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EXPERIMENTAL ASPECTS REGARDING THE METAL CUTTING TRIBOSYSTEM OF THE BALL NOSE END MILL

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ABSTRACT

Ball nose end mills are highly used for 3-5 axis milling operations. The tribosystem of the ball nose end mill demands a detailed study of its internal processes. The current paper concerns a few aspects regarding tool wear during milling. Some direct and indirect effects of tool wear over machined surface quality and productivity are being assessed. The experiments undertaken offer data regarding tool wear influence over the quality of the machined surface, acoustic emissions and process energy. As a result, conclusions are drawn regarding the cutting strategy used for milling operations with this type of tools and the proper structuring of a tribosystem in its complexity.

KEYWORDS: milling, ball nose end mills, wear.

1. INTRODUCTION

The concept of tribosystem [2, 8, 13] is more and more encountered in the field of metal cutting. The metal cutting tribosystem of ball nose end mills in 3-5 axis manufacturing systems for machining complex surfaces makes no exception.

The tribosystemic approach of metal cutting issues has the advantage of underlining a complex of phenomena and effects, each depending on certain parameters and cutting conditions.

The undertaken experiments are part of a project called *Contributions to the metal cutting tribosystem* and they were conducted in an industrial environment i.e. The Research Center of RAMIRA S.A. Baia Mare, Romania.

All the experiments described in this paper are substantiated on the experimental directions described in ISO 8688-2/1989 [17] concerning end mills.

2. EXPERIMENTAL SETUP

The experiment consisted of two parts. The first part focused on studying the global quality of the machined surface with respect to the tool path strategy.

Similar studies were developed by [3, 5, 7, 15].

The tool path strategy with the most convenient effects regarding the machined surface quality was promoted in the second part of the experiment in order to evaluate the tool wear and the impact it has upon the quality of the machined surface, the acoustic emissions and the amount of electric power consumption. The target of this study was to assess the possibility of tool wear detection using acoustic emissions, to find a possible influence of tool wear over power consumption, as well as to monitor the wear phenomenon while milling flat surfaces with this type of tool in a vertical position.

Hypothesis: The machined surface was chosen to be a flat one because these experiments were aimed at obtaining some data which will be used as a reference for those machining situations when the tool will have a certain inclination with respect to the workpiece's surface. Another reason for machining flat surfaces during testing was that in 3 axis milling there is no possibility for tool inclination when machining complex surfaces. Moreover, during milling operations of such surfaces, the tool reaches points/regions when it is perpendicular to the workpiece's surface.

The cutting was performed on a C45 workpiece Table 1, annealed, according to the recommendations set by ISO 8688-2/1989 Tool life testing in milling [17]. The average hardness of this material was 170HB.

The tools used for these experiments were purchased from SECO TOOLS manufacturer - Table 2.

The insert was selected according to the material to be machined and the type of machining (finishing).

The machine tool was a 5-axis OKUMA MU-400VA with 30kW engine. The following milling conditions were applied: a_a=0,3mm, a_r=0,3mm, Vf=1452mm/min, f_z=0,07mm/tooth, n=10368 rev./min.

Table 1. Chemical composition

C	0,420	**S**	0,009	**Cu**	0,010
Si	0,240	**Al**	0,002	**Ni**	0,015
Mn	0,640	**As**	0,004	**Cr**	0,020
P	0,019	**Ti**	0,003	**Mo**	0,009

Table 2. Tool specifications

Tool Tail Code	MM12-20095.3-3027
Insert Code	MM12-14014-B120PF-M03,F15M D=14mm, 2 flutes
Insert Coating	TiC, TiN and Al_2O_3 Multilayer

For the first part of the experiment the following tool path strategies were chosen – Fig.1 – A – climb milling, B – conventional milling, C – raster milling, D - offset milling.

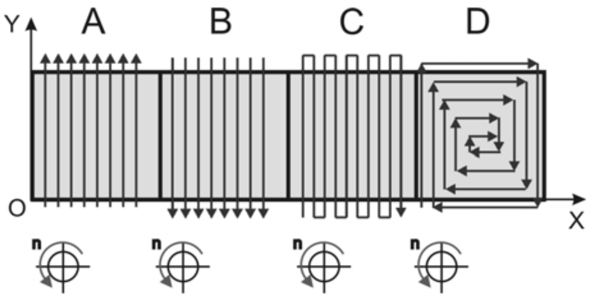

Fig.1. Utilized tool path strategies

A surface area of 564 mm^2 was designated to be machined with each tool path strategy.

