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USING HSM TECHNOLOGY IN MACHINING OF THIN-WALLED AIRCRAFT STRUCTURES

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Abstract: Subtracting manufacturing technologies have entered that realm of production possibilities which, even a few years ago, could not be directly adapted to direct production conditions. The current machines, i.e. heavy, rigid cutting machines using high spindle speed and high feed speed, allow for manufacturing very thin and relatively long parts for use in the automotive or aerospace industry. In addition, the introduction and implementation of new 70XX aluminium alloys with high strength parameters, as well as monolithic diamond cutting tools for special machining, have had a significant impact on the introduction of high-speed machining (HSM) technologies. The main advantage of the applied manufacturing method is obtaining a very good smoothness and surface roughness, reaching even $Sz = 6–10\ \mu m$ and $Sa < 3\ \mu m$, and about four times faster and more efficient machining compared to conventional machining (for the beam part). Moreover, fixed and repeatable milling process of the HSM method, reduction of operational control, easy assembly of components and increase in the finishing efficiency compared to other methods of plastic processing (forming) are other benefits. The authors present a method using HSM for the manufacturing of aircraft parts, such as the chassis beam at the front of a commuter aircraft. The chassis beam assembly is made of two parts, front and rear, which – through a bolted connection – form a complete element replacing the previous part made using traditional technology, i.e., cavity machining, bending and plastic forming. The implementation of HSM technology eliminates many operations related to the construction of components, assembling the components (riveting) and additional controls during construction and assembly.

Key words: aviation, high-speed machining, milling, thin-walled parts, integral structures

1. INTRODUCTION

Aircraft constructions require meeting three basic criteria: adequate strength, rigidity and minimum weight of the structure. These features determine the cross-sectional areas and the minimum dimensions of the thickness of the structural elements. Small local buckling of the elements of an aircraft structure (frames, spars, ribs, etc.) is acceptable for different payload capacities and weight scenarios, but surpassing the load limits of components practically guarantees the structure's destruction, due to the low construction safety factor.

Therefore, the methodology behind the design and fabrication of airplane components requires constant improvements. Rapid progress in materials science and manufacturing systems permits the production of aggregate parts of complex shapes. Such integral assemblies make it possible to apply material properties in a more appropriate way and also enable a substantial boost in the mechanical parameters of their primary framework. The most vital benefit from implementing the aggregate parts is the cost savings from the minimisation of steps in manufacturing. Rib T-shape elements significantly increase strength and reduce the weight of the structure. Owing to this, a structure with substantially improved capacity limits can be manufactured by lowering thicknesses and utilising hardened longitudinal parts that are spaced appropriately [11].

The current trend in the development of subtracting manufacturing is the growth in the cutting velocity. A very large increase in cutting speed occurred with the introduction of new tool materials and tool coatings that increase durability [6]. It can be assumed that cutting speeds used during high-speed machining (HSM) are 5–10 times greater than conventional cutting speeds, which depend on the type of material being machined [13]. To define the HSM process, different values are used to characterise the cutting process. These values include cutting forces, friction force in the cutting zone, specific cutting energy and the ratio of the spindle motor power demand to its maximum rotational speed.

The growing interest in HSM, especially in the aviation industry, is associated with a number of benefits obtained after the implementation of cutting at high speeds. The effect of the increase in the rotational speed is a reduction in the machining time and, thus, an increase in machining efficiency. Other additional beneficial effects of the introduction of high-speed milling can include a reduction in the cutting forces needed, a reduction in the percentage of cutting heat penetrating through 88% of the workpiece, reduction in the roughness of the treated surface, as well as greater processing capabilities in thin-walled elements and more favourable chip forms.

It is assumed that HSM begins when increasing the cutting speed vc results in a decrease in cutting forces, which can be expressed by the following expression:

$$\frac{\partial F}{\partial v_c} < 0, \text{ for HSM} \tag{1}$$

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$\frac{\partial F}{\partial v_c} > 0$, for conventional treatment [9] (2)

High-speed milling was first used to produce small elements of aircraft constructions approximately 12 years ago. However, the use of this method for an entire assembly, such as the front chassis beam, is a great process and product achievement. The front chassis beam is a critical structural element of the aircraft, which is subjected to special supervision and control during the entire production process, not only due to its external dimensions of 3,000 × 500 mm but also due to the significant loads it bears during the touchdown phase of the aircraft's flight, where, in some significant cases, non-axial forces may occur. In the presented work, the authors, as part of the planned works for the project, developed and made a prototype of the chassis beam assembly using high-speed milling technology. This technology makes it possible to create elements that have a complicated shape with a small wall thickness of the reinforcing ribs.

