Journal of Machine Engineering, 2018, Vol. 18, No. 1, 80-87
ISSN 1895-7595 (Print) ISSN 2391-8071 (Online)

Received: *27 November 2017* / Accepted: *29 January 2018* / Published online: *12 March 2018*

process precision, face milling,
radiator, paths strategies,
flatness deviation

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THE EFFECT OF ALTERNATIVE CUTTER PATHS ON FLATNESS DEVIATIONS IN THE FACE MILLING OF ALUMINUM PLATE PARTS

In this paper the relationships between the alternative machining paths and flatness deviations of the aluminum plate part, were presented. The flatness tolerance of the main surface of the plate part has crucial meaning due to the assembly requirement of piezoelectric elements on the radiator. The aluminum bodies under investigation are the base part of the radiators with crimped feathers for the train industry. The surface of the aluminum plate part was milled using three different milling strategies: along of longer or shorter side of workpiece and at an angle of 45°. The aluminum bodies were machined on milling centre ecoMILL 70 DMG MORI. The flatness deviation measurements were carried out on the Coordinated Measuring Machine Altera 7.5.5 Nikon Metrology NV. These measurements were made during the manufacturing process of the radiator, namely after machining, however, before the process crimping of feathers. The results that were obtained enables the validation of assumed milling path strategies in connection of the subsequent machining and assembly processes.

1. INTRODUCTION

Optimization of the face milling operations is aimed at selecting the right machining strategy, which will allow achieving better quality while lowering the energy demand of the cutting process. Such optimizations are often performed on the basis of production tests, but FEM simulations [1] and CAD/CAM simulations [2] are proposed more and more frequently.

Research studies have shown that selecting the proper machining strategy might have a significant impact on the quality of the flat surface [3,4]. One of the factors that has an effect on the quality of the surface to be machined is a kind of the fixture system of the workpiece, especially its flatness deviations. The design and optimization of fixture layout and structure, fixture force, and its sequence, computational analysis of fixture status, etc., were thoroughly studied for the improvement of machining accuracy. The preload from

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DOI: 10.5604/01.3001.0010.8825

the side-clamping force is a vital factor affecting workpiece flatness. On the other hand, when preloading from side clamping is not crucial, mainly thermal deformation of the plate-shaped body has a distinct effect on deviations. The simultaneous control with computational analyses of the above parameters enables minimization of flatness deviations after machining [5,6]. State-of-the-art CNC machine tools, new cutting tool designs and advance materials give many possibilities to improve workpiece surface accuracy e.g. flatness exploiting machining process optimization, for example in face milling process by means of cutting depth compensation method or optimization of the feed rate [7], tool path and workpiece orientation analysis [3,4].

The purpose of the studies was to investigate, which machining strategy would allow lower values of flatness deviation, assuming that the fixturing method and machining parameters were not changed. The method of the workpiece fixturing in this case is determined by the proportions of the part dimensions to the size of the machine tool work table. A change in the type of fastening would entail rising costs for the purchase of specialized equipment and therefore, it was decided to look for opportunities to improve the quality of machining using another machining strategy.

2. MATERIAL AND METHODS

2.1. WORKPIECE MATERIAL

The plate parts were made of aluminium grade EN AW 6082-T651 (according to the standard PN-EN 485). Mechanical properties of the material according to EN755-2: yield stress $R_{p0.2}$ = 260 MPa, tensile strength R_m = 310 MPa, hardness 9 HB. The chemical composition is shown in Table 1. The raw-material for manufacturing bodies of radiators was a plate with thickness 20 mm, which was cut on the circular sawing machine to the desired size of 623 × 411 mm.

