilled to screw the work piece firmly to the dynamometer. From figure 1 we can see how the whole work piece looks.

For tests, we implemented only a part of the whole geometry to our work piece. On one side a 2D path was machined and on the other side, a 3D path. In doing so, a lot of space was saved and the work piece was optimized. After machining one side, the work piece was rotated for 180°. This means that one work piece was used for 4 different tools (for two 2D and two 3D paths).

In the end of the test, the surface roughness was also measured.

5. RESULTS

Measured cutting forces are in some cases very high. This is especially noticeable at the 2D path testing for manufacturer (man.) 1, first tool. The value for maximum force climbs to 3522 N but the tool did not fail or break. Nevertheless this tool is inappropriate for use in machining of high strength alloys. The forces are too high and the wear of the tool is also considerable higher than the wear of other tools. High cutting forces can also lead to a catastrophic failure of the cutting tool, damaging work piece and the machine centre. Other tools are better and more suitable for this job. Table 3 – 6 shows the best tool in each category.

Material OCR	3D Tool		
Min. cutting force [N]	Man. 2 second tool **409**	Man. 1 second tool **426**	Man. 2 first tool **524**
Min. surface roughness [mm]	K88UF **1.499**	Man. 1 second tool **1.549**	Man. 2 first tool **1.837**

Tab. 3. Results for 3D – OCR material

Material GGG	3D Tool		
Min. cutting force [N]	Man. 1 second tool **347**	Man. 2 second tool **407**	K88UF **433**
Min. surface roughness [mm]	Man. 1 second tool **1.367**	K88UF **1.522**	Man. 2 first tool **1.573**

Tab. 4. Results for 3D – GGG material

Material OCR	2D Tool		
Min. cutting force [N]	Man. 2 first tool **565**	Man. 2 second tool **774**	Man. 1 second tool **860**
Min. surface roughness [mm]	Man. 2 first tool **0.64**	Man. 2 second tool **0.712**	SK 41 **0.921**

Tab. 5. Results for 2D – OCR material

Material GGG	2D Tool		
Min. cutting force [N]	Man. 2 first tool **559**	Man. 2 second tool **656**	Man. 1 second tool **814**
Min. surface roughness [mm]	Man. 1 first tool **1.193**	SK 41 **1.425**	Man. 2 second tool **1.6**

Tab. 6. Results for 2D – GGG material

In consequence, the higher the cutting forces, the higher the tool wear. The self developed tools were adequate for 3D machining. For 2D machining the tool was second best at surface roughness but at cutting forces it was on last place.

6. CONCLUSION

The newly developed prototypes for 3D machinig are suited for further work. The prototype for 2D machining needs further modifications. For ongoing tests, we sugest:

- Adapted tool geometry for self developed tools,
- Different machinig paameters,
- Different data acquisition modules.

The developing and production costs are not that much higher from the stock prices so it is recommendable to manufacture own cutting tools.

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