

# High speed machining of the thin-walled aircraft constructions

## Obróbka z wysokimi prędkościami skrawania cienkościennych konstrukcji lotniczych

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DOI: <https://doi.org/10.17814/mechanik.2017.8-9.105>

Machining operations of thin-walled elements generate a lot of production process issues related to deformations and elastic and plastic displacements of the workpiece. Due to displacements of the milled workpiece, vibrations can occur, and thus, geometric errors may occur on surface in the structure of the workpiece. Furthermore, plastic deformation can also cause shape problems and be a source of internal stresses in the **surface layer, which are highly difficult to remove and lead to deformation of the workpiece after machining**. Consequently, this leads to an increase in the manufacturing costs of machining operations, especially of thin-walled elements, due to shortages and increased manufacturing time. It is recommended that multiple methods for minimizing machining errors be utilized to improve the quality of thin walled elements, such as: optimization of the machining strategy, increase of the cutting speed  $v_c$ , optimization of cutting parameters, especially feed per blade  $f_z$ , the radial depth of cut  $a_e$  due to the minimization of the cutting force component perpendicular to the surface of the milled wall.

**KEYWORDS:** high speed machining, milling, thin-walled constructions

HSM (high speed machining) is used in the aerospace industry, especially in the processing of aluminum alloys [6]. The HSM distinguishes itself from other milling techniques, is such selection of parameters as the milling width, cutting depth, feed and cutting speed – which ensures good quality and accuracy of the workpiece's dimensions and shapes while also delivering high productivity to shorten the manufacturing process of integral parts.

Introducing the HSM method makes it possible to make very complex integral thin-walled aircraft parts. At present, the design of the aircraft structure is designed to consist mainly of integral components which, in previously used technologies, have been produced by joining parts by welding, welding or riveting. These include ribs, longitudinal members, girders and frames, as well as body and wing coverings. After milling these parts are assembled into larger assemblies.

High-speed machining allows economical production of integral parts by reducing the machining time, but also improves the quality of the machined surface, since the cutting forces are considerably smaller than in conventional machining operations [1, 5].

One of the main factors determining the introduction of the HSM method in the aerospace industry is the productivity of the cutting process  $Q$  in  $\text{mm}^3/\text{min}$ , dependent on the depth and width of cutting  $a_p$  and  $a_e$  and feed  $V_f$  [4,8]. Excessive cutting parameters, especially feed rate and depth, cause an adverse effect such as chatter. The range of permissible, stable operation of the machine is presented by the so-called bag curve depicting the depth of cut from the tool rotational speed for the remaining process parameters.

In the case of thin-walled constructions, the ratio of the height to the thickness of the milled wall is a representative parameter; it can be [7]:

- small <15:1,
- moderate >15:1 to <30:1,
- high >30:1.

This factor affects the stiffness of the workpiece, and consequently the deformation produced during machining. In order to reduce the wall deflection, a suitable number of tool passages is used and reduces the contact time of the tool to the workpiece by using a high cutting speed and low cutting depth ratio  $a_p$  to the width of the  $a_e$  cut layer. The stability of the tool and the workpiece is important. In the case of less rigid support of the milled piece of the thin-walled object, use a counter-rotating milling. At a height-to-thickness ratio of less than 15:1, one side of the wall is treated in non-overlapping transitions. Repeat the milling for the other side. It is also useful to divide the machining allowance into parts for roughing and finishing, with appropriate depths of cut.

### Subject of study

The object of the work was an aircraft made of aluminum alloy 7075 (EN 10204) with a chemical composition: Al 89.72%; Cu 0.09%; Mn 0.11%; Mg 1.6%; Zn 0.03%; Si + Fe 2.5%. Two panels of  $60 \times 1190 \times 1215$  mm

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and a weight of 243 kg were used as semi-finished materials. The dimensions of the workpiece were as follows: 1012×1354×55.8 mm. The walls were 1, 2 and 3 mm thick. The greatest flat free surface (no ribs) was 385.4×393×1 mm. The ratio of the height of the ribs to their thickness  $h/g$  was in the range of 10÷12.9. The rays pass between the walls and the ribs were 2 mm.