The following measurements were taken: the roughness of the machined surface for each tool path strategy, the machining time required for each tool path strategy and the surface quality/texture highlighting the asperities resulted from the cutting and feed movements.

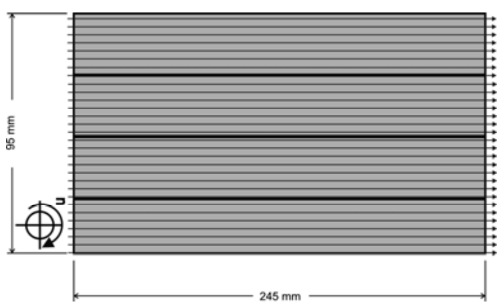

Fig.2. Cutting direction and strategy

For the second part of the experiment the milling operation was performed on a workpiece measuring 95x95x245mm (figure 2), in 15 minute-rounds, a number of 4 rounds being completed until the "cleaning" of the surface with another Ø120 end mill, in order to remove the previously machined surface. This was done before advancing with another stepdown on the Z axis in order not to alter the outcome of the cutting process. The tool life criterion was chosen to be the roughness level, that is, the cutting operation was carried out up to 4 times the initial value of the roughness.

The surface roughness level and the surface profile were monitored by means of a portable TR200 roughness tester made by Micro Photonics Inc. The device used for tool wear assessment was an I.O.R. optical stereoscope, having a 20x-80x magnifying power and a Nikon Coolpix S1 camera. The quality of the surface/surface texture was recorded by means of a digital camera as part of a CV-HB 100-type Brinell hardness testing device supplied by CV Instruments Europe BV, having a magnifying power of 30x. The electrical power consumption was monitored using a FLUKE 435 device. The sound levels were monitored with the help of a Bruel&Kjaer 2250 sound meter, provided with a free-field microphone with 0° angle of incidence. The sound levels were recorded every 15 minutes during cutting, applying a 5-second averaging sample and using the A weighting curve as main and the C weighting curve as a second, the peaks being recorded on the A curve. The emission frequency of the cutting tool was observed, its value being determined by the formula in rel.1.

$$F = \frac{n \cdot z}{60} \qquad (1)$$

where *n* stands for revolutions and *z* stands for the number of flutes. Replacing the values in rel.1 we get rel.2

$$F = \frac{10368 \cdot 2}{60} = 345,6Hz \qquad (2).$$

Experiments were conducted in an environment having a temperature of 20°C and 45,2% humidity and using cutting fluid (Blasocut 2000CF from Blaser Swisslube) for the machining operations.

3. RESULTS AND DISCUSSIONS

Figure 3 represents the measured roughness using the 4 tool path strategies.

Regarding the tool path strategy, it can be seen on the one hand that the most efficient with respect to the machined surface quality is the climb milling (A - strategy) and on the other hand the most undesirable when it comes to surface quality on OX direction (pick feed direction) is the offset milling (D - strategy).

Analyzing the data in table 3 we might also state that one way raster milling (climb – A strategy) is to be used when production is oriented on optimum surface quality. When the main concern is to obtaining the optimum productivity time and then the surface quality, strategy C (raster milling) is recommended.

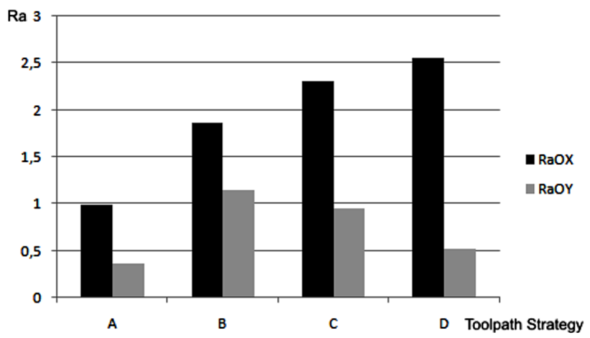

Fig.3 Ra roughness obtained

Table 3. Cutting times

Cutting strategy	A	B	C	D
Cutting time[min]	3:34	3:34	1:21	1:22

Considering the surface profile presented in figure 4 we may conclude that the best surface in terms of uniformity was obtained using the one way raster milling strategy especially when climb milling (Strategy A). This can be observed both on feed direction and also on pick feed direction.