Table 1. Chemical composition of material EN AW 6082 according to EN-573-3:1994 (weight%, remainder Al)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Others
0.7 – 1.3	Max. 0.5	Max. 0.1	0.4 – 1.0	0.6 – 1.2	Max. 0.25	Max. 0.2	Max. 0.1	0.05 – 0.15

2.2. FACE MILLING

The machining of aluminium plate parts was carried out on the milling centre ecoMill 70 DMG MORI, which is located at Radmor S.A. WB Group company in Gdynia, Poland. The face milling was performed with the use of the face milling head with six cutting tool inserts, diameter D = 80 mm and approach angle (tool cutting edge angle) κ_r = 45° (f. PAFANA, Poland). The face cutter was equipped with cutting tool inserts type

SEHT 1204 AFFN-A grade of cemented carbide of the species NK20M (K20 according to ISO grade classification) with chip breakers of type A [8]. This kind of cutting tool inserts is dedicated to machining of aluminium material. The aluminium plate part was damped on machine tool work table with the use of 6 pieces side clamps NU10 by Lenzkes company.

On the opposite side of the plate part only grooves (for the crimped feathers) were machined, however, the rest of the surface was not face milled. The next operation was face milling of primary flat surface of the plate part. On the analysed main flat surface was machined the circumferential groove under the seal, which divided this surface into two parts: Basic plane and Flange plane (Fig. 1). The face milling operation of primary flat surface is essential, while excessive values of flatness deviation of the surface after being machined, can cause damage to piezoelectric components when assembled into the radiator. The main flat surface was machined using three types of milled strategies: along the longer (Strategy #1) and shorter (Strategy #3) side of the workpiece and at an angle of 45° (Strategy #2) (Fig. 2).

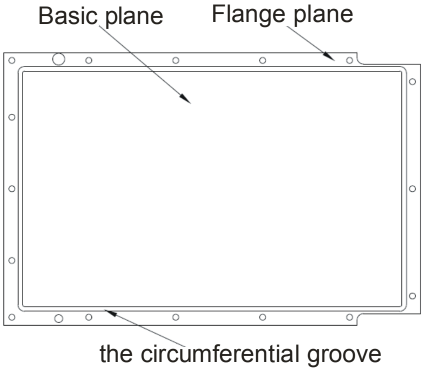

Fig. 1. Basic plane and Flange plane separated by a groove

The distance between the tool paths of 60 mm was established, it led to the width of the face cutter in the next passage overlapping the previous passage with width of 20 mm. The machining parameters of the flat surface were as follows: rotational speed n = 1050 min^{-1} (cutting speed v_c = 264 m/min), feed speed v_f = 600 mm/min (feed per tooth f_z = 0.095 mm), cutting depth a_p = 0.7 mm. The movements of the tool were performed by the machine tool in accordance with the CNC program on the Heidenhain TNC 620 control system.

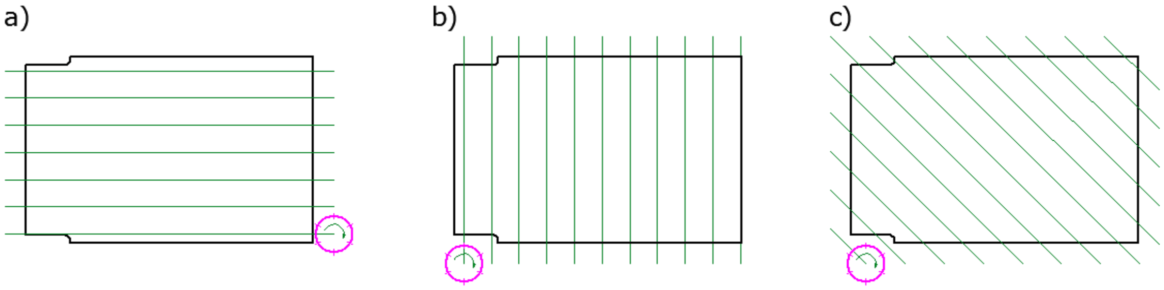

Fig. 2. Machining strategies along the longer – Strategy #1 (a) and shorter – Strategy #3 (b) side of workpiece and at an angle of 45° – Strategy #2 (c)

2.3. MEASUREMENT OF FLATNESS DEVIATIONS

The measurements of flatness deviations were carried out on the Coordinated Measuring Machine Altera 7.5.5 Nikon Metrology NV with the software CMM Manager, which is located at the Gdansk University of Technology, Mechanical Engineering Faculty, Department of Manufacturing Engineering and Automation.