The frame was milled on DMG MORI DMU 75 machine tools (roughing). Two versions of the machining have been realized. Deficient roughing treatment was done with spindle  $n = 15\,000$  rev/min, and was for the preparation of bases for subsequent machining operations. Object mounted on the machine table by means of clamping claws.

The details were made in two phases: shaping and finishing. The work was carried out on two parts (and two machine tools) simultaneously, using symmetrical and asymmetrical processing of the pocket. For asymmetrical machining, the milling of the pocket was alternated with respect to the symmetry axis of the frame. At the end of the work, the frame deformation was evaluated.

Two-sided execution of the pockets required preparation of machining bases and bases necessary for fixing and fixing the workpiece on the machine (fig. 1). For this purpose, a cylindrical flange was proposed and made from a blank, forming a machining base, and the holes allowed to fix the workpiece on the machine table. These databases have been removed in the final machining operations frames, after its finishing.

According to the assumptions of the construction documentation, the tolerance of the linear dimensions of the frame is determined by the norm BN-85/3813-79 – Deviations of dimensions, shape and position for aeronautical products. For gable frame these tolerances are  $g = 1\div3$  mm, deviations: 0 to  $-0.25$  mm. The rib height  $h = 20$  to 25.8 mm, the deviation from 0 to 0.52 mm. For the overall dimensions of the design documentation 1012×1354 mm deviation are: 0 to  $-2.6$  mm.

Machining of the frame covered two stages: pre-treatment and finishing. The number of passes in all

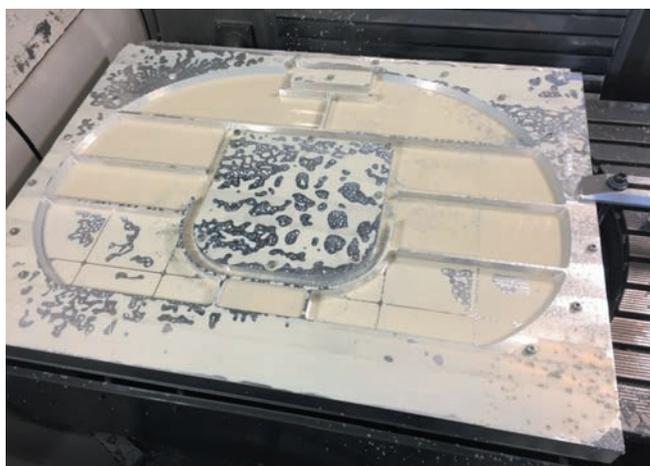


Fig. 1. Fixing the frame with the use of technological bases and additional holes made when milling the pocket

cases was determined by the wall dimensions and the axial depth of cut. The basic requirement was to ensure that this process was carried out in such a way that, in particular with regard to the ribs, the minimum deflection was achieved, and that the surface roughness was additionally achieved during finishing. In the workmanship, the final tolerances were 2 mm for large faces and about 0.2 mm for ribs of 1÷3 mm. In order to reduce the deflection of the wall during machining, the forces occurring during cutting were reduced. This effect is achieved by high cutting speed high feed per tooth.

Another succession of high-accuracy slabs (height/thickness ratio of about 13) was the right strategy. The best results were obtained by alternating pocket processing, with the change of processing sides and machining to the same level in each pocket [14]. In the case of thin walls, counter-rotating milling was used. The highest milling yield was obtained with a milling cutter  $\varnothing 16$  mm, and the lowest roughness and surface weld was obtained with a milling cutter  $\varnothing 8$  mm, with a rotational speed of 20,000 rpm.

As a result of the treatment, the frame was obtained in accordance with the construction documentation (fig. 2).

The weight of the finished frame was 3.15 kg and the weight of the starting material was 243 kg, i.e. the weight of the product was 1.3% of the batch material. 98.7% of the blank were changed into chips. Thus, the buy-to-fly ratio (weight ratio of the starting material to the weight of the finished part) was 77.1. On this basis it can be stated that the use of HSM milling for the construction of thin-walled structures – although the mass of chips can be up to 95% of the batch material – is justified. It should be emphasized that the weight of the original frame used on the aircraft so far is 3.85 kg.



