INFLUENCE OF MATERIAL REMOVAL WAY ON THIN-WALLED PART QUALITY BY MILLING

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The article is focused on research of influence of material removal way on thin-walled part quality by milling. There were chosen three ways of material removal. Rib parts produced using these various ways of material removal showed different quality of surface already on visual inspection. To quantify the dimensional deviation of parts these were scanned by GOM ATOS 1350 and compared to CAD models. The results are colour deviation maps that showed suitability alternatively non-suitability of some of the ways of material removal and also influence of cutting environment on the quality of parts produced some of these ways.

Keywords:
thin-walled part, chatter, milling, 3D scanning, dynamic model

Introduction

Thin-walled parts are important in automotive, power and aerospace industry. Elastic thin-walled parts are such parts whose wall thickness is lower than 5 mm and the cut depth a_p is greater than 30 mm [Budak 1995]. A thin-walled profile is such a profile where the wall thickness t_i is low when considering other dimensions, deformations are small when considering the thickness of walls b_i, rigidity of laying is infinitely big [Trebuna 1999]. A thin-walled part is such a part where the thickness *h* is lower than height *b*, i.e. *(1/80~1/100)b<<h<<(1/8~1/5)b,* (where *h* is the wall thickness (mm), *b* is the wall height (mm)) [Aijun 2008]. By milling of thin-walled parts there occur cutting forces causing vibration of the part. This leads to decrease of their quality. The article is focused on research of influence of material removal way on thin-walled part quality by milling.

2. Selection of milling model

The dynamic model is built by a rigid tool and elastic workpiece (Fig. 1). The shape of the thin-walled part and tool selected for the experiment correspond with the milling model given. The selection of the milling model was influenced mainly by the effort to eliminate the tool vibration so that the workpiece became the elastic member of the set tool-workpiece. The model shows the way of upmilling with a single degree of freedom.

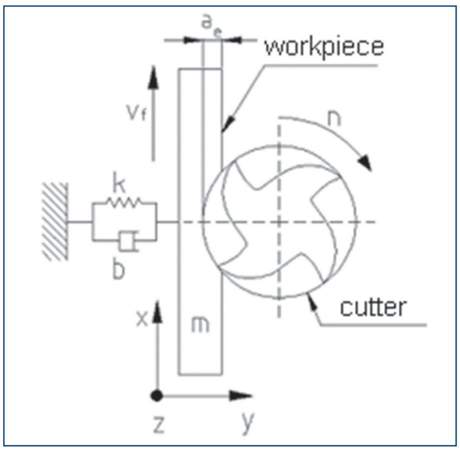

Figure 1. *Dynamic model of upmilling with a single degree of freedom*

3. Selection of experimental ways of material removal

We chose three ways of a large number of ways of material removal. Two ways are used by rib part milling (Fig. 3, 4) and a classical way of part milling (Fig. 2). Since the ways of material removal do not have exact names we decided to call them as follows:

1. SOM (blue colour) – it is the way of material take off (Fig. 2) used for milling of most of the parts, where first it comes to roughing of the part surface and after roughing the finishing of the part surface follows.

2. SOM (green colour) – it is the way of material take off used for milling of rib parts (Fig. 3), the milling procedure is divided into roughing and finishing. In this way the roughing alternates with finishing. One depth of cut *(a_p)* is by roughing and finishing is divided into smaller depths of cut.

3. SOM (orange colour) – is the way of material take off used for rib parts milling. The machining/milling procedure is the same as by 2 SOM with the difference that by 3 SOM there are two depths of cut a_{p1} and a_{p2} (Fig. 4). The depth of cut a_{p2} is smaller than a_{p1} and is applied on the first level and removes by the last level.

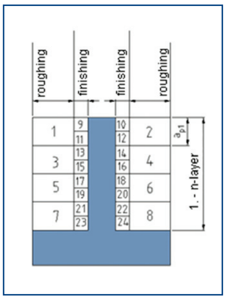

Figure 2. *SOM*
a_{p1} – first depth of cut

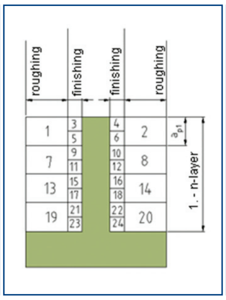

Figure 3. *SOM*
a_{p1} – first depth of cut

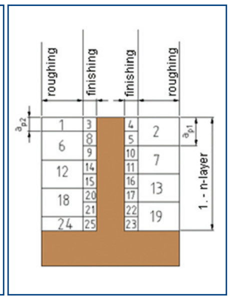

Figure 4. *SOM*
a_{p1} – first depth of cut,
a_{p2} – second depth of cut

4. Experimental proposal

To experiment conditions we include the machine, workpiece shape and size and subsequently the final shape of the rib part, tool, cutting conditions, cooling medium and software's.