In a series of preceding tests, the authors checked and demonstrated the application of the high-speed milling method for another construction part, i.e. the front beam of the aircraft [4]. It was proved that it is possible to obtain a minimum wall thickness of <0.6 mm for a ribbed plate without losing the required geometry of the structural element. Obtaining the minimum wall thickness of the ribbed plate allows for a significant reduction in product weight of up to 20% compared to conventional solutions. The use of the high-speed milling method to create integral parts additionally reduces the number of fastener elements necessary to connect the entire assembly.

Manufacture of the thin-surfaced parts comes with many technical problems related to distortions and alterations of the part resulting from its elasticity and plasticity. Vibrations can be caused by deformations of the ground part, and thus, flaws may occur in the structure's shape. In addition, permanent deformities can also generate geometric errors and cause interior stress in the outermost sheet, which are rather challenging to reduce and result in deformity of the post-machining part. This results in expanded fabrication expenses for production processes, particularly for thin-sided parts, resulting from low quantities and greater fabrication time [12].

The commonly used rule for choosing materials to be used in the manufacture of aircraft is the durability-to-weight relation. Elements are devised and the proper materials (aluminium, titanium, steel and composite) are chosen depending on the aircraft's capacities [5, 7]. Full block material, a forging, or a casting is used for workpieces. Composites, aluminium alloys and titanium alloys are the most commonly used materials for aircraft constructions. Considering the implementation of composite materials in aircraft structures, fatigue failure analysis needs to be taken into account [8]. Lately, intense corporate rivalries within the aviation industry have resulted in the rather rapid growth of contemporary fabrication processes.

Nowadays, many aircraft parts are fabricated for off-the-shelf sale from a full amount of material. The aggregate parts of aircraft usually demand deletion of up to 98% of the raw material during the course of manufacturing. To successfully fulfil such mass production processes, it is essential that the most economical methods be utilised so that the manufacturing can be profitable. High-speed milling technology creates or enhances this possibility. Furthermore, the fabricated workpieces are homogeneous and possess improved mechanical properties. The absence of joints fastened with rivets leads to a lower weight piece structure with a better strength-to-weight ratio [1]. An aircraft beam structure made of stamped, bent and riveted sections is shown in Fig. 1. The same structure can be successfully made using the HSM technology, which vastly saves manufacturing time and labour intensity (Fig. 2).

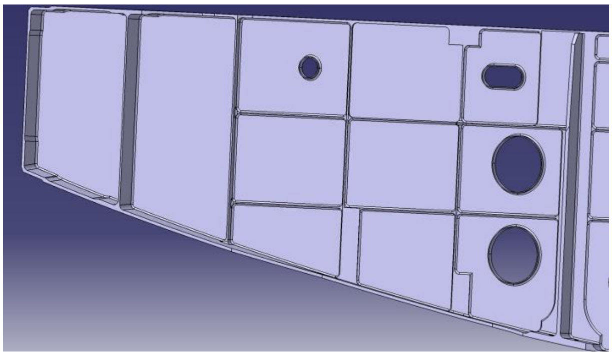

Fig. 1. Structure of aircraft beam designed for HSM made of stamped and bent sections. HSM, high-speed machining

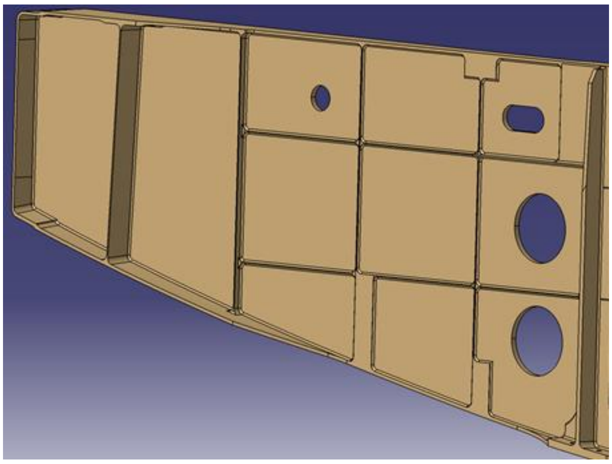

Fig. 2. Structure of aircraft beam designed for HSM milled using the HSM method. HSM, high-speed machining

The modern CAM systems do not just calculate a tool's pathway but are also utilised for its checking, authentication and optimisation with the goal of reducing the number of errors.