Fig. 2. Ready-made frame of an airplane produced in the milling process

In order to check the shape, dimensions and spatial displacements of the frames, the optical measurement was performed using a GOM scanner (fig. 3). These tests allow to determine the linear dimensions of particular elements of the frame and to create digital and

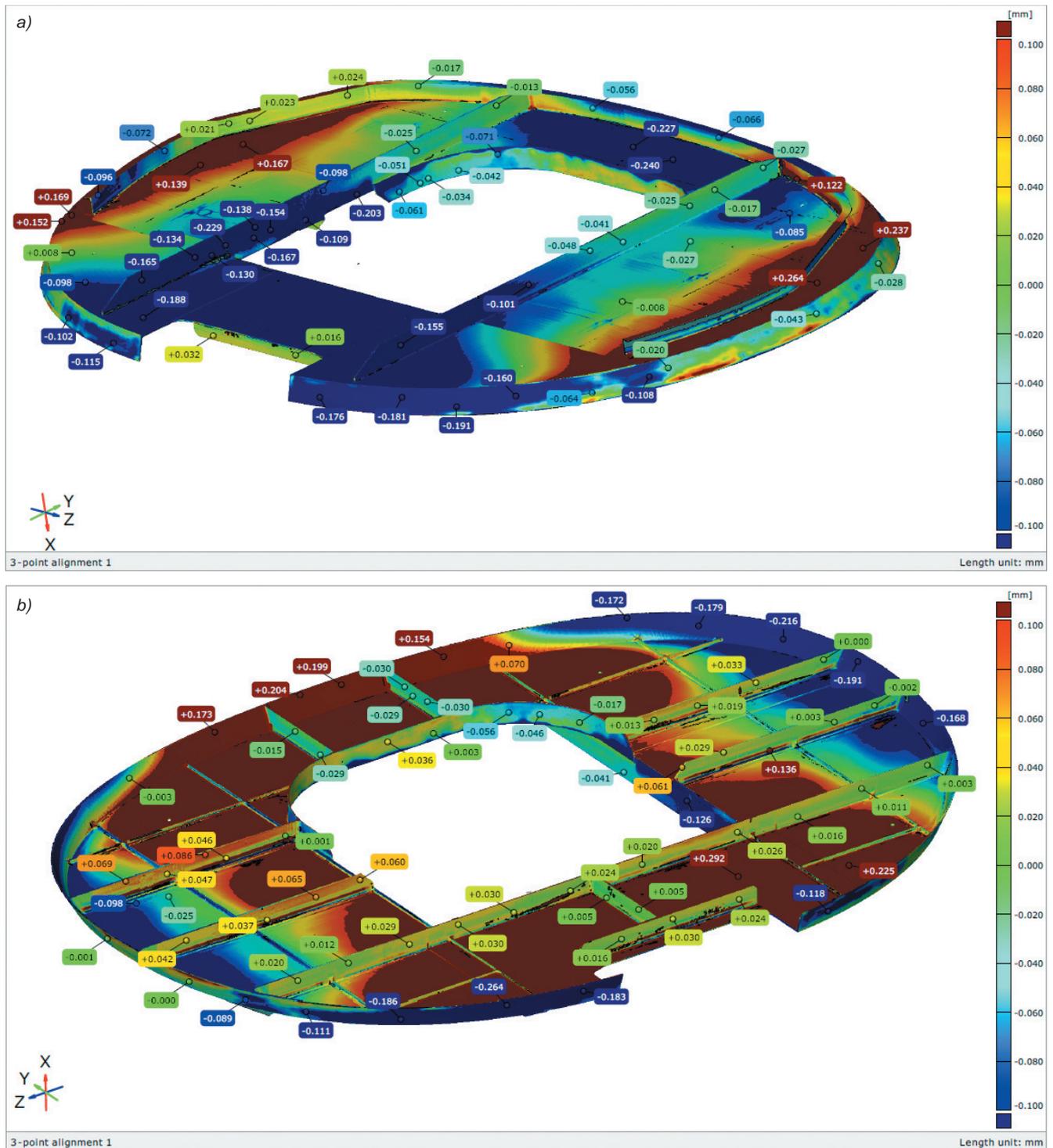


Fig. 3. Maps of frame elements displacement after HSM milling: a) top view, b) bottom view