The whole flat surface, for which the flatness deviation measurements were made, has been divided into two parts: the Basic plane and the Flange plane. This division was due to the difference in the admissible flatness deviations for both flat surface parts. For the Flange plane are not required low values of deviations flatness, because it is designed to mount the radiator on the cabinet of the device. Whereas, the Basic plane should have low values of flatness errors, because fragile piezoelectric elements are mounted on it. For each of these parts a separate measurement was done.

The measurement of flatness deviations for the Basic plane includes 60 measuring points. On the Flange plane were 84 measuring points. The number of measurement points was chosen according to Bartkowiak and Gessner's proposal [9], since, that number is sufficient to obtain the maximum deviation from the baseline with the probability of 90%.

3. RESULTS AND DISCUSSION

For the Basic plane, the mean value and median of the flatness of all test samples were at a similar level, it indicating the stability of the received data, although the dispersion of test results was approximately 0.06 mm (Table 2). It could be emphasized, that for the Flange plane, the average flatness deviation of the test samples was greater by 0.042 mm from those obtained for the Basic plane. Likewise, in this case the mean value and median of the samples were at similar level. However, the dispersion of results was much higher, close to 0.09 mm.

Table 2. Main statistics of flatness deviation for basic and flange plans

	Basic Plane				Flange Plane			
	Max	Min	Mean	Median	Max	Min	Mean	Median
Flatness [mm]	0.177	0.119	0.144	0.138	0.236	0.145	0.186	0.180
Max deviation [mm]	0.100	0.068			0.123	0.069		
Min deviation [mm]	-0.050	-0.082			-0.076	-0.127		
RMS	0.060	0.042			0.084	0.054		

The largest flatness deviations for the Basic plane were obtained for radiator plates machined along the longer side (Table 3). Measured values of the flatness were in the range: 0.177–0.172 mm, with a maximum deviation of 0.1 mm and a minimum of 0.082–.072 mm. Figure 3 presents views of deviations at the individual measurement points for the Test sample #1.

Table 3. Measuring results of the Basic plane for the machining path strategies under investigation

	Strategy #1		Strategy #2		Strategy #3	
Test sample No.	1	2	3	4	5	6
Flatness [mm]	0.177	0.172	0.139	0.119	0.119	0.136
Max deviation [mm]	0.095	0.100	0.081	0.070	0.068	0.083
Min deviation [mm]	-0.082	-0.072	-0.058	-0.050	-0.051	-0.053
RMS	0.060	0.051	0.042	0.043	0.042	0.045

The largest flatness deviations for the Basic plane were obtained for radiator plates machined along the longer side (Table 3). Measured values of the flatness were in the range: 0.177–0.172 mm, with a maximum deviation of 0.100 mm and a minimum of 0.082–0.072 mm. Figure 3 presents views of deviations at the individual measurement points for the Test sample #1.

On the other hand, in the case of strategy with face milling at the 45° angle to the side of the radiator and finally along the shorter side of the radiator plate, lower flatness deviation values were observed, but with a greater variance of 0.02 mm. In both cases the flatness deviation ranges between 0.119 and 0.139 mm and was even lower by 0.06 mm in comparison with those obtained in Strategy #1. The maximum and minimum deviation values were at similar level, Fig. 4 presents the results for the Test sample #4.

