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# ROUGHNESS OF MACHINED SURFACE OF HARDENED STEEL AFTER MICRO END MILLING

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*ШОРСТКІСТЬ ОБРОБЛЕНОЇ ПОВЕРХНІ ЗАГАРТОВАНОЇ СТАЛІ ПІСЛЯ КІНЦЕВОГО ФРЕЗЕРУВАННЯ*

*Робота присвячена шорсткості обробленої поверхні після циліндричного фрезерования з різними параметрами зрізання $f_z$ і $a_e$. Дійсні висоти мікронерівності порівняли з розрахованими теоретично. Це дозволило виявити дійсні причини максимальних розбіжностей дійсних і розрахованих параметрів шорсткості.*

*Работа посвящена шероховатости обработанной поверхности после цилиндрического фрезерования с разными параметрами срезания $f_z$ и $a_e$. Действительные высоты микронеровности сравнили с рассчитанными теоретически. Это позволило выявить действительные причины максимальных расхождений действительных и рассчитанных параметров шероховатости.*

*Work is devoted to a roughness of the processed surface after cylindrical milling with different parameters of cutting $_{fz}$ and $_{ae}$. The valid heights of microroughness have compared with calculated theoretically. It has allowed to reveal the valid reasons of the maximal divergences of the valid and calculated parameters of a roughness.*

## 1. INTRODUCTION

As it is known one of the most important factors influencing the roughness of the machined surface is feed $f_z$ (geometric-kinematic mapping of the tooths in the work material). The increase in feed per tooth $f_z$ leads to increased roughness of machined surface, which has been confirmed in many publications, both in relation to milling in conventional terms or in HSM terms [1,5-8]. Feed per tooth $f_z$, cutting speed $v_c$ and axial depth of cut $a_p$ and the radial depth of cut $a_e$, are the most common factors taken into account when developing forecasting models. However, theoretical models describing the changes in surface roughness parameters as a function of the geometric-kinematic parameters often differ significantly from the actual surface roughness, especially for small values of feed [6,7].

## 2. RANGE, CONDITIONS AND TECHNIQUE OF RESEARCH

The study was conducted during the up and down dry milling of samples made of hardened steel 55NiCrMoV (52 HRC) under the conditions presented in Tab. 1. Milling took place on the milling machine FND32F made of AVIA at maximum possible speed of the spindle *n*. Axial depth of cut $a_p$ was chosen so as to be a complete multiple of axial pitch of the mill.

Feedrate $f_z$ was changed in the range of 0,01-0,08 mm/tooth with a higher concentration in the small values of feeds.

Milling width $a_e$ was varied smoothly from 0 to 2,5mm. In the range there was the certainty that the average normal feed force $F_{fN\,śr}$ acting perpendicular to the machined surface (fig. 1) will change the direction during up milling (see Fig. 4), as in [2] took place at $a_e \approx 0{,}25d$ for $\lambda_s = 50^{\circ}$. In studies of the impact of milling width $a_e$ on roughness four-tooth mill with larger grooves for chips and reduced value for $a_p$ were used, due to the high value of the $a_e$.

Table 1 – Range of research

| | Testing of influence of feedrate $f_z$ on roughness | Testing of impact of milling width $a_e$ on roughness |
|---|---|---|
| mill | D15266000 HX made of Fraisa, $d$=6mm, $z$=6, $\lambda_s$=55° | U5348391 HX made of Fraisa, $d$=8mm, $z$=4, $\lambda_s$=55° |
| $f_z$ [mm/tooth] | 0,01 0,015 0,02 0,025 0,03 0,035 0,04 0,045 0,05 0,06 0,07 0,08 | 0,04 |
| $a_e$ [mm] | 0,1 | 0-2,5 |
| $a_p$ [mm] | 13,2 | 4,4 |
| $n$ [rev/min] | 1400 | |
| milling type | down milling and up milling | |

Roughness measurements were done on to the T500 made of Hommelwerke with the T5E measuring tip and Turbo DATAWIN software. Roughness sampling length $lr$=0,8 mm, traversing length $ln$=5$lr$=4,0 mm, wavelength of cut-off filter $\lambda c$(cut-off)=0,8 mm and filter ISO 11562(M1) were used.

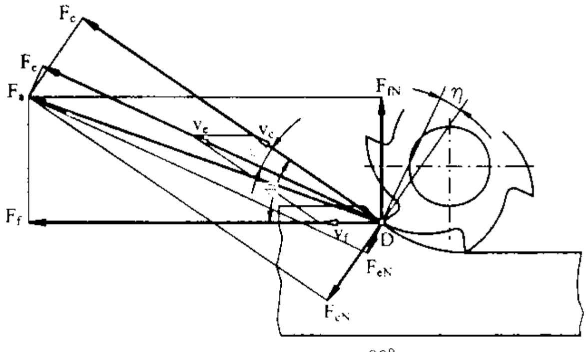


Figure 1 – Decomposition of forces during milling

Machined surface roughness was recorded after each pass parallel to the vector $v_f$. Three repeatings of measurements were performed on milled surfaces with any of the feeds $f_z$ used and fourteen measurements on surfaces milled with variable milling width $a_e$.