The essence of the aerospace industry sector is low-quantity manufacturing which necessitates elasticity immediately at the technological fabrication preparation phase, wherein unified CAD and CAM programmes are particularly helpful.

The design scheme for production of thin-sided complex assemblies made for the aeronautics industrial sector necessitates consideration of the standard conventions recommended for the programming of CNC machines, as well as the special features of thin-sided parts with a high proportion of wall height to wall thickness, especially whenever HSM is used. For this technology, it is crucial to select a proper fabrication procedure, particularly for flat, thin-sided aircraft parts, such as frameworks, beams, ribs, etc. In such cases, the wall's ratio of height-to-wall thickness is the normal parameter.

This relationship represents the elastic rigidity of the part and, specifically, the malformations that take place during production. To minimise wall bending, the most suitable amount of tool runs should be utilised. Additionally, the time of machine-to-part contact should be minimised by using a high cutting speed and a low ratio of cut depth ap to cut layer width ae. The solidity of the tool and the machined wall is of great importance to the process. In areas where there is weaker support of the thin-sided piece, reverse milling should be used. For a height-to-thickness ratio <15:1, machining should be done for only one side of the part's surface, in non-overlapping passes. Grinding should be repeated for the reverse side and an allowance must be made for finish production [10, 17].

2. CHARACTERISTICS OF HSM METHODS

The aerospace industry uses thin-walled pocket constructions made of aluminium alloys, which ensures low mass and high stiffness. They constitute up to 60% of the product weight. As blanks for their production, plates of a certain plastically processed thickness are used above all. Due to significant weight loss of up to 98%, modern, high-performance machining methods, such as milling: HPC roughing and HSC finishing machining, are used when making thin-walled parts.

The main problem encountered during the machining of thin-walled structures is their elastic and plastic deformations, which occur during the milling of thin-walled elements. After removing the load, the wall resiliently returns to its original position. The tool-holder-spindle layout also resists elastic deformation. HSM of deep, thin-walled pocket constructions requires the use of tools with large overhangs, which increases the deformation of this system.

Elastic deformation of the tool and the workpiece, in addition to shape errors, may cause process instability, which affects the quality of the work surfaces. This lack of machining stability results in the development of vibrations and the so-called "chatter" of the machined wall.

Stabilisation of machining conditions can be achieved through the appropriate selection of cutting parameters or the use of tools with geometry that reduces the vibration tendency. In order to minimise the vibrations, tools with different blade pitches and variable helix angles are used. Due to different helix angles, successive cutting edges produce chips with variable cross-sections. This ensures reduced harmonic vibrations and reduced cutting forces, which allows the efficiency of the machining process to be increased.

Increasing the cutting speed to the range corresponding to the HSC machining results in lower cutting forces, which reduces the distortion of both the thin-walled elements and the tool. Reduction of the cutting forces, especially the component perpendicular to the machined surface, which has the greatest impact on wall deformation, can also be obtained by optimising the cutting parameters, i.e. feed fz, depth ap and cutting width ae. Lower cutting resistance generates lower machining stresses, which reduces deformation of the workpiece and ensures higher quality and accuracy. Additionally, the rise in the cutting velocity has an advantageous effect on the surface quality, which is characterised by a greater regularity in machining marks and lower roughness and waviness in relation to the machined surfaces with classic cutting parameters.

When machining the high walls of the elements, it is advisable to apply the appropriate machining strategy. The experience of the authors allows distinguishing the following methods of processing:

- Method I – separate treatment of each side of the wall (recommended at a wall height-to-thickness ratio of <15:1),
- Method II – alternate processing of both sides of the wall for a constant level – (height-to-thickness ratio of <30:1),
- Method III – alternating machining of both sides of the wall with a level difference – (height-to-thickness ratio of <30:1),
- Method IV – alternating processing of both sides of the wall with a constant level and increasing wall thickness towards its base (height-to-thickness ratio of >30:1).