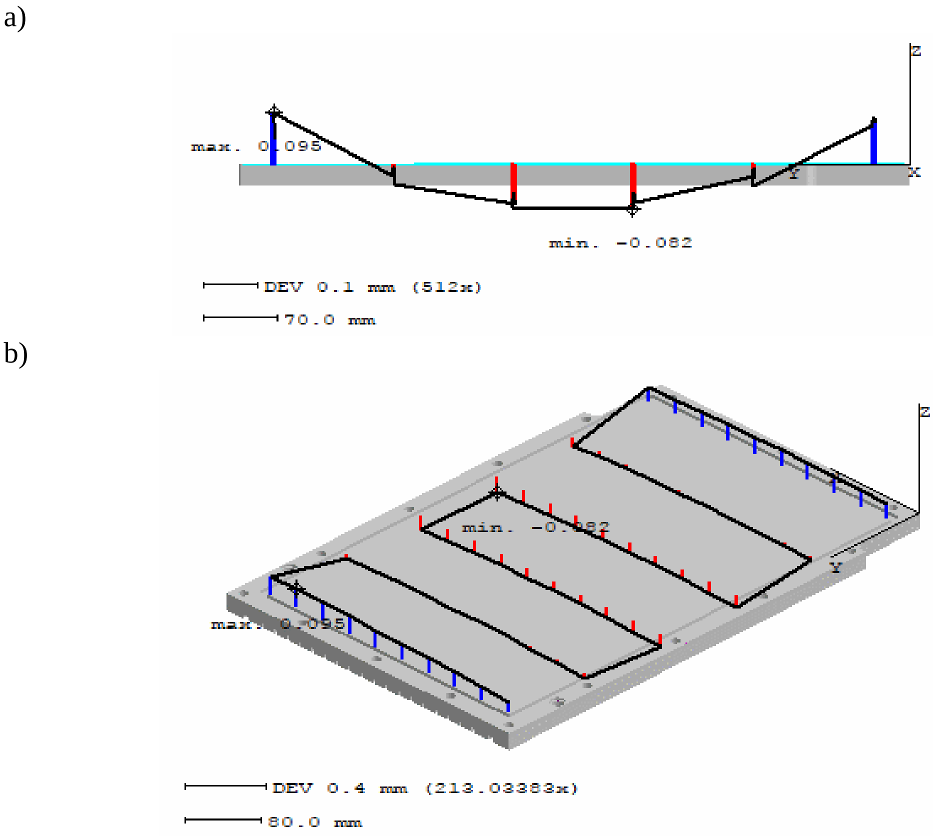

Fig. 3. Flatness deviations of the Test sample #1, Strategy #1: side (a) and isometric (b) view

Table 4. Measuring results of the Flange plane for the machining path strategies under investigation

	Strategy #1		Strategy #2		Strategy #3	
Test sample No.	1	2	3	4	5	6
Flatness [mm]	0.236	0.223	0.183	0.145	0.152	0.176
Max deviation [mm]	0.109	0.123	0.094	0.069	0.074	0.096
Min deviation [mm]	-0.127	-0.100	-0.089	-0.076	-0.078	-0.080
RMS	0.084	0.074	0.055	0.054	0.055	0.055

For the Flange plane as well as for the Basic plane, the largest deviations were observed for machining path strategy #1: flatness values were about 0.236–0.223 mm, with a maximum deviation of 0.123 mm and a minimum of -0.127 mm (Table 4). The flatness deviations for machining path Strategies #2 and #3 were between 0.145–0.183 mm and were even lower by 0.09 mm than those obtained in Strategy #1. Exemplary deviation views for Test samples #1 and #4 are shown in Fig. 5 and Fig. 6 respectively.