### *3. RESULTS AND ANALYSIS OF RESEARCH*

For recommended by the manufacturer of the feed mill feedrate $f_z$=0,035 mm/tooth, there is very little discrepancy between real roughness and roughness calculated with a formula taking into account diameter of the cutter as feed per revolution $f = f_z \cdot z$ (fig. 2). Discrepancies between roughness parameters $Rz_{t0}$ and $Rz$

are much larger for the conditions assumed in studies of the parameter $a_e$ impact on roughness (fig. 4).

Simultaneously, it can be seen that during up and down milling similar roughness height are obtained. This is contrary to some literature dates [8], according to thich the down milling provides about 6,5 times lower roughness parameter *Ra*.

Significant differences in the height of roughness for these milling types occur only at the feed $f_z \geq 0{,}07$mm/tooth (fig. 2,3). For the feed differences in cycloid tracks of the tooth in up and down milling should be taken into account [7]. These differences are taken into account by for example formula (1) [4,5], where the plus sign is inserted for up milling, while minus sign for down milling.

$$Rz_{t0} = \frac{f_z}{8\left(\frac{D}{2} \pm \frac{f_z z}{\pi}\right)} \qquad (1)$$

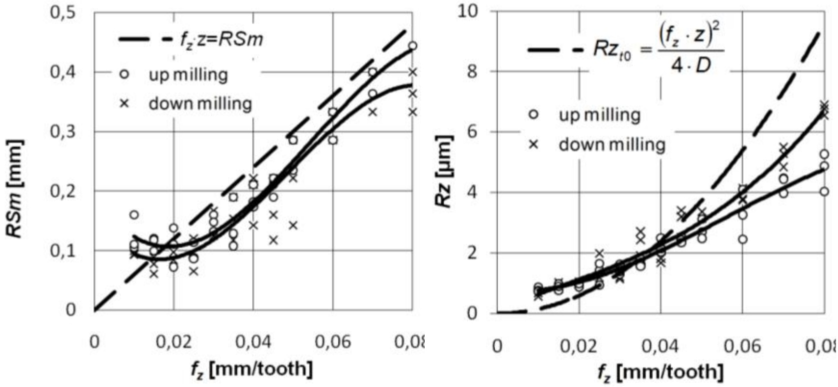


Figure 2 – Influence of feedrate $f_z$ on parameters *Rz* and *RSm* during down and up end milling

At very low feed rates (corresponding to the thickness of cut less than the minimum one) disturbance of the tooth's mapping in the work material can be seen, due to cyclic movement of the tooth (fig. 2 for $f_z$=0.01mm/tooth). This phenomenon is also observed by other cutting methods such as face milling.

Figure 4 shows that in up milling for $a_e \approx 2$ mm mean value of normal feed force $F_{fN\,śr}$ changing sense. Around the mean value changes value and sense instantaneous force $F_{fN}$ [1-3].

In the vicinity of the width for up milling is a sharp increase in the amount of machined surface roughness, and about two times reduction in the roughness interval (fig. 4,5). The increase in roughness is probably caused by vibration in a direction perpendicular to the machined surface.

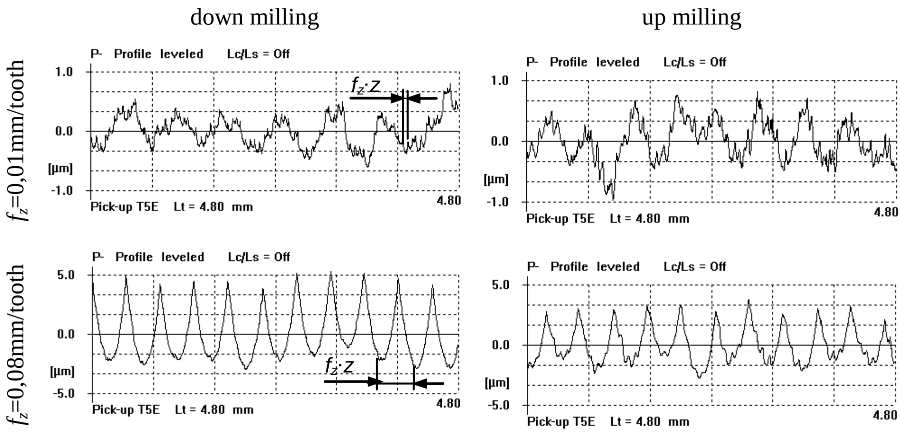


Figure 3 – Primary profiles obtained after down and up end milling
with various feedrates $f_z$

