12th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2008, Istanbul, Turkey, 26-30 August, 2008

NUMERICAL SIMULATION MODEL FOR THE DETERMINATION OF SURFACE ROUGHNESS IN SIDE MILLING AS A FUNCTION OF FEED AND OF THE TOOL EDGES RADII

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

ABSTRACT
A numerical model was developed in order to predict the surface roughness before machining the part. This model is based on the geometric tool-part intersection and allows defining the surface topography of the part as a function of the feed and of the radii of the tool edges. In this first study the problem of runout, i.e. differences between the radii of the different tool edges, is analyzed.
The computational model allows determining the value of the average roughness (Ra) and the maximum roughness height (peak-to-valley) (Rt) along a line, in the direction of the feed, for a family of tools defined by an average radius of the edge and its standard deviation, assuming a normal behaviour.
It was observed that the obtained values of average roughness Ra do not follow a normal distribution even though the values of the radii were randomly taken according to a normal law.
A graphic was also obtained with the maximum and minimum value of average roughness Ra for each value of feed per tooth and per turn f_z.
Keywords: surface roughness, runout, side milling

1. INTRODUCTION
In the manufacturing of contours, cavities or pockets, vertical walls are usually obtained by means of side milling. In the finishing operations the walls have to meet some requirements regarding surface roughness, as for example in the manufacturing of moulds for plastic injection or in the manufacturing of dies, where such requirements are important.

Some of the geometric variables that influence surface roughness are: excentricity, tool edge grinding errors, inclination of the tool axis and its flexion during the milling process.

Several authors have studied the influence of different factors on surface roughness obtained by milling processes. Saï et al. [1] have studied the evolution of residual stresses, microstructure, microhardness and roughness in relation to cutting speed and feed in face milling. Vivancos et al. [2] have investigated the influence of cutting conditions in the surface roughness in high-speed side milling of hardened die steels. Lee et al. [3] developed a theoretical model that includes the effect of the cutting tool axis inclination on surface roughness in high-speed face milling. Franco et al [4] studied the influence of axial and radial runout on surface roughness in face milling, with round insert cutting tools, using a numerical model.

In the present work, for the side milling processes with cylindrical milling tool, a numerical simulation study is performed in order to obtain the histogram of frequencies of the average roughness

R_a. Therefore numerical algorithms that allow the generation of the surface topography from the edge radius and the feed have been developed.

2. NUMERICAL SIMULATION MODEL

A computational algorithm was developed in order to simulate surface topography along a contour line, machined by a cylindrical milling tool in the feed direction. The effect of the tool geometry is represented by the intersection of each one of the tool edges with the part moving with a certain feed value.

The hypotheses of the developed model are: the cutting tool is new or has little wear, the cutting tool is robust (without flexion and without axis tilt angle), the machined material has rigid walls and the cutting speed is much higher than the feed speed.

The input data of the software are: the number of cutting edges, the radius of each one of the cutting edges, the feed per tooth f_z. The output data are the roughness profile graphic and the average roughness R_a value.

3. RESULTS

The study of side milling of a vertical wall with a cylindrical milling tool of diameter 6 mm and 6 teeth was performed, for feed per tooth values f_z of 0,02, 0,06, 0,1 y 0,15 mm/tooth/turn.

The radii of 2 new tools from different manufacturers were measured. From the measures the average radius (r average = 2.9858 mm) and standard deviation (σ = 0.005937 mm) were calculated.

Average roughness R_a was calculated for N random combinations of radii at the a.m. values of feed per tooth. A study of the sensibility of the model was performed in which it was found that from N = 2000 the distribution of frequencies remains almost constant.

At Fig. 1, 2, 3 and 4 the distribution of the frequency histograms for R_a is presented for 2000 random combinations of distributions of the radius value between the 6 tool edges, characterized by the above mentioned values for average radius and standard deviation.

