14th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2010, Mediterranean Cruise, 11-18 September 2010

STUDY OF THE INFLUENCE OF THE RELATIONSHIP BETWEEN FEED PER TOOTH AND RADIAL DEPTH ON THE SURFACE TOPOGRAPHY AND SURFACE ROUGHNESS OBTAINED IN BALL-END MILLING PROCESSES

I. Buj-Corral; J. Vivancos-Calvet; H. González-Rojas; A. Domínguez-Fernández
Technical University of Catalonia (UPC). Departament of Mechanical Engineering.
School of Industrial Engineering of Barcelona (ETSEIB), Avda. Diagonal 647, 08028-Barcelona, Spain

ABSTRACT
In ball-end milling processes, feed per tooth, radial depth and their relationship have influence on the surface topography shape and on the surface roughness values, and all these have influence on the difficulty degree for manual polishing after end milling processes.
This paper presents the study of the influence of feed per tooth and turn, radial depth and their relationship, on the surface topography and roughness values in ball-end milling processes.
A numerical model was developed in order to predict the surface topography and surface roughness of machined parts. This model is based on the geometric tool-part intersection and allows defining the surface topography of the part as a function of feed per tooth and turn, radial depth, axial depth, tool radius, number of teeth, radii values of each tooth, helix angle of the teeth, angle offset between teeth and eccentricity. The model generates the surface topography and allows analyzing it and determining the 2D roughness parameters and the Abbott-Firestone curve along a line, as well as the 3D roughness parameters.
Keywords: surface roughness, ball-end milling processes, relationship feed per tooth and radial depth

1. INTRODUCTION
Several authors have studied the influence of cutting conditions on topography and roughness obtained in ball-end milling processes, following different methodologies and using different models. For example, some of them use design of experiments [1], some others employ numerical simulation [2,3] or the called ridge method [4,5].
In the finishing processes of moulds and dies it is important to be able to optimize the cutting conditions of the ball-end milling process, having into account the difficulty degree for polishing after milling. Feed per tooth, radial depth and their relationship have an important influence on the surface topography shape and on the surface roughness values, and all these have influence on the difficulty degree for manual polishing after end milling processes.
This paper presents the study of the influence of feed per tooth and turn, radial depth and their relationship, on the surface topography and on the roughness values in ball-end milling processes, using a numerical model developed to predict the surface topography and the roughness values after machining a part.

2. DEVELOPED MODEL
A numerical simulation computer program was developed for the surface milling of horizontal flat surfaces with ball-end milling tool. It determines the geometric intersection between tool and part, along its relative movement, removing the material of the part that intersects with the cutting edges of the tool. No geometric approximation of the trajectory of the tool edge radii is considered. Only the

increment of turn of the tool in each movement interval is considered, in the direction of the feed per tooth and turn. By means of both simulations and experiments it was proved that the classical approximation of circular furrows along the feed per tooth and turn f_z does not correspond to reality for high feed per tooth and turn values. The hypotheses of the developed model are: the tool is new or has little wear, the tool is robust (without flexion) and does not have tilt angle. Neither plasticity, propagation of cracks, vibrations, thermal effects nor adhesion of the material are considered.
Depending on the milling tool diameter, on the number of teeth, on the helix angle of the teeth, on the angle offset between teeth, on the radius of each tooth, on the feed per tooth and per turn f_z, on the radial depth (Rd), on the axial depth (Ad), on the eccentricity value and on the angular position of eccentricity with respect to the first tooth, the program determines different issues: a file with the heights z_i corresponding to each position x_i, y_i (which is related to the chosen resolution), the graphical representation of the surface topography 3D and the analysis of the surface in 2D and 3D. In 2D, any line on the horizontal flat machined surface (either along the feed direction or along the perpendicular direction to the feed) can be selected. The program gives the roughness profile/topography with the roughness parameters and the Abbott-Firestone curve both in 2D and 3D. From the 2D and 3D results, the program gives the area distribution curve (2D), the volume distribution curve (3D), the total material volume and the total void volume. In an interactive way, the value of the Abbott-Firestone curve corresponding to a certain height z_i value can be seen (% of surface bearing area ratio). In addition, the volume of peaks over z_i and the volume of voids under z_i (both in percentage and in absolute value) are calculated. In an interactive way it is also possible to see the material volume and the void volume between two heights.

3. METHODOLOGY

For a spherical tool of 6 mm diameter with 2 edges, initially the program was validated by contrasting simulated results with experimental results. Once the program was validated, a wide study was carried out about the variation of roughness topography and roughness values as a function of feed per tooth and turn f_z, of radial depth of cut Rd and of their relationship. For doing that 256 simulations were performed and the values of roughness Sa and St were represented as a function of f_z and Rd. This wide study about the variation of surface topography and roughness parameters as a function of f_z and Rd constitutes a contribution of great interest, as the simulation does not take into account other variables that are difficult to control in experimental tests.

4. RESULTS

4.1. Roughness topography

Regarding the validation of the simulation program, in Figures 1 and 2 both topography and roughness values are compared between simulation tests and experimental tests, for two different cases. The results of simulation agree with the experimental results. The differences can be attributed to the fact that the model does not take into account other factors that influence roughness, such as the material plasticity, vibrations, tool flexion and other possible causes.
As can be seen in Figures 1 and 2, roughness topography changes with f_z. In Figure 1, f_z is low and in Figure 2, f_z is high. If Rd is lowered, the influence of f_z diminishes because of the successive very close cutting steps in the direction of Rd.