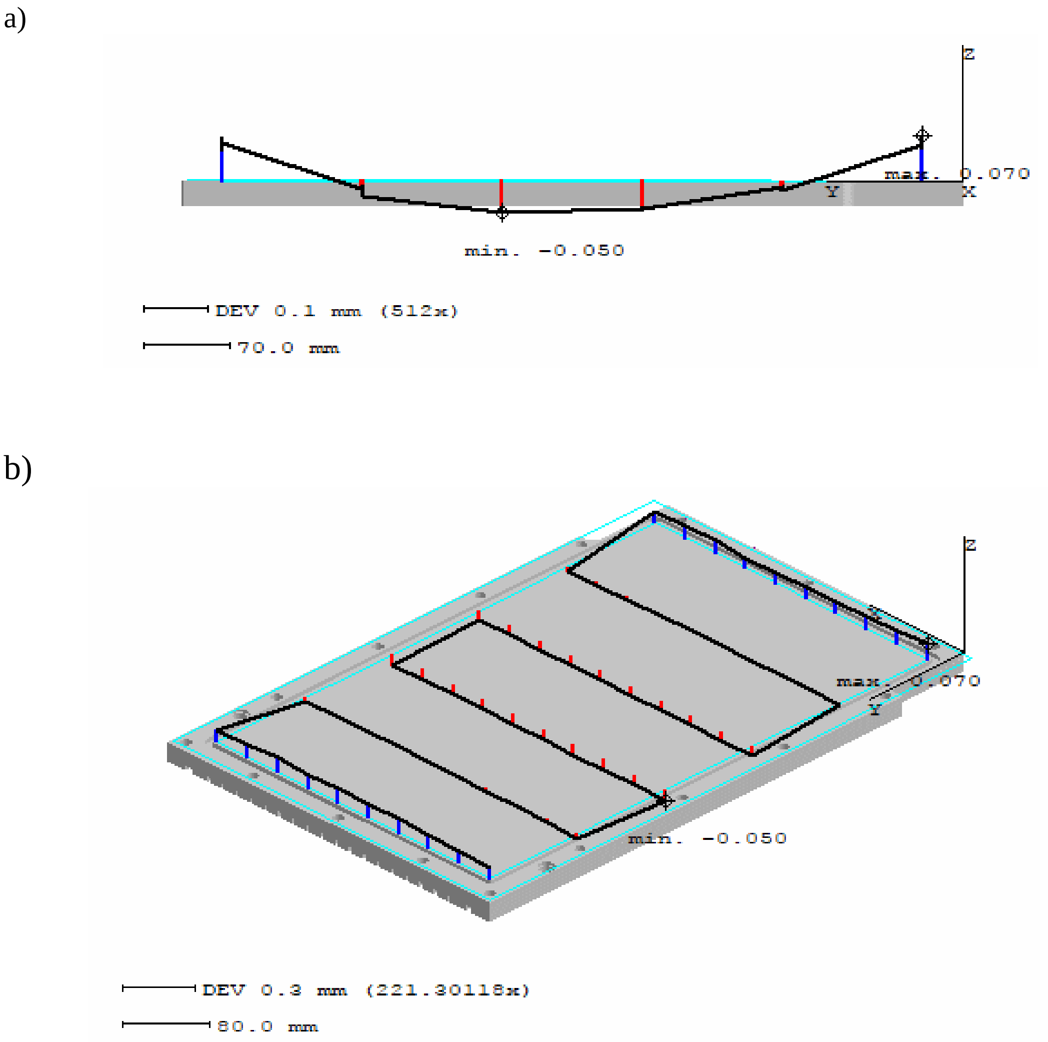

Fig. 4. Flatness deviations of the Test sample #4 ,Strategy #2: side (a) and isometric (b) view

