The influence of inclination of the axis of the toroidal tool on a flat surface roughness

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Abstract. The paper follows the experimental analysis of the influence of the tool axis inclination on the roughness on a flat surface. The tool used in this case is a toroidal cutter radius around the corner. This will process a flat surface in 4 cases. We will experiment with the processing of a flat surface with the tool axis inclined in the positive direction A, negative direction A, positive direction B and negative direction B. The term of comparison in the four cases is surface quality. The purpose paper is to determine the best option for inclination tool toroidal.

1. Introduction

The milling is one of the main methods for forming the surface components and is widely used in the processing of complex surfaces continuous development of the technology of digital control. Good surface integrity plays an important role in wear performance, corrosion resistance, stability and reliability of components.

Nowadays, researchers are conducting active surface area studies through the milling process of the various tool directions.

The toroidal milling is widely used in the machining of complex parts with curved surfaces. For the same toolpath, you can often choose a variety of tool orientations due to its geometric features. According to previous papers [1, 2] where the optimal regimes for processing a complex surface have been deduced, it has been deduced that with the increase in speed and feed the surface quality increases and the processing time decreases.

Cosma M. [3] asserts that machining is characterized by a high extent of productivity, precision of form and dimension, universality, and flexibility, with great difficulty, especially for complex geometric shapes, due to the high additions processing and due to the increased use of high resistivity materials, hard and extraordinary, which are difficult to scrape.

Pașca I. [4] claims that the productivity of machining operations with spherical milling head is considerably effective when it is performed on numerically controlled machine tools, allowing greater flexibility in the cutting.

In this paper, the research focuses on the possibilities of machining on numerically controlled machines using toroidal milling machines, by providing a tilt angle of the tool axis relative to the normal work surface. Analysis of the milling process by tilting the axis of the tool after one angle of inclination is useful in relation to the inclination by two angles, due to the fact that the creation of the NC program piece is easy, possibility of collision to be avoided are smaller and easier to avoid.
The direction of inclination of the tool axis and the angle at which the cutting tool is inclined relative to the normal to the surface to be machined, is an important factor that determines the evolution of the roughness of the machined surfaces. It is therefore necessary to establish the optimum values of the inclination of the axis of the tool, which has the lowest roughness or avoiding the insertion direction and the angles which determine the roughness values of the high and low surface quality by default.

The slope optimization direction has been analyzed by a considerable number of researchers, but identifying a clear direction was not possible because the views are divided. Thus, in the paper [5], the optimal tilting direction of the tool was identified as being in the direction of advance. According to a previous paper [6], we have found that the best surface quality is obtained by processing in the advance direction due to the chip that is removed and no longer returns to the surface as in the case of the advance processing.

2. Influence of cutting parameters on roughness
The influence of the angle of inclination of the axis of the tool, which can be applied for different processing strategies, on surface roughness was also analyzed in paper [7], where the best surface quality was obtained by applying low tilt values.

When milling in 5 axes, the tool axis is usually oriented almost normally on the surface. An end mills may be inclined at an angle so that closely matches the surface of the machined surface design. Vickers [8] describes how to calculate the effective tool radius depending on the angle of inclination of the tool. For example, when an end mills, which is 40 mm in diameter and inclined 25 °, with the addition of 4 mm, the height of the resulting chip is 0.012mm; in contrast, the height of the cut is 0.1 mm for a spherical milling cutter with the same diameter and pitch.

To save processing time, improving the quality of the surface of the workpiece and the service life of the tool, Toh [9], identified and reviewed three main areas of research literature, namely Analytical analysis of the milling plane, the input and output performed by the movement cutter and tilt with milling effects.

Ko considered cutting force, surface roughness and tool wear synthetic results indicating 15 degrees of the angle of inclination of the workpiece were optimal, and milling down the downwardly to cut was the best trajectory of the tool [10 ].

3. Experimental status
The paper proposes that depending on the choice of the angle of inclination corresponding to a certain axis, rotation angles of the tool can be practiced around the axis.

The factor that influences the cutting contact position is not only the angle of inclination, but also the angle of rotation. There are four typical orientations of the tool, as shown in Figure 1. The coordinates X, Y and Z represents the direction of the step, and respectively the feeding direction of the Z axis of the machine. Tool orientations according to the angle of rotation of 0 °, 90 °, 180 ° and 270 ° respectively represent the milling direction and the tool inclination of 15 °, 30 °, 45 ° and 60 ° represent the angle of inclination between the tool and the surface. Figure 1 shows the positioning of the tool in the four cases of the angle of rotation at a 30 ° inclination.

For the purpose of the study, it is proposed to process 16 surfaces, the cutting regimes remain constant in all cases and the 16 tool positions are determined according to the angle of inclination of 15 °, 30 °, 45 °, 60 ° and the angle of rotation 0 °, 90 °, 180 °, and 270 °.