For roughing thin-walled elements, counter-rotational milling is recommended for all strategies. A finishing allowance of approximately 0.2–1.0 mm should be left for the finishing treatment, depending on the final wall thickness. However, these machining methods have some drawbacks as follows:

- Multiple tool passes introduce additional stresses of their own, which can have a significant influence on the formation and form of deformation of the machined walls.
- Making subsequent passes after previous machining marks may cause a regeneration effect and, thus, loss of stability of the treated wall.
- During machining of subsequent layers and contact of the cutting edge of the tool with the previously machined surface, it accelerates the tool wear and causes loss of quality in the machined surface.

The above factors make it increasingly advisable to finish the thin walls at their full height. However, this requires the use of tools with appropriate geometry characterised by different blade pitches and a variable or differing helix angle. Densely ribbed structures are often used in aviation structural elements. They have the form of thin-walled elements with complex geometry and a significant depth of recesses between the ribs. This type of machining requires the use of "slender" tools with large overhangs and therefore low stiffness. Providing high performance involves the deformation of both the machine and the part, which affects the accuracy of the shaped walls.

In the case of HSC machining, mainly monolithic diamond tools and heat-shrinkable holders are used to ensure secure and accurate fastening [2, 3]. In HSC machining, especially when the tool reach is increased, its dynamic balancing is decisive. Poor balancing, like the low stiffness of the tool, may cause it to lose its stability during operation and may adversely affect the spindle-bearing arrangement.

The HSM machining process requires the use of synthetic cooling and lubricating fluids, which are primarily characterised by good machining properties. The lubricating fluid used in the research-and-development (R&D) works was an emulsion called HYCUT ET 46 (Oemeta company).

3. EXPERIMENTAL PROCEDURE

In the authors' own research, the use of HSC machining in the production of aircraft construction components was addressed. In the production of the most heavily loaded components, aluminium alloys from the 70XX group are used. Rigid alloys are characterised by high plasticity, and their mechanical properties depend on the chemical composition of a given alloy. The increase in strength of these alloys is achieved by heat treatment. In addition, increase in strength is obtained by strengthening the work-up during cold forming in combination with precipitation hardening. Multi-component aluminium alloys with alloy additions such as Mg and Cu, known as zinc dural, show the highest strength properties among all aluminium alloys. In the hardened state, their yield point ranges from $R_{p0.2}$ = 600 MPa to

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$R_{p0.2}$ = 700 MPa and tensile strength ranges from R_m = 700 MPa to R_m = 780 MPa. Heat treatment of 70XX alloys consists of recrystallising annealing at 390–430 °C and precipitation hardening. Saturation is carried out at a temperature of 465–480 °C. Ageing, however, is done at a temperature of 120–150 °C. In the shaping of aeronautical elements from aluminium alloys, the aim is to make milling the basic machining process used in their production.

The material used in the research was 7075 T6 aluminium alloy with tensile strength properties in the supersaturated state (Fig. 3). The chemical composition of the material is given below (Tab. 1, Tab. 2):

Tab. 1. Chemical composition of the 7075 T6 aluminium alloy [%]

Al	Mg	Cu	Mn	Zn	Si + Fe
89.72	1.6	0.09	0.11	0.03	2.5

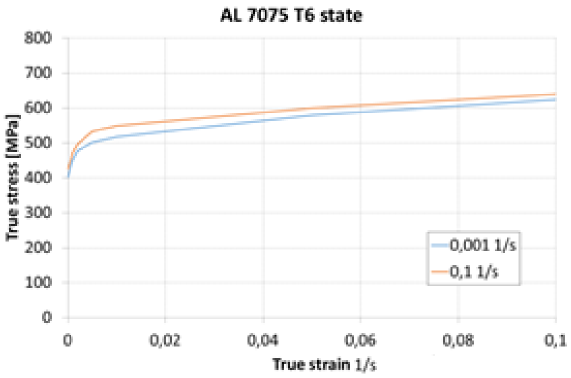

Fig. 3. Stretching chart of an aluminium alloy sample 7075 for the supersaturation condition T6