As the aim of these experiments was to study the tool wear with respect to the machined surface quality, the A strategy (climb milling) was chosen for the second part of the experiment.

The variation of roughness using this type of milling with respect to time can be observed in figure 5. It displays an initial leap up to minute 30, followed by a flat zone until minute 75, after which it went up almost exponentially. Up to minute 120 this variation can be said to follow the classical laws regarding tool wear against the cutting length. This variation in the surface quality according to the tool wear can be noticed also in figure 6.

However, the tool life criterion was reached in the 120th minute but the cutting operation was not stopped. It was carried out further, the tool showing a stable cutting behavior, both in what regards the roughness of the machined surface and from the perspective of acoustic emissions and electrical power consumption.

The roughness of the machined surface, rendered by Ra [µm], underwent a 3µm linear variation along 120 minutes, starting from minute 120 until minute 240 (fig.5).

This slow linear variation can also be observed in the photos taken with the surface camera (fig.7).

The sound levels presented in figure 8 also display a similar trend as the one followed by roughness.

These variations in the sound level match – to a great extent – the trend described by [4, 6, 10, 14].

The electrical power consumption recorded does not vary once with the appearance and progress of the wear; it stays constant (1,2kW/1,2kW/1,0kW). The cause of this phenomenon might be, on the one hand the size and mass consequently the momentum of the 5-axis cutting machine used in these experiments, and on the other hand, the cutting conditions specific to finishing, which implies much lower cutting forces in comparison to the process of roughing. It would be necessary to check/test the electrical power consumption of this type of tool on a smaller-size machines and/or using higher sensitivity measuring equipment.

Based on the undertaken analysis, it was observed that while cutting the tool lost gradually its coating, and uniform flank wear showed up on both