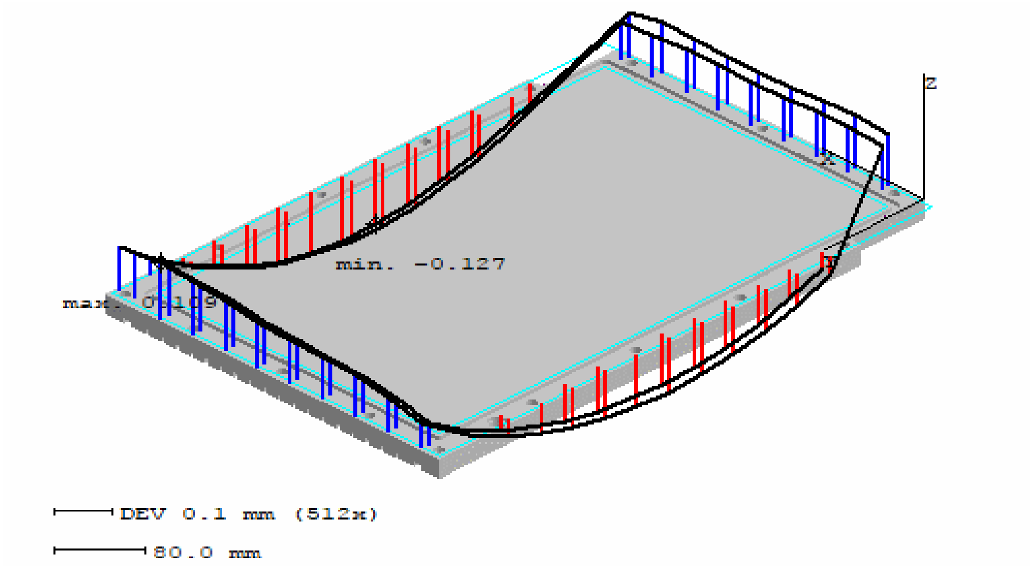

Fig. 5. Flatness deviations of the Test sample #1, Strategy #1

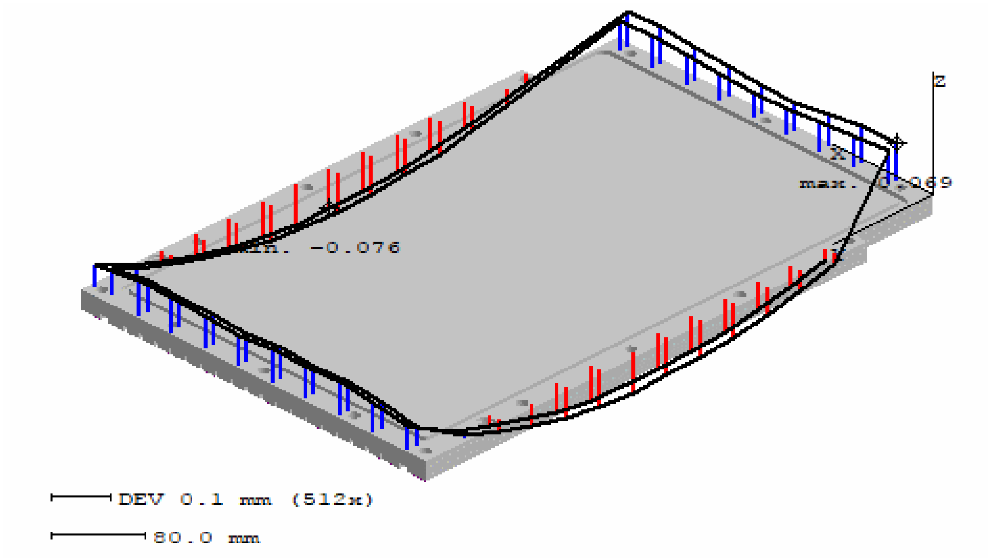

Fig. 6. Flatness deviations of the Test sample #4,Strategy #2

Comparable to the Basic plane in all test samples regardless of the adopted machining path strategy noticeable U-shape of deviations with extremes in central and side parts of the plate can be observed.

4. CONCLUSIONS

The conducted analyses of the effect of the face milling strategy upon flatness errors revealed that the length of the face milled section affects the values of flatness deviations. The longer the face milling section, the greater the values of flatness deviation.

For all three milling strategies tested deformations in the U-shape were observed, and it can be caused by the fixture system of the plate part. The greatest flatness deviations were obtained for Strategy #1 (along the longer side). The both Strategies #2 and #3 have given comparable effects.

The plate part was fixed by means of clamps on the long sides. The edges of plate part on sides, which were not clamped by the fixturing could be bent during the exit of the tool insert into the workpiece, and this phenomenon could cause greater maximum values of flatness deviations in this area.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Mechanical Department of the RADMOR S.A. company for materials and tools used in the presented investigation.

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