A B

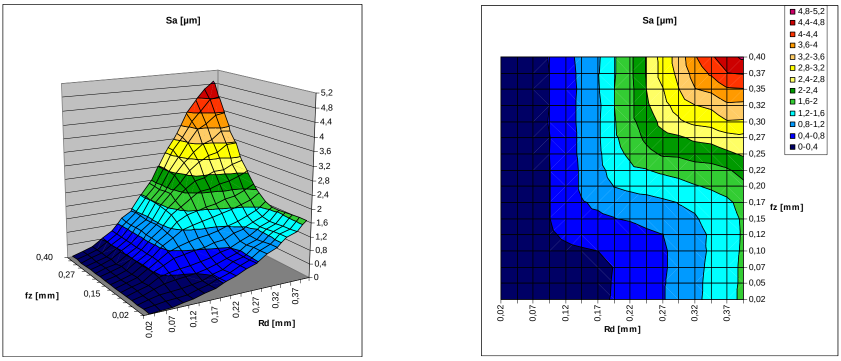
Figure 1. Milling with f_z=0,04 mm·tooth^{-1}·turn^{-1} and Rd=0,40 mm. A) Real measured topography: Sa=1.57 µm, St=10.00 µm. B) Simulated topography: Sa=1.70 µm, St=6.73 µm

A B

Figure 2. Milling with f_z=0,20 mm·tooth^{-1}·turn^{-1} and Rd=0,40 mm. A) Real measured topography: Sa=2.90 µm, St=12.20 µm . B) Simulated topography: Sa=1.92 µm, St=8.67 µm

4.2. Sa and St roughness values

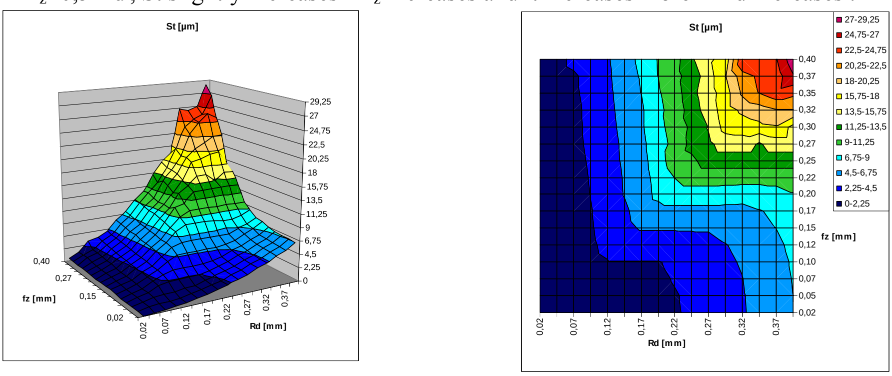
From the analysis of Figures 3A and 3B it can be seen that Sa is minimal when f_z and Rd are also minimal. In the area of the graphic with ≈ f_z>Rd , if f_z rises, Sa remains almost constant and the machining operation is faster. On the contrary, if Rd increases, Sa also increases. In the area of the graphic with ≈ 0,45·a_r<f_z<a_r , Sa increases if f_z increases and Sa incresases moderately if Rd increases. In the area with ≈ f_z<0,45·a_r , Sa reamains almost constant if f_z increaeses, and the cutting time decreases. Sa increases if Rd increases.



A B

Figure 3. 3D arithmetic average roughness Sa graphics

From the analysis of the results of the performed simulations, in Figures 4A and 4B it can be seen that St is minimal when f_z and Rd are minimal. In the area of the graphic with ≈ f_z>Rd , if f_z increases, St slightly increases and if Rd increases, St increases in a more important way. In the area of the graphic with ≈ 0,5·Rd<f_z<Rd , St increases if f_z increases and it remains almost constant if Rd increases. In the area with ≈ f_z<0,5·Rd , St slightly increases if f_z increases and it increases more if Rd increases .



A B

Figure 4. 3D Peak-to-valley roughness St graphics

5. CONCLUSIONS

The main conclusions of this work are:

- The roughness topography varies significantly when the f_z value changes. If Rd is very low, this influence of f_z is lowered by the successive steps in the direction of Rd.
- Regarding the influence of the variation of f_z and Rd on the Sa and St roughness values, it was observed that depending on the relationship between f_z and Rd, the corresponding influence of each one of them can be significantly different. For example, according to the results of the simulations, in the area of the graphic where $\approx f_z > Rd$, if f_z increases, Sa only changes slightly and the machining operation is faster. If Rd increases, then Sa increaess. When contrasting the simulation results with the experimental results, it will be possible to determine a relationship between f_z and Rd that optimizes the relationship between productivity and the quality of surface finish.

ACKNOWLEDGEMENTS

The authors would like to thank the Spanish Ministry of Science and Education for the financial support of Project DPI2007-66546.

6. REFERENCES

[1] Vivancos J., Luis C.J., Costa Ll., Ortiz J.A.: Optimal machining parameters selection in high speed milling of hardened steels for injection moulds, Journal of Materials Processing Technology, Volume 155-156 (2004) 1505-1512

[2] Gao T., Zhang W., Qiu K., Wan M.: Numerical simulation of machined surface topography and roughness in milling process, ASME, Volume 128 (2006) 96-103

[3] Quinsat Y., Sabourin L., Lartigue C.: Surface topography in ball end milling process: Description of 3D surface roughness parameter, Journal of Materials Processing Technology, Volume 195 (2008) 135-143.

[4] Jung T.S., Yang M.Y., Lee K.J.: A new approach to analyzing machined surfaces by ball-end milling, Part I: Formulation of characteristic lines of cut remainder, Int. J. Adv. Manuf. Technol., 25 (2005) 833-840.

[5] Jung T.S., Yang M.Y., Lee K.J.: A new approach to analyzing machined surfaces by ball-end milling, Part II: Roughness prediction and experimental verification, Int. J. Adv. Manuf. Technol., 25 (2005) 841-849.