Improving Roughness Using Toroidal Milling for Complex Surface Processing

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Abstract: *The paper aims to study the processing of complex and convex surfaces using a cutting tool in a milling radius called toroidal end milling in terms of roughness. Roughness presents important influences on machine parts and not only be in operation contact surfaces are either fixed or mobile. This paper includes a series of 11 experiments in which different regimes are tested with the main purpose of finding the optimum regimen for the work to be subjected to the toroidal milling using the roughness value Ra and Rt as the comparison criterion. For roughness determination, the TR200 is used as a measuring tool and data is loaded into a software called Time Surf. At the end of this paper a point of view will be determined regarding the roughness obtained with the toroidal milling.*

Keywords: *Tribology of complex surfaces, roughness, toroidal milling, processing regimes.*

1. Introduction

The roughness defined by SR ISO 4287: 1993[12] represents the set of micro irregularities (relative to an ideal geometric surface) of the surface resulting from a manufacturing process and which are not deviant in shape.
Surface roughness can have a major impact on the proper operation of a product. However, the large number of factors that influence the surface finish of a piece makes it difficult to choose the machining parameters appropriate to it. Selection of the proper strategy for processing and processing parameters such as depth of axial cutting, the radial depth of cut, power per tooth, the cutting speed and the inclination of the tool may lead to an increase in productivity and an increase in surface quality.
In general roughness is defined as the set of surface irregularities whose pitch is relatively small and which includes the irregularities resulting from the manufacturing processes.
According to Vișan A. and Ionescu N. [11], the main causes of influence that determine the roughness of the surfaces are:

- Method and process of surface generation;
- Tool geometry;
- Parameters of the processing regime;
- The properties of the material;
- Processing environment;
- Errors of technical processing systems.

Mike S. Lou et al.[9] states that surface roughness is an important measure of the technological quality of a product and a factor that greatly influences the cost of production. Surface quality is a very important role in the processing performance through a high-quality processed surface that significantly improves wear resistance or corrosion resistance. In addition, surface roughness also affects the surface of friction, light reflection, the ability to retain a lubricant, and electrical or thermal resistance.
Surface roughness is one of the most important parameters to determine the quality of the product. The roughness process is very dynamic, complex and process-dependent. There are two types of factors that influence the finish of the surface and, implicitly, the surface quality of a workpiece. Primary factors are the kinematic geometry of the tool that theoretically affects the surface and can be calculated from processing parameters called controllable factors such as rotation speed, feed rate and cutting depth, and the second category of factors is represented by non-geometric components including tool wear, deformation workpiece material, vibrations, tool deformation, and machine tool axle misalignment errors.

According to Lamikis et al.[8] cutting force is one of the factors that most influence the surface finish of the work surface and the life of the tool in milling complex surfaces. This is due to the fact that the thickness of the non-deformed chip varies with a variation following the cutting force as well as due to the variation of the surface slope in the cutting direction.
Depending on the types of continuous or discontinuous chips, surface finishing will increase directly with increased friction between tool surface and chips formed.
Kalpakjian, S.[7] affirm that in general the use of fluids in surface finishing processes improves the quality of the surface, they reduce the additional friction coefficient by pumping the fluid at high pressures on the surface of the blade considerably reduces adherence between the tool and the chip resulting from the surface velocity.
Decreasing the roughness of a surface will obviously increase manufacturing costs, typically compromising the cost of manufacturing a component and its performance.
According to Alauddin et al. [1] they showed that when the cutting speed is increased, productivity increases, but implicitly, also the quality of the surface. Hasegawa et al.[5] affirm that the surface finishing can be characterized by various parameters such as the average roughness Ra, the maximum height of the profile from its mean line Rp, the square root mean height Rq as well as the maximum height of the profile Rt. The current stage uses the average roughness Ra to characterize the surface quality on a large scale in industry.
Roughness, the important parameter of the surface layer, has a great influence on the wear resistance, fatigue resistance, corrosion resistance and the precision fits. In the case of gadget adjustments, irregularities (asperities) result in a decrease in the real bearing surface compared to the theoretical one considered in the calculations, which produces local increases in the contact pressure, sometimes well above those considered in the dimensioning calculations. They have the effect of accelerating contact surfaces and gaming increase, especially during the first run-up period, especially as the initial (technological) roughness is higher. These effects justify the application of correct roll-out programs after fitting.