Tab. 2. Mechanical properties of the 7075 T6 aluminium alloy tested at a temperature of 21–22 °C

R_m	565 MPa
Yield strength $Rp_{0.2}$	520 MPa
Young's modulus *E*	72 GPa
Poisson's ratio *v*	0.33
Elongation	13,5%
Hardness (Fig. 4)	180 HV1

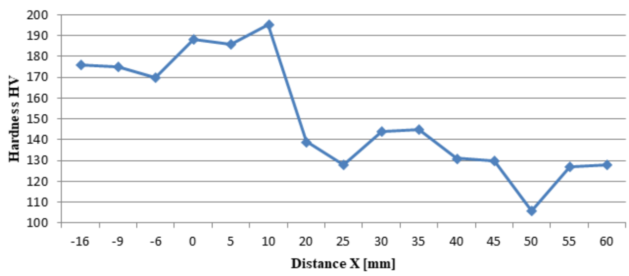

Fig. 4. Ageing at the temperature of 150 °C for 24 h with air cooling

Blocks with dimensions of 1,055 mm × 510 mm × 50 mm, with a total weight of 76 kg, were used as semi-completed products and were delivered in a solution state.

The size of the workpieces was 1017.5 mm × 354 mm × 48 mm. The thicknesses of the walls were 1 mm, 2 mm, 3 mm and 5 mm. The biggest open, flat surfaces (devoid of ribs) were of size 338.5 mm × 108.8 mm × 1 mm. The ratio of the ribs' height to their thickness, h/g, was in the range between 9.6 and 28.5. The radius passing between the walls and the ribs was 1.5 mm. The roughing was carried out with a spindle having a rotational velocity of n = 22,500 rev/min (cutting tool d = 12 mm) and finishing n =45,000 rev/min (cutting tool max d = 6 mm); this was meant to get the machining datum surfaces prepared for later operations. The workpiece was attached to the machining table using pressure clamps and the machining was done in a dual-phase process: shaping and finishing. Two parts were fabricated concurrently on the two machines, while equal and unequal machining processes of the pockets were used. For the first, the beam receptacles were positioned symmetrically to the part's axis and they were fabricated in an alternating fashion. For the unequal machining, the receptacles were ground intermittently in relation to the axis running through the symmetry of the beam. For such a method, internal malformations of the beam were roughly calculated after the machining phase.

Production of the two-sided beam receptacles required preparation of the machining foundations in which the supports needed to rest and position the part on the milling machine. Therefore, a rim with holes forming cylinders was created from the semi-finished material. The rim was a machining datum surface and the holes permitted the part to be fastened to the machine table (Fig. 5). The supports were only added on an as-needed basis and were excised after completion of the last beam fabrication operation.

Based on the presumption of the manufacturing documentation, the limits of the linear parameters of the beam are established by the norm BN-85/3813-79: Deviations of non-tolerated dimensions, shape and location for aviation products.

For the beam's sides, the tolerances are as follows:
- g = 0.8–5 mm; deviations: ±0.05 mm.
- For the rib height:
- h = 11.9–40 mm; deviations: ±0.1 mm.
- For the overall dimensions:
- 1,017.5 mm × 354 mm; dimensions: ±0.3mm.

Fig. 5. Chassis beam made using the HSM method with two integral parts. HSM, high-speed machining

The mechanical tooling of the beam was performed in two phases: pre-machining and finishing. The number of machine runs in all cases was determined by the wall measurements and the axial cut depth. The fundamental obligation of the machining process was to guarantee as minimal malformation of the ribs as possible and also to secure appropriate surface roughness during the finishing machining. In the fabricated beam, 1.5 mm finishing tolerances were used for large part surfaces and 0.1 mm on the rib walls with a thickness of 0.8–3 mm. To reduce the wall deformity, the time needed to connect the tool and the part being machined had to be shortened. This was achieved by using high-speed cutting (i.e., high tool rotation speed). The later treatment, which established a high degree of machining precision of the smooth beam walls (the height-to-thickness ratio was maintained somewhere <30), was done to maintain a proper machining strategy. The most effective way was intermittent receptacle machining with a switch in machining sides and keeping the machining at equal amounts for each pocket. While machining thin sides, it is generally suggested that one grind in reverse. The weight of the complete, final frame was 4.65 kg (1.8 kg upper + 2.85 lower) and the weight of the initial material was 186 kg (76 kg + 110 kg), so the part's weight was 2.2% of the material started with; 97.8% of the semi-finished material was recycled into chips. This equals a "buy-to-fly" ratio (weight of the starting material to the weight of the final product) of 39. This technical process can be used for thin-sided structure manufacturing, wherein the chips' mass can be up to 97.8% of the starting material. It should be underscored that the beam's weight is 4.65 kg.