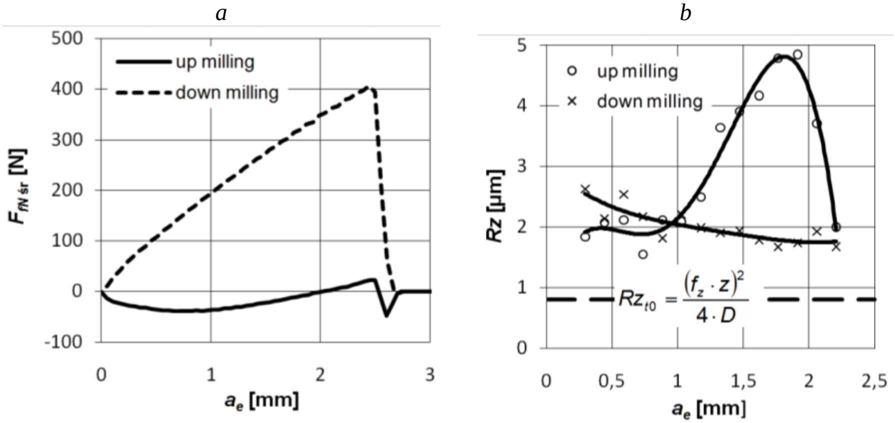


Figure 4 – Influence of milling width $a_e$ on mean value of normal feed force $F_{fN\,śr}$
a) and roughness parameter *Rz* b) during down and up end milling

## 4. *CONCLUSIONS*

Calculation of surface roughness in end milling is a very difficult task. Frequently in the calculation of the theoretical surface roughness is assumed that the cutter diameter maps per revolution of the mill. Such mapping is the result of radial run the cutter tooth. Calculation of the theoretical roughness in this way includes large errors, which further increase when:

- feed $f_z$ is very large and it cannot be assumed that in the work material is mapping diameter of the mill but epicycloids of different shape for up and down milling;

- feed $f_z$ is very small, and disturbance of theoretical mapping occurs, due to cyclic movement of the tooth relative to the machined surface;
- up milling with width $a_e$, at which the mean normal feed force $F_{fN\,śr}\approx 0$, and there are changes in the value and sense of the instantaneous force $F_{fN}$.

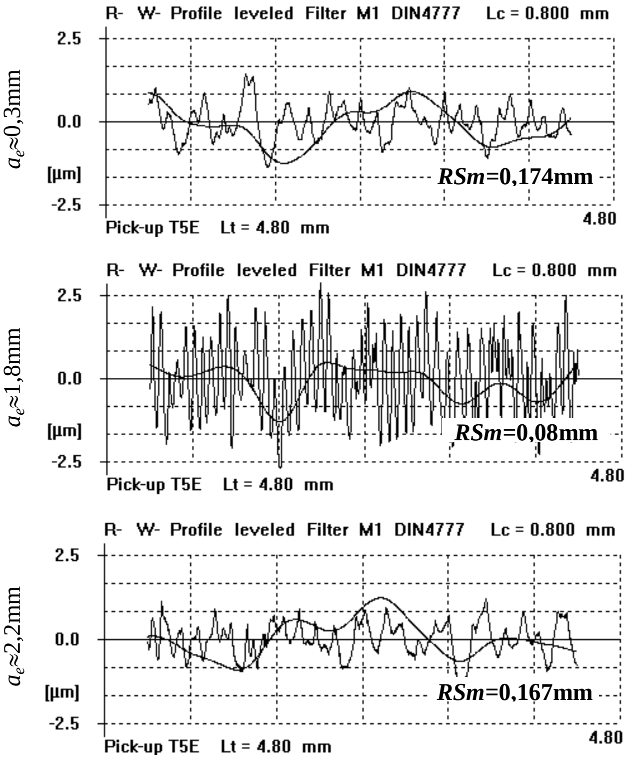


Figure 5 – Roughness R- and waviness W- profiles obtained after up end milling with various milling widths $a_e$


**References: 1.** *Ignatov, M.G., - Perminov, A.E., - Prokof'ev, E. Yu.* (2008): Influence of the Vertical Cutting Force on the Surface Precision and Roughness in Opposed Milling, Russian Engineering Research, Vol. 28, No. 9, p. 864-865. **2.** *Lee, S.K., - Ko, S.L.* (2001): Improvement of the accuracy in the machining of a deep shoulder cut by end milling, Journal of Materials Processing Technology, Vol. 111, p.244-249. **3.** *Liu, X.W., - Cheng, K., - Webb, D., - Luo, X.C.* (2002): Prediction of cutting force distribution and its influence on dimensional accuracy in peripheral milling, International Journal of Machine Tools and Manufacture, Vol. 42, p.791-800. **4.** *Martelotti, M.* (1941): Analysis of the milling process, Transactions of the ASME, Vol. 63, p. 667-700. **5.** *Montgomery, D., - Altintas, Y.* (1991): Mechanism of cutting forces and surface generation in dynamic milling, Journal of Engineering for Industry, Vol. 113, s.160-168. **6.** *Nowicki, B.* (1991): Struktura geometryczna. Chropowatość i falistość, WNT, Warszawa. **7.** *Radovanovic, M.* (2002): Determination of theoretical roughness profile height by peripheral milling, The Annals "Dunărea de Jos", Univeristy of Galati, Fascicle V, Technologies in Machine Building, p. 32-35. **8.** Materials of the Sandvik company.



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