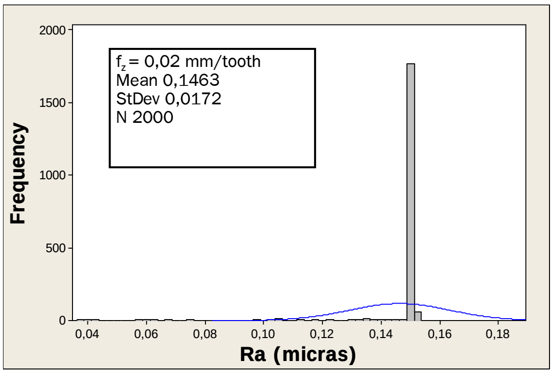

Figure 1. R_a frequency histogram for f_z = 0,02 mm/tooth/turn

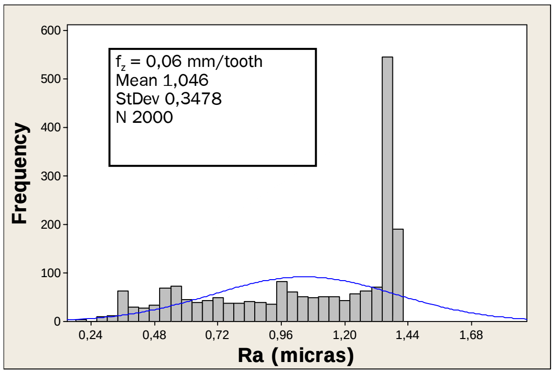

Figure 2. R_a frequency histogram for f_z = 0,06 mm/tooth/turn

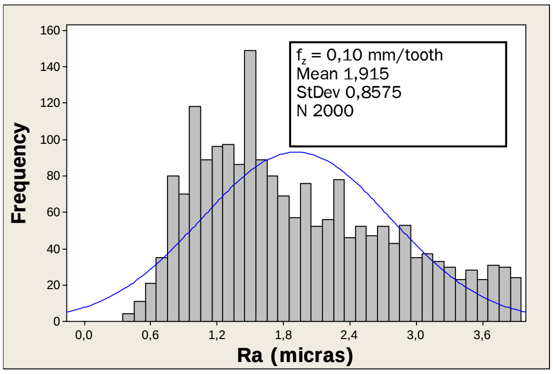

Figure 3. R_a frequency histogram for f_z = 0,10 mm/tooth/turn

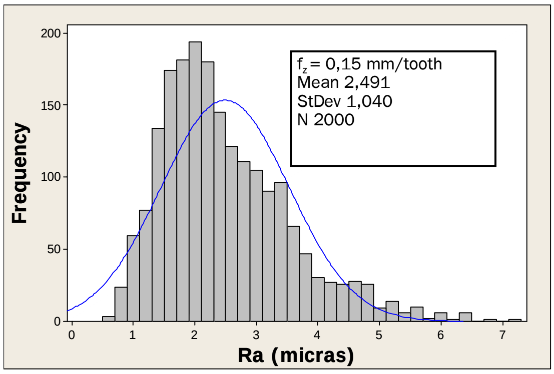

Figure 4. R_a frequency histogram for f_z = 0,15 mm/tooth/turn

It can be observed that the values of average roughness *Ra* do not follow a normal distribution although the radii were randomly taken according to a normal law.

The roughness parameter R_a increases when feed per tooth f_z increases. For low feed values the random variation of radii does not significantly influence roughness (Fig. 1) and the main R_a value obtained corresponds to the theoretical one calculated using the feed rate in Equation 2, with a probability of 0.88 (see Table 1). In this case the tool feed marks on the part's surface are performed by the longest edge in each turn. On the contrary, for higher feed values, the random variation of radii significantly influences roughness (Fig. 4) and gives rise to a wide frequency distribution for R_a. Then the probability of obtaining the R_a value defined by Equation 2 is 0.00 (see Table 1).

Table 1. Probability values of occurrence of roughness R_a

f_z (mm/tooth/turn)	Probability *p*	*Ra* (μm)
0.02	0.88	0.15
0.06	0.27	1.38
0.1	0.02	3.84
0.15	0.00	8.64

At Fig. 5 the range for R_a is shown as a function of feed per tooth f_z as a result of random cutting tool radii. It can be seen that when feed per tooth f_z increases the R_a values increase as well as its range.