2. Roughness parameters and their influence

In order to determine the surface quality with the corner cutter, the main parameters taken into account are the arithmetic deviation of the assessed profile Ra and the total height of the profile Rt..

2.1 Deviation of arithmetic mean of Ra

Also known as AA arithmetic mean or CLA Central Medium Line, is the arithmetic mean of the absolute values of the deviations of the profile effectively measured from the median line of the profile within the basic lengths. The average roughness is the area between the roughness profile and the midline, or the integral of the height of the profile height over the length of the evaluation.
Average roughness is undoubtedly the most commonly used parameter for measuring the surface quality. The oldest analogue roughness measuring instruments only measured Ra by drawing a continuous peak back and forth on a surface and electronic integration (finding the mean). It is easy enough to take the absolute value of a signal and integrate a signal using only the analogous electronics. This is the main reason Ra has such a long history.
In terms of the graph, the average roughness is the area between the roughness profile and its center line divided by the length of the evaluation (normally five sample lengths, each length being equal to one sample cutting).

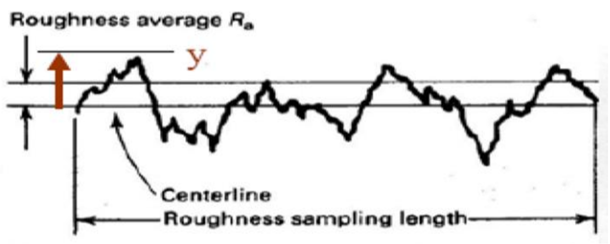

Fig. 1. The graphical representation of the arithmetic mean deviation Ra (Jigar.T [6])

The average roughness value Ra is the arithmetic mean value of the sums of all roughness profile values. According to Dragu D., et al. [9] the deviation of the arithmetic average of the roughness can be calculated with the relation:

$$Ra = \frac{1}{l}\int_0^l y_R dx_R \tag{1}$$

Where:
l- is the length of the reference line;
yR- the height of the roughness;
dxR- the distance along the „l” dimension.

2.2 Total profile height Rt

It represents the vertical distance between the highest and lowest points of the profile.

$$Rt = Z_{\max} + Y_{\max} \tag{2}$$

Where:
Zmax- maximum height;
Ymax- maximum depth.
This parameter is very sensitive to high peaks or deep scratches; Rt is defined as the vertical distance between the highest peak and the smallest scratch along the length of the profile rating.

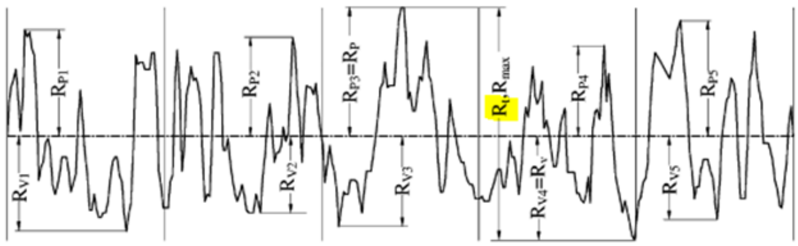

Fig. 2. Graphic representation of the total height Rt (Gadelmawa, E.S., et al., 2002 [3])