To verify the results, we propose the experimental analysis of the 16 surfaces measured in the feed direction and perpendicular to the feed.
3.1. **Practical experimental part**

For the practice was used a CNC machining center CMX 50 U 5-axis, manufacturing year 2017 in the firm SC Ramira S.A.

![CMX 50U machining center](image)

*Figure 2. CMX 50U machining center.*

The toroidal milling cutter or corner cutter has a diameter of Ø16 with a maximum cutting depth of 32 mm. Its corner radius is 4 mm having a number of 4 teeth, and the radial clearance angle of 9 degrees, the oscillating angle of 44 degrees and the cutting edge angle of the tool being 90 degrees. The milling cutter has a cylindrical form of PVD carbide without cooling channels.

![The toroidal milling cutter](image)

*Figure 3. The toroidal milling cutter.*

3.2. **The workpiece**

The piece has the shape of a parallelepiped, the dimensions of 28x25x35 mm, being processed only one of the plane surfaces on which a certain surface quality is obtained.
The material by used in the experiment is C45 (1.0503). After analysing the material using a spectrometer it presents the following chemical components: Fe 98.6%, C 0.463%, Mn 0.556%, Si 0.177%, P 0.003%, Cr 0.011%, Mo 0.048%, Ni 0.054%, Al 0.258%, Cu 0.01%, Ti 0.013, and so on, according to the analyses results that the material is C45.

The cutting regimes used in the experiment are the same across all 16 samples and these are represented by shaft speed n = 12,000 rpm, feed rate 2200 mm / min with a tooth feed of 0.044 mm. Addition of processing ap = 1 mm and step ae = 0.2 mm. The coolant used is the emulsion.

3.3. Comparison of the roughness of the 16 surfaces processed with the toroidal milling

The tool used to measure the roughness of the two surfaces is the TR 200 roughness, capable of measuring 13 roughness parameters and viewing the roughness profile, having an interface capable of hooking to a computer, the software being used as TimeSurf.

![Figure 4. Measure the roughness of the 16 surfaces.](image)

| Angle of rotation | Angle of inclination | Direction of measurement relative to the feed direction |
|-------------------|----------------------|-------------------------------------------------------|
|                   |                      | Ra [µm] | Perpendicular | Parallel | Rt [µm] | Perpendicular |
| 1. 0°              | 15°                  | 0.757   | 0.363         | 5.266    | 2.653   |
| 2. 30°             | 15°                  | 0.757   | 0.291         | 4.299    | 2.113   |
| 3. 45°             | 60°                  | 0.738   | 0.346         | 5.786    | 2.339   |
| 4. 60°             | 15°                  | 0.342   | 0.607         | 4.533    | 3.833   |
| 5. 30°             | 0.227                | 0.654   | 1.959         | 4.120    |
| 6. 45°             | 0.226                | 0.965   | 2.253         | 4.780    |
| 7. 60°             | 0.189                | 1.733   | 2.593         | 10.133   |
| 8. 15°             | 0.602                | 0.438   | 5.460         | 3.753    |
| 9. 30°             | 0.646                | 0.296   | 4.720         | 2.406    |
| 10. 45°            | 0.882                | 0.341   | 5.946         | 3.018    |
| 11. 60°            | 0.733                | 0.313   | 5.286         | 2.180    |
| 12. 15°            | 0.340                | 0.938   | 2.533         | 5.833    |
| 13. 30°            | 0.363                | 0.632   | 2.553         | 4.780    |
| 14. 45°            | 0.161                | 0.961   | 1.759         | 4.960    |
| 15. 60°            | 0.199                | 1.802   | 1.393         | 6.819    |
The method of measuring the surface was carried out by measuring three values of the roughness in the direction of advance of the three values of roughness and perpendicular to the feed direction. For comparison, it was chosen to monitor the Ra and Rt values. The table below shows the average of the three measured values.

4. Experimental results
According to the experiments carried out in this paper, the comparisons of the 16 types of processing are presented in turn in the four diagrams.

**Figure 5.** The graphical representation of the roughness values Ra measured in the direction parallel to the feed and the direction perpendicular to the feed.

**Figure 6.** The graphical representation of roughness values Rt measured in the direction parallel to the respective feed in the direction perpendicular to the feed.
The results indicate that the tool guidelines have a great influence on surface roughness, surface morphology and residual loading, but little on microhydration.

5. Conclusions
According to the measurements, the minimum value of Ra measured in the direction parallel to the feed is obtained when the angle of rotation is 270° and the tool angle of inclination is 45° being 0.161 μm.

Analyzing the minimum value of Rt it was experimentally deduced that its lowest value is 1.393 μm measured in the direction parallel to the feed when the tool angle of rotation is 270° and the angle of inclination of the tool to the surface is 60°.

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