contour maps that represent stereometry of the frame. The maps allow to determine the displacement of the large surface of the frame, resulting from the stresses generated in the structure during machining [2, 3]. Analysis of the measurement results indicates that the deviation of the linear dimensions is within the tolerances provided. The plate is deformed primarily with respect to the shorter axis of symmetry. The displacement coordinates are symmetrical to the longer axis. The largest displacements are 0.57 mm. The results should be treated as existing preferences displacements and evaluate them in the context of the measuring method used. The

GOM type scanner provides accurate measurements at  $\pm 0.25$  mm, and consequently, results can be burdened with errors. This method, however, in a qualitative way shows what deformation should be expected when processing products of similar structure.

To accurately assess the thickness of the ribs that are most relevant for structural strength, they were measured with a micrometer. Measurements were made at the points where the largest displacements were expected during mechanical machining: at the base of the ribs and at their apexes. The results of the measurements are shown in Table.

TABLE. Dimensions of selected wall thicknesses

Point number	Dimension at base	Dimension on top	Point number	Dimension at base	Dimension on top	Point number	Dimension at base	Dimension on top
1	2,00	2,02	11	3,01	3,01	21	2,01	2,02
2	2,01	2,02	12	2,05	2,01	22	2,05	2,02
3	2,01	1,95	13	2,01	2,01	23	1,99	2,00
4	1,95	2,02	14	2,01	2,01	24	1,05	
5	2,00	2,02	15	2,00	2,02	25	1,07	
6	2,05	2,00	16	2,00	2,00	26	1,06	
7	1,96	1,95	17	2,00	2,00	27	2,00	2,02
8	1,95	1,96	18	1,98		28	2,00	2,01
9	2,00	2,05	19	2,00		29	2,01	2,02
10	3,01	3,01	20	1,95		30	2,01	2,01

To evaluate the shape, dimensions and displacement of the frame as a ready-to-install subassembly, it was checked on a device used to inspect the frames in planes. Studies have shown that the dimensions of the frame are within the tolerances provided for in the technical documentation and in accordance with BN-85/3813-79.

## Conclusions

The high-speed milling cutter provides high-precision thin-wall construction with machined aluminum alloys 7075. The correct selection of cutting parameters ensures the surface roughness and corrugation required for this product class. In the case of wall treatments with a height-to-thickness ratio of <15, the impact of deformation on the dimensional accuracy of the workpiece is of little importance. With greater wall slippage, this effect becomes visible and should be minimized by selecting the cutting parameters (feed, depth of cut) [9, 10].

Ensuring dimensional dimensioning during machining requires the correct selection of machining centers and the method of fixing the workpiece. In additional structures, additional bases should be provided to ensure rigidity of the fastening and removal in the end operations.

The use of the HSM method for both roughing and finishing can reduce the time it takes to produce an item. In the case of serial production, thanks to the experience gained during the production of the prototype and the proven control program, the frame can be shortened to 15 hours.

HSM (high-speed milling) is now one of the key milling methods used in the aerospace industry. Another factor that distinguishes it from other milling techniques is the selection of cutting parameters, cutting depth, feed rate and cutting speed [11, 13].

Works and studies were carried out under the project „699757/SAT-AM”, subject: JTI-CS2-2015CPW02-AIR-02-07. More Affordable Small Aircraft Manufacturing; Airframe etc. Grant Agreement No: CS2-AIR-GAM-2014-2015-01 (annex III), co-financed by

Horizons 2020 Clean Sky 2. Special thanks go to the following entities: Institute of Aviation, Szel-Tech Szeli-ga Grzegorz, Zakłady Lotnicze Margański & Mysłowski, PZL Mielec, CIRA, Eurotech, Metrol and Ultratech.

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