2.3 The influence of roughness

Roughness presents important influences on machine parts and not only be in operation contact surfaces, whether stationary or movable. The most important influences are:
The influence of roughness on fatigue resistance. The profile line consisting of peaks and recesses, the latter being stress concentrators. The influence of roughness on fatigue resistance is presented in the calculation for periodic stresses (especially the symmetrical alternating cycle), by the surface condition coefficient.
The influence of roughness on corrosion resistance. According to Gheorghe D. et al.[4], In the working environment of the machine organ, due to the differences in the electro-chemical potential due to the alloy's non-homogeneity, portions of the alloy surface are converted into anodic elements and others into cathode elements. In the presence of an environment that assumes the quality of an electrolyte an anodic dissociation is caused. This is all the more pronounced as the roughness is larger and sharp, due to the micro-currents in the electrolysis process which has a preferential attitude to flow through the peaks. In many situations, even if the surfaces are free but work in a corrosive environment, it is imperative that the surfaces have small roughness to obtain good corrosion resistance.
The influence of roughness on wear resistance. The surfaces of the contacting pieces have asperities, and when pressed by certain forces (F), the contact tips deform elastically, then plastic and when they have a relatively tangential displacement. They break out as wear. In the initial period, the wear period grows very quickly, after which its evolution is much slower. This wear has a much shorter run-out period if the surfaces in contact have a better smoothness.

3. Experimental setup

According to experiments carried out in a previous paper, A.R. Osan, et al.[10] the use of toroidal cutters in complex surface processing can be successfully applied and processing in the climb milling is more efficient than conventional milling.

3.1 Practical experimental part

For practical experiments it has been used numerical control centre of the 3-axis MCV 1016 of the firm S.C. Ramira S.A.

Fig. 3. Vertical machining center in 3 axis MCV 1016

The cutting tool used was a toroidal cutter JHP780160E2R400.0Z4-M64 with a carbide coating of Ø16 with a number of 4 teeth and a radius of R4.

Fig. 4. The toroidal milling cutter

3.2 The workpiece

The material used in the experiment is C45 (1.0503) with the following characteristics: 0.42 ... 0.50% C, 0.5 ... 0.80% Mn, 0.17 ... 0.37% Si, maximum 0.040% P etc. The piece has the shape of a square being machined only one of the ends representing the active part of the piece.

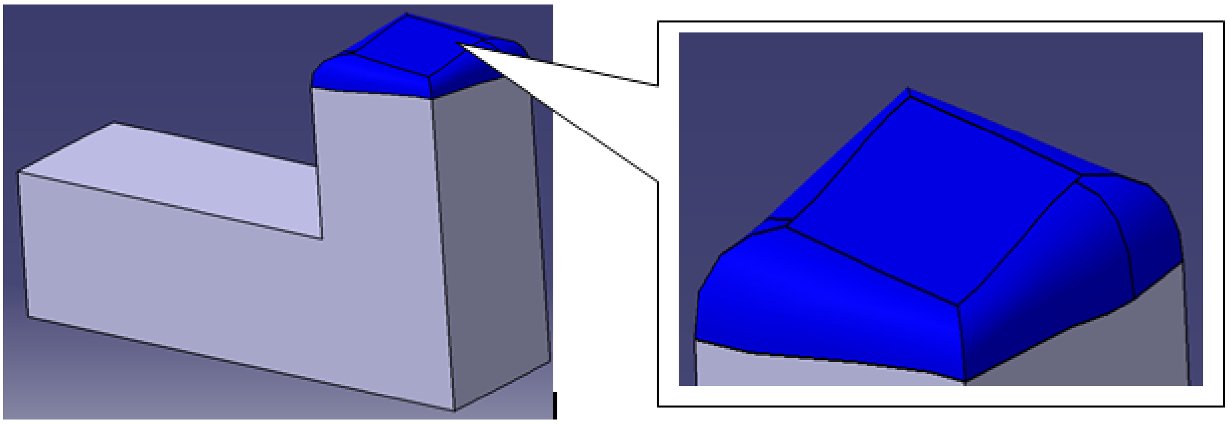

Fig. 5. Surface 3D model

The 11 experiments were performed on the machine MCV 1016 as shown in Figure 3, and a milling cutter used for cutting is one piece with the corner radius r4 and a diameter of ø16 and is provided in Figure 4. For reference number 1, the speed and propulsion proposed by the tool manufacturer were used, with the following increasing exponentially by 10% each, the reference 10 having double cutting parameters from the original ones and the benchmark 11 four times higher. The processing was carried out with a 1 mm machining feed having a 0.2 mm pitch using coolant.