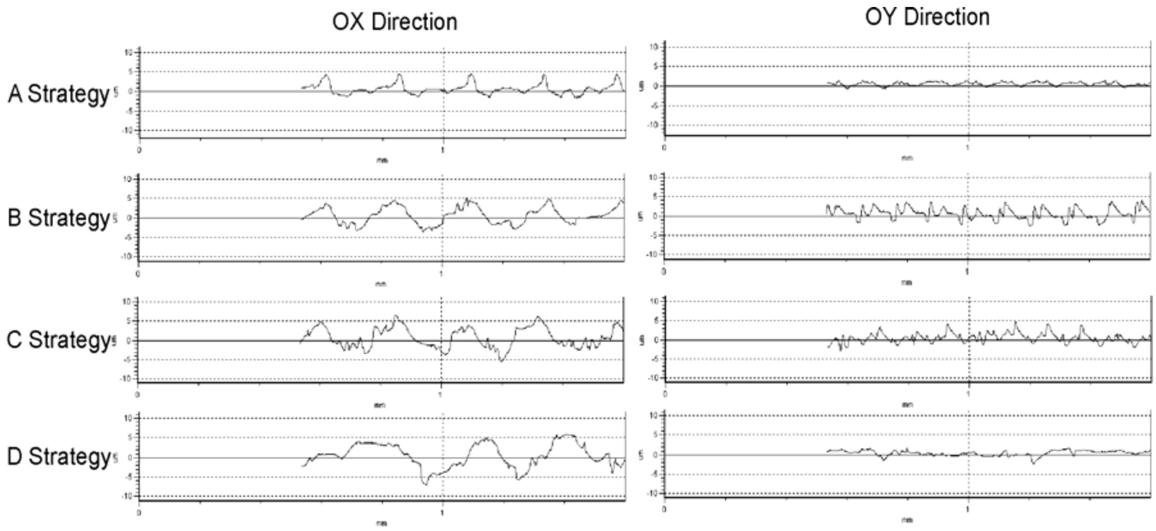

Fig.4. Surface profile for each tool path strategy

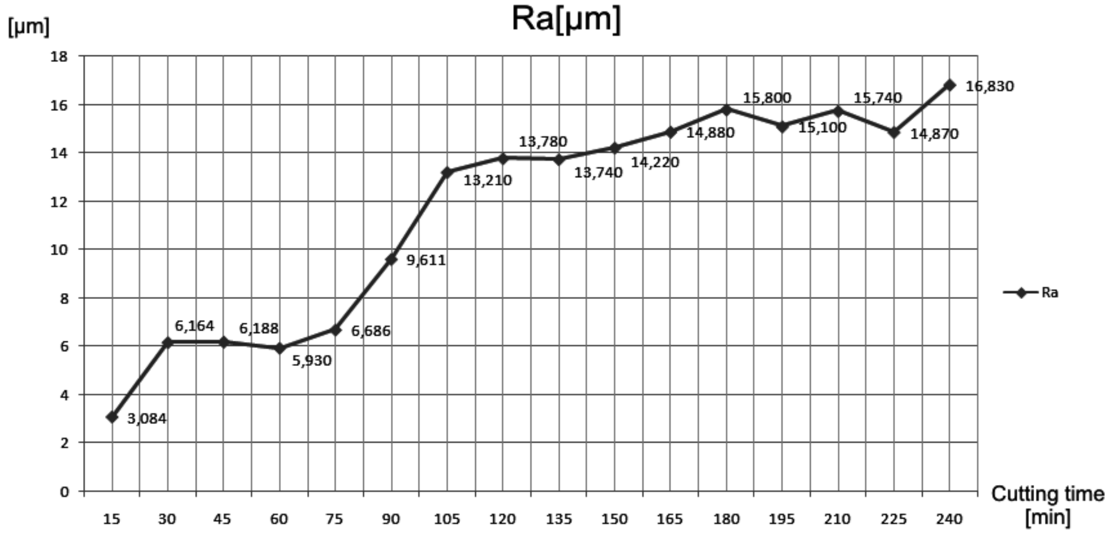

Fig.5. Roughness Ra over time with respect to tool wear

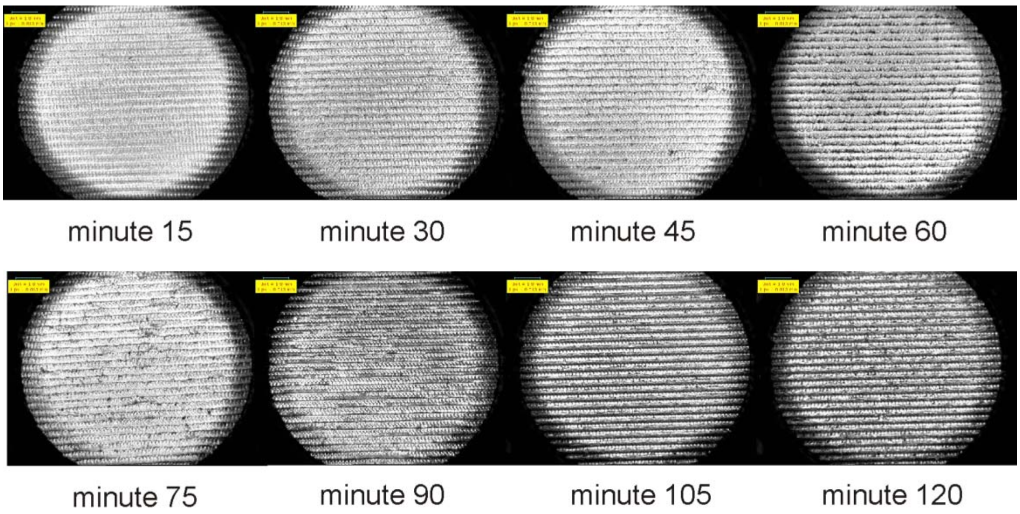

Fig.6. Photos of the surface texture taken at different cutting times

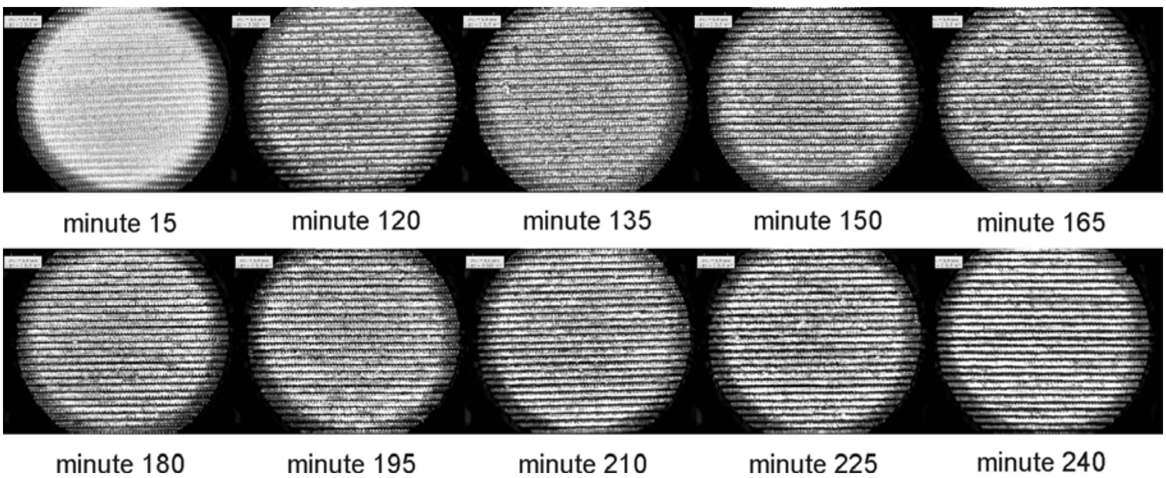

Fig.7. Photos of the surface texture taken at different cutting times

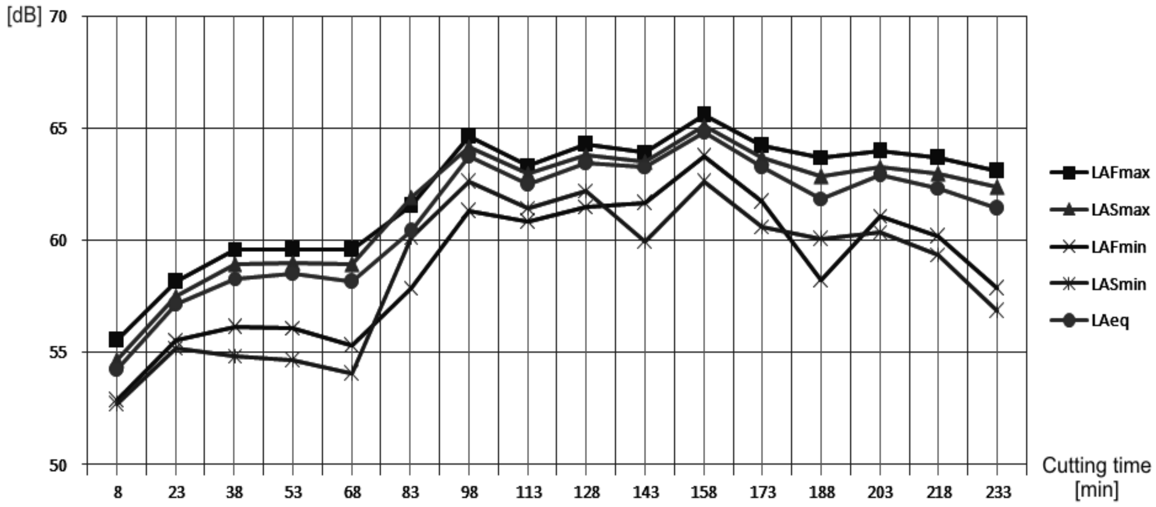

Fig.8. Sound levels for the cutting process

(LAFmax – maximum time-weighted sound levels on the A fast weighting curve,
LASmax – maximum time-weighted sound levels on the A slow weighting curve,
LAFmin – minimum time-weighted sound levels on the A fast weighting curve,
LASmin – minimum time-weighted sound levels on the A slow weighting curve,
LAeq – the equivalent continuous sound levels on the A curve)

flutes of the insert. This type of wear is an indicator that the cutting data was properly set according to the type of the material and the cutting conditions. This type of wear has been noticed by other researchers [11] both in the case of ball nose end mills [12] and in the case of normal end mills [1, 16].