By introducing the HSM technology, in relation to classic milling methods, currently designed aircraft structures consist mainly of integral thin-walled elements, which were previously produced by plastic forming technologies and then joined using welding or riveting technologies. In the HSM technology, after machining, these parts are directly assembled in the semi-assembly or assembly process, bypassing the assembly into larger assemblies. Achieving high efficiency of HSM of high-strength aluminium alloys, especially in roughing, requires machine tools with high rigidity and high power on the machine spindle.

The time needed to manufacture the frame (including software preparation time) was 250 h (CAM software) and 300 h (time of milling). The manufacturing time of the beam can be minimised to 30 h for the production series by applying the successfully tested control system and the lessons learned through the mock-up processing. The roughing time of the beam is estimated to be around 20 h, and the finishing takes around 10 h, which comes to about 30 h in total to fabricate the frame using the HSM technique. A comparison of the HSM technology to the conventional machining process shows that about 4 times as many hours are necessary to fabricate the beam by traditional milling methods. The authors of the work, together with the industrial consortium, plan to develop the technological process and complete the construction of an entire integral beam of the aircraft front chassis using HSM technology, without the need to divide it into front and rear parts combined with bolts. This possibility results from the recent purchase of an appropriate machine tool. Moreover, for wall machining with a height-to-thickness proportion <15, the effect of structural malformation defects on the geometric accuracy of the part is insignificant. In the case of narrower walls, this outcome becomes detectable and should be kept to a minimum through fine-tuning of the machining parameters, i.e., piece feed rate, milling extent, machining direction, etc.

4. QUALITY OF SURFACE

Inspection of the geometric dimensions and surface roughness of the processed beam allows us to draw a number of interesting conclusions. The surface quality after milling depends on the type of material to be machined and the geometry of the cutting tool. The cooling conditions have a substantial effect on the results of the treated surface. Cooling with emulsion significantly improves the surface roughness. During milling of the above-mentioned beam, a surface roughness of S_z = 6–10 μm and S_a <3 μm was obtained (Fig. 6).

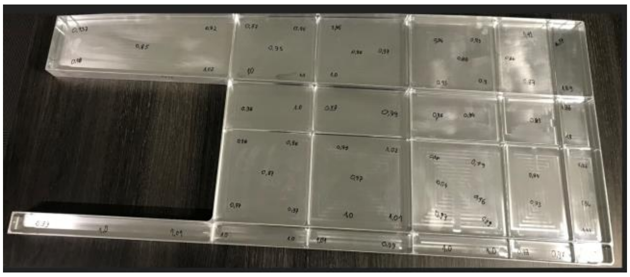

Fig. 6 Points of control measurements of wall thickness using CMM and micrometre methods

During milling with end milling cutters, with both conventional machining and with increased cutting speed, the best surface quality was obtained after machining with a diamond tool. The processing was carried out with a diamond milling cutter of d = 12 mm and d = 6 mm, respectively. The milling width was a_e = 10 mm and a_e = 5 mm, respectively. The choice of the diamond tool resulted from our own preliminary tests, where a tool with the carbide plate was used to chip off the cutting edge and this process subsequently destroyed the sample. This cannot be allowed when machining expensive integral parts. After machining of series 7075 alloys, the roughness of the machined surface was improved as seen by measuring the following parameters: S_a (arithmetic average of the roughness profile); S_z (the largest height of the profile). Increasing the feed above f_z = 0.2 mm per blade results in a significant increase in roughness.

The beam's specifications were assessed by an optic scanner in order to verify its geometry, linear measurements and spatial displacements (Fig. 7). This study helped us to ascertain the geometric parameters of specific beam details and to produce computerised and relief maps displaying the beam's