Fig. 6. Workpieces processed

3.3 Machine and verification method

Direct palpation method
This method consists in measuring the surface roughness by palpating the profile with a touch probe (ac) along the measuring direction. The device used is the touch probe roughness with the possibility of amplified profile recording. The profile gauges generally operate on the basis of an electrical principle.
The electronic device is built from the transducer subassembly and the electronic unit. Alternative voltage produced by the oscillator is transmitted to the inductor probe transducer via the symmetrical transformer. When moving the touch probe, which is a diamond or sapphire, with a peak angle of 60 ° and a radius r of between 1 and 10 microns, the surface of the piece due to irregularities will oscillate vertically and with it and the bobbin core thus modifying the relative impedance of it. The impedance variation changes the circuit voltage, amplified, rectified, and indicated by the device.
The method offers a number of advantages such as: universality, rapid profile recording, magnification, and long scanning lengths, and all the information on surface micro-geometry can be reproduced in the modern ones provided with the computer.
The device used to check the roughness is the TIME TR 200, this portable absolute measuring device has the sensitivity required to measure the very fine roughness of the tens and microns.

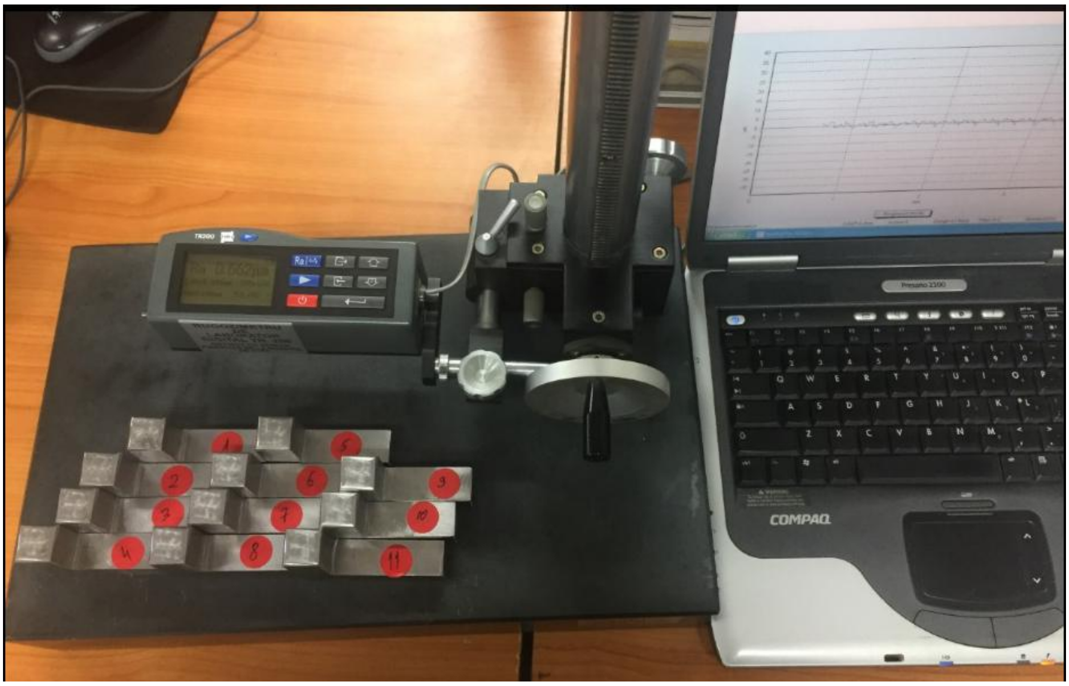

Fig. 7. Roughness measurement with TIM 200 TR

Table 1.1 contains the results of surface roughness measurements, both parallel and perpendicular to the feed direction. It is also noted that the roughness of the surface is analysed both in terms of roughness Ra and Rt, for a complete analysis of the surface processed. All of this was done in order to obtain an overview of the profile of the surface obtained from toroidal milling under different conditions created by the change of the main shaft speed and the cutting advance.