- *Machine* – DMG HSC 105 linear with Heidenhain iTNC 530 control system, spindle frequency of revolutions is 42 000 min^{-1}, by experiments the spindle frequency of revolutions 10 000 min^{-1} was used.

- *Measurement instrument* – GOM ATOS I 350 3D optical scanner with measuring volume MV240, for obtaining the dimension deviation after machining, un-coded reference point 3,2 mm diameter

- *Softwares* – ATOS 6.0.2-5 software for obtaining 3D scan of a real part and colour deviation maps. CIMCO Edit 5 for simulation of generated tool path. PowerSHAPE CAD software for rib parts models development.

- *Tool* – end mill with tip radius (Fig. 5), with MEGA-T coating, the tool selection was consulted with the tool producer SECO TOOLS Company. The tool is used for machining the aluminium alloys [SECO TOOLS 2010]. Tool overhang was 60 mm.

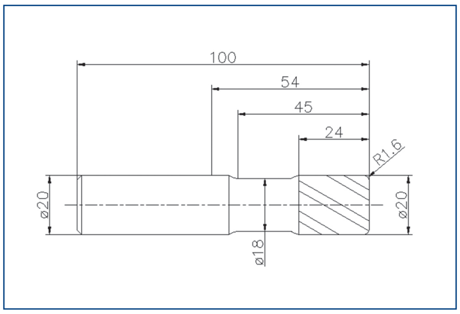

Figure 5. *Tool dimensions*

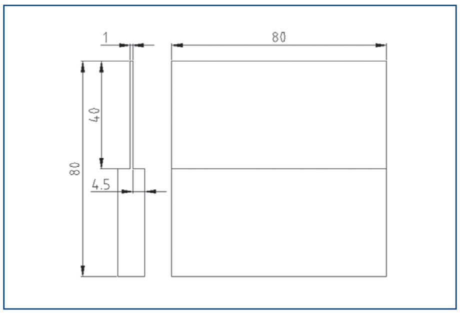

Figure 7. *Final shape of a part*

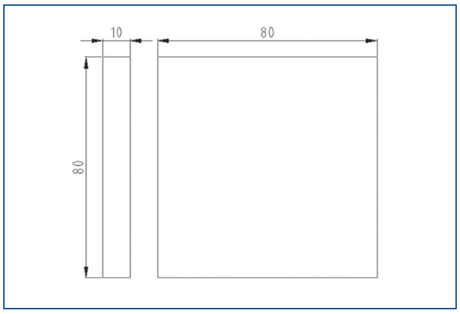

Figure 6. *Shape of experimental samples (semiproduct)*

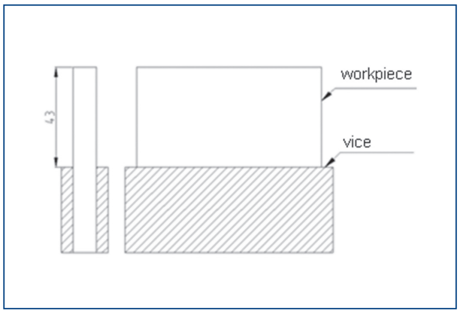

Figure 8. *Overhang of a part in vice*

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
Amount [%]	0,7 – 1,3	0,5	0,1	0,4 – 1,0	0,6 – 1,2	0,2	0,1	0,25	remainder

Table 1. *Chemical composition of EN AW 6082 aluminium alloy [IMC 2010]*

EN standard	Forming	Welding	Machining
6082	bad	good	good

Table 2. *Suitability of EN AW 6082 aluminium alloy for various applications [IMC 2010].*

- *Workpiece material* – EN 6082 aluminium alloy. Chemical composition is shown in Tab. 1, 2. The semiproduct shape is illustrated in Fig. 6 and the final shape of the part after milling is shown in Fig. 7.

- *Parameters of cutting process* – cutting speed – v_c = 638 [m/min], feed per tooth – f_z = 0,125 [mm], depth of cut – a_p = 4 [mm], width of cut – a_e =1 [mm] are the most important parameters of the cutting process.

- *Cooling medium* – we used compressed air and 5% emulsion BlasoCut by Blaser Company as a coolant.

- *Fixture* – machine vice, semiproduct overhang in the vice was 43 mm (Fig. 8).