In time, this type of wear became more and more severe, until it caused the flattening of the tool's tip. Shortly after the onset of this flat area on the tip of the tool, (minute 90), there was a new spherical/cone like structure which developed – figure 9. As the milling process went on, after the interval of 120 minutes necessary to reach the tool life criterion priory established, the spherical-shaped wear expanded. This type of wear I presume would suitably fall under the name of "omega"-type of wear (fig.9). This type of wear rose until it reached about 0,085mm in height, Ø0,33 mm diameter at the base of the cone and the cone angle of about 103° (after 240 minutes of cutting).

It is noticeable that at the end of the cutting process there was a 0,17mm difference between the initial and final length of the tool. The machined surface was measured using the dial-indicator with a 0,01 mm accuracy. There weren't recorded changes from the desired surface profile within the same cutting set (15 minutes reference time). For this reason we can assume that the shortening of the tool is less than 0,01mm every 15 minutes.

On these grounds, it is recommended that during the finish milling operations, on longer than 15 minutes ongoing rounds, using this type of tool and without tilting the tool, active correction of the tool length should be made. If this is not possible, the tool must be measured at certain points in time, in order to check the change in length. It is also important to correlate these data with the wear on other regions of the cutting edge [9].

A study over the newly found type of wear is required both from the perspective of its causes and the tool materials that favor its appearance, and from the perspective of the effects it can have over the quality of the machined surface.

4. CONCLUSSIONS

Further research must be oriented on A strategy for optimum machined surface quality and on C strategy for optimum productivity.

The sound level during the machining operation can be successfully used to monitor the degree of tool wear and to track the moments when it is necessary to work out certain corrections in order to prevent possible profile errors of the machined surface.

The electrical power consumption was constant regardless of the milling strategy applied for cutting (one way raster, raster, offset – figure 1).

The power consumption kept its values along the progress of the wear phenomenon.

It is required to optimize the power consumption from the perspective of the time taken by the cutting process.

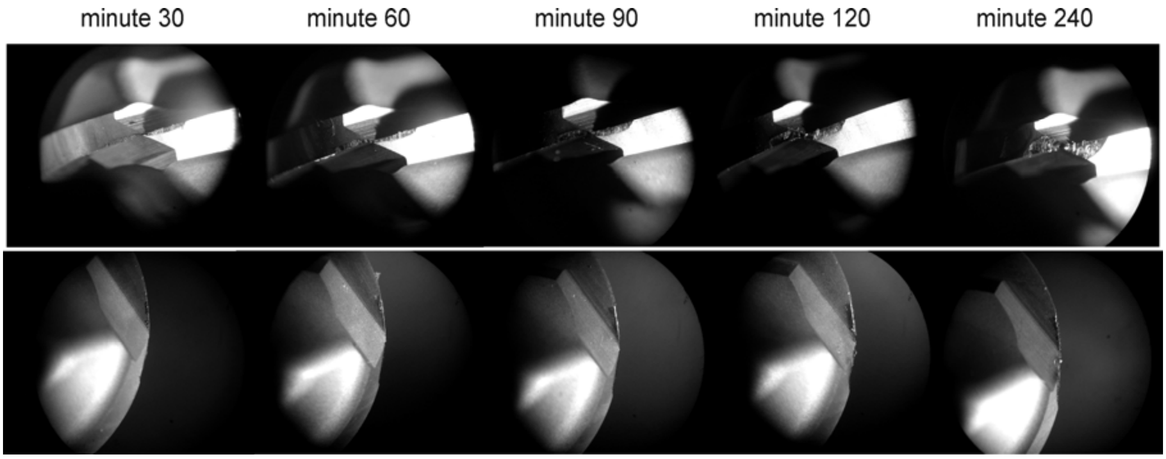

Fig.9. Tool wear with respect to machining time

The type of tool wear named by the author "omega" was identified, requiring thorough analysis with respect to the causes that lead to it as well as to its tribologic behavior.

The eco-technological vision regarding cutting fluids and their life-cycle requires integration within the metal cutting tribosystem.

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