Table 1: Data centralization

Nr. Ctr	Speed (rpm)	Cutting speed (mm/min)	Ra [μm]		Rt [μm]	
			Direction of measurement relative to the feed direction			
			Parallel	Perpendicular	Parallel	Perpendicular
1.	1204	361	0.795	0.986	9.279	10.530
2.	1324	397	0.847	0.962	6.840	8.140
3.	1444	433	0.813	0.955	6.940	8.100
4.	1565	439	0.893	0.937	6.559	8.850
5.	1685	505	0.818	0.850	7.059	8.800
6.	1806	541	0.727	0.838	7.159	8.020
7.	1926	577	0.881	0.965	7.480	8.199
8.	2046	613	0.825	0.897	6.019	9.520
9.	2167	650	0.798	0.942	7.860	8.100
10.	2408	722	0.711	0.798	7.320	7.400
11.	4814	1444	0.450	0.476	3.680	3.900

4. Experimental results

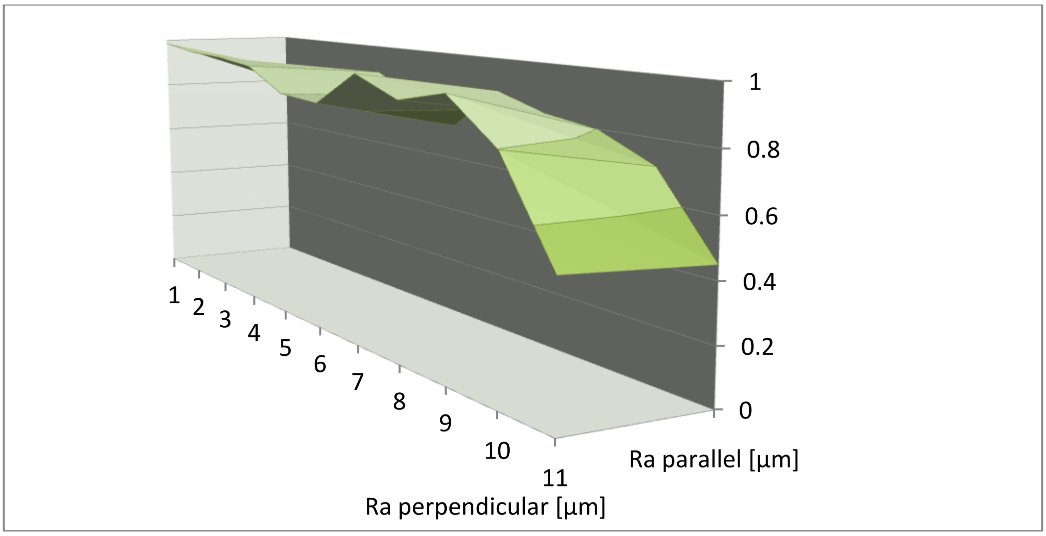

Fig. 8. Graphic representation of the roughness of the 11 landmarks

Based on the analysis of the centralized experimental results in Table 1.1, we noticed that the lowest values for Ra, 0.450 µm in the case of parallel roughness measurement in the direction of the feed and 0.476 µm for the measurements made perpendicular to the feed direction are due to the large processing regimes of 4814 rpm the main shaft speed and the 1444 mm / min feed rate. The maximum values for Ra reached 0.893 µm for the measurements made in the direction of the advance and 0.986 µm for the measurements made perpendicular to the direction of the advance, all of which are caused by the small working regimes.
Analysing the measurements for the vertical distance between the highest and lowest values of the profile (Rt), it can be seen that the minimum value of 3.680 µm is recorded in the case of the roughness measurement in the direction of the advance following the processing of the reference 11 and the maximum value Rt being 10.530 µm after processing with small regimes and measuring in the direction perpendicular to the feed.

5. Conclusions

The reference 11 made at 4814 rpm and the 1444 mm / min feed having the 0.2 step and a 1 mm processing addition is considered to have the best surface quality, the minimum average roughness value (Ra) measured in the direction of the feed is 0,450 µm and the vertical distance between the highest and lowest points of the profile (Rt) has the value of the minimum value of 3,680 µm.
The use of round corner cutters for complex surface processing can result in superior surface quality due to the use of larger machining regimes, increasing productivity at the same time and this can considerably influence the surface tribology that can reduce wear, corrosion or fatigue.

Acknowledgments

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