5. Evaluation of thin-walled part surface quality

Thin-walled parts produced via various ways of material removal visibly showed the difference in the surface quality. As a result of the change in the way of material removal, waves appeared on the parts surface which was caused by the thin-walled part vibration in milling, this resulted in the dimensional change of the thin-walled part (wall thickness). To quantify the dimension deviation of thin-walled parts, the produced part were scanned by optical 3D scanner GOM ATOS I and subsequently compared with CAD model. We can see the comparison in the colour deviation maps which provide information on real dimension deviation. Coloured deviation maps transparently illustrate the difference in produced parts quality. The process of developing the colour deviation map is shown in Fig. 9.

The following part provides colour deviation maps of rib parts produced by three ways of material removal. Individual surfaces refer to colour deviation map which was developed by the connection of CAD model and 3D scan of the real part. The colour map illustrates the deviation. Differences of all ways of material removal occurred on parts are shown in Figs. 10 to 21.

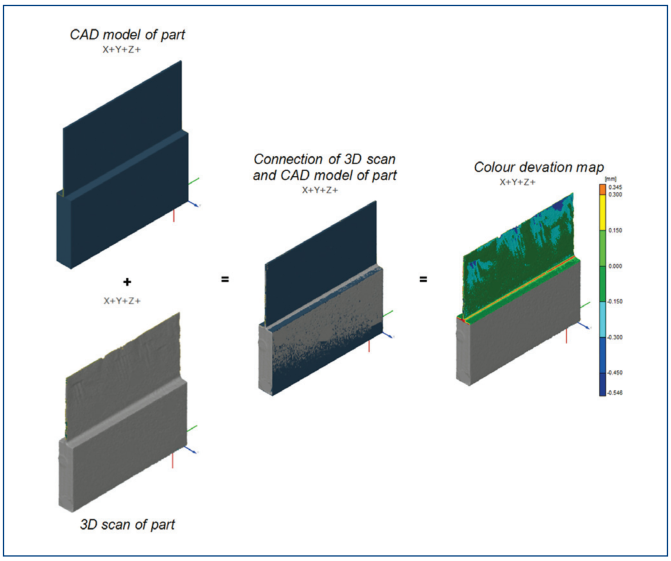

Figure 9. *Scheme of colour deviation map development*

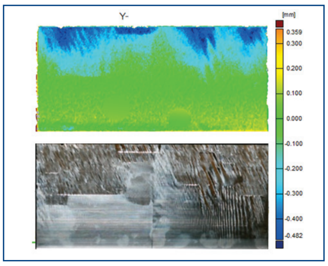

Figure 10. *Face side of rib part wall (1 SOM, a_p = 4 mm, air)*

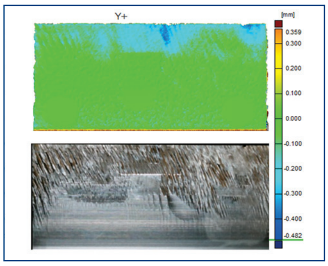

Figure 11. *Back side of rib part wall (1 SOM, a_p = 4 mm, air)*

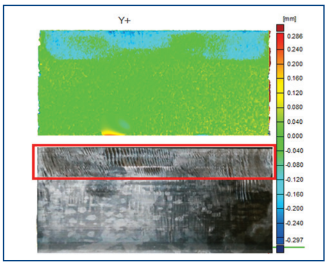

Figure 12. *Face side of rib part wall (1 SOM, a_p = 4 mm, 5% emulsion)*

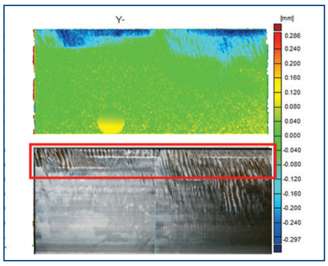

Figure 13. *Back side of rib part wall (1 SOM, a_p = 4 mm, 5% emulsion)*

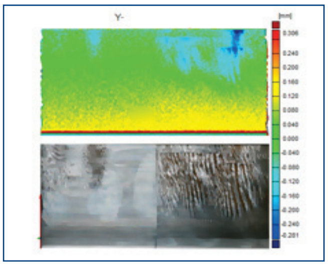

Figure 14. *Face side of rib part wall (2 SOM, a_p = 4 mm, air)*

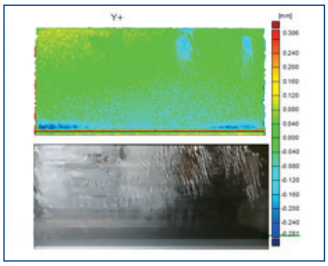

Figure 15. *Back side of rib part wall (2 SOM, a_p = 4 mm, air)*

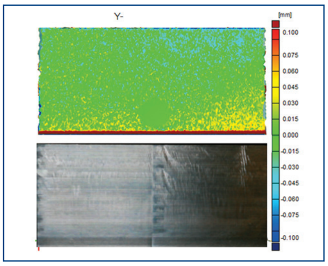

Figure 16. *Face side of rib part wall (2 SOM, a_p = 4 mm, 5% emulsion).*

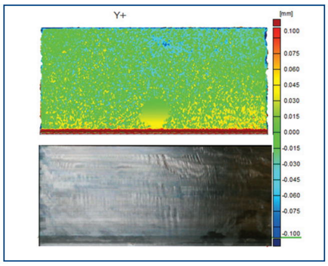

Figure 17. *Back side of rib part wall (2 SOM, a_p = 4 mm, 5% emulsion)*

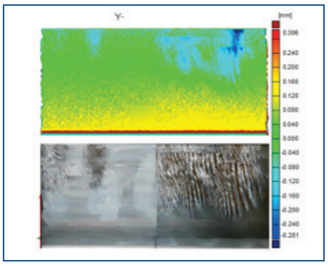

Figure 18. *Face side of rib part wall (3 SOM, a_{p1} = 4 mm, a_{p2} = 2 mm, air)*

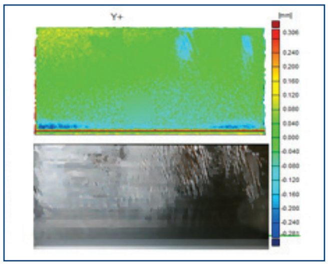

Figure 19. *Back side of rib part wall (3 SOM, a_{p1} = 4 mm, a_{p2} = 2 mm, air)*

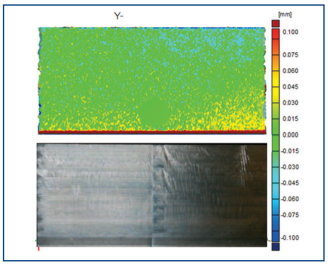

Figure 20. *Face side of rib part wall (3 SOM, a_{p1} = 4 mm, a_{p2} = 2 mm, 5% emulsion).*

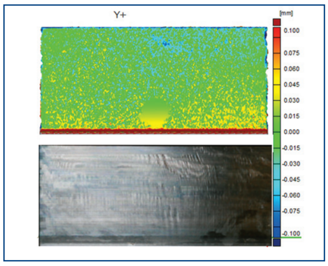