The maximum and minimum values of R_a for each value of feed per tooth f_z were represented. At the same graphic two curves were drawn. One of them corresponds to the calculated value of R_a in case all the teeth have exactly the same radius (Ec. 1) and therefore the number of feed marks per turn on the part's surface is equal to the number of tool edges. The other curve corresponds to the calculated value of R_a in case there are errors in the teeth radii (Ec. 2) and therefore there is a main feed mark per turn at the roughness profile generated by one of the edges.

$$R_a = 32\frac{f_z^2}{r} \quad (1)$$

$$R_a = 32\frac{f^2}{r} \quad (2)$$

Where
f_z is the feed per tooth (mm per tooth and turn)
f is the feed rate (mm per turn)
R_a is the average roughness (μm)
r is the tool cutting edge radius (mm)

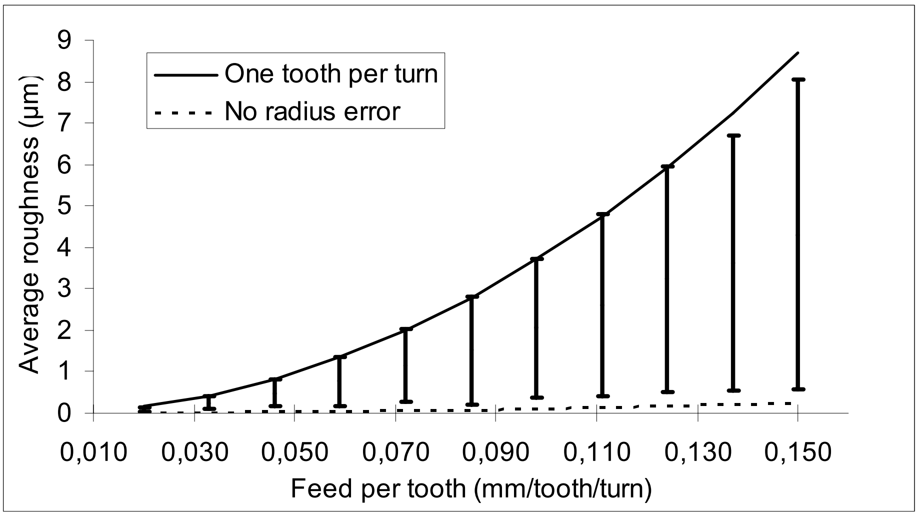

Figure5. Average roughness (μm) vs feed per tooth (mm/tooth/turn)

4. CONCLUSIONS

A methodology and a software tool was developed in order to simulate and analyze the influence of the errors of the tool edge radii of a milling tool in the roughness obtained by side milling of vertical walls, as a function of the feed per tooth f_z of the tool.

For low feed values the system behaves as if the tool only had one cutting edge.

The obtained values of R_a do not follow a normal distribution although the values of the radii were randomly taken according to a normal law.

5. ACKNOWLEDGMENTS

The authors would like to thank the Spanish Ministry of Science and Education of the Spanish Government for the financial support of Project DPI2007-66546 which gave rise to this paper. They also thank Mrs. Elena Baró and Mr. Ramón Casado for their contribution to the simulations and measurements made.

6. REFERENCES

[1] Saï W.B., Salah N.B., Lebrun J.L.: Influence of machining by finishing milling on surface characteristics, International Journal of Machine Tools and Manufacture 41 (3) (2001) 443-450

[2] Vivancos J., Luis C.J., Ortiz J.A., González H.A.: Analysis of factors affecting the high-speed side milling of hardened die steels, Journal of Materials Processing Technology Volumes 162-163 (2005) 696 – 701

[3] Lee K.Y., Kang M.C., Jeong Y.H., Lee D.W., Kim J.S.: Simulation of surface roughness and profile in high-speed end milling, Journal of Materials Processing Technology 113 (1-3) (2001) 410-415.

[4] Franco P., Estrems M., Faura F.: Influence of radial and axial runouts on surface roughness in face milling with round insert cutting tools, International Journal of Machine Tools and Manufacture 44 (2004) 1555-1565.