Figure 21. *Back side of rib part wall (3 SOM, a_{p1} = 4 mm, a_{p2} = 2 mm, 5% emulsion)*

6. Discussion

Milling of thin-walled parts by using air was accompanied by unpleasant sound. In general, we can say that 1 SOM is not suitable for thin-walled rib parts milling. The surface quality by 1 SOM was the worst one that was caused by the way of material removal. Usage of this way would be possible for smaller depths of cut. By 2 SOM and 3 SOM the part surface quality decrease is visible as well.

If we compare the face and back sides of the part wall, we can see the difference in the surface quality. The difference can be caused by incorrect air (emulsion) supply to the back wall side. Further the surface quality can be influenced by the change of thin-walled part rigidity during milling. This effect can be followed on pictures 10 to 21 of the real thin-walled surfaces. The tool enters to and exits of the material in the middle of the workpiece because the deflection in the middle is lower than on the edge [Buransky 2011].

A significant difference occurred by the change of cutting process using 5% emulsion Blasocut BC 25. Using 5% emulsion the surface quality was the worst, only by 1 SOM, especially in the upper part (Figs. 12, 13), where the waved surface can be seen (red frame). For the machining of thin-walled parts we strongly recommend to use the cutting fluid since it significantly improves the machined surface quality. The best surface quality was achieved by 5% emulsion by 2 SOM (Figs. 18, 19) and 3 SOM (Figs. 20, 21), these parts showed almost no visible waves on their surfaces.

7. Conclusions

During the experiment there were followed and evaluated also accompanying effects of the machining process (cutting forces). The modal and harmonic analysis was prepared. Listed measurements and analysis proved good conformity with results of machining processes from the quality of produced parts point of view [Buransky 2011].

Findings obtained by the research can contribute to increase of the quality of produced thin-walled parts. These are used also in pedagogical process within study programs Computer Aided Production Technologies and Computer Aided Design and Production [Baranek 2013].

The article is focused on 3-axes milling of thin-walled parts. The results of another research [Kovac 2012] expanded research of this issue to 5-axis machining. There was detected that in case of 5-axis machining it is necessary to use other ways of material removal by machining of thin-walled parts.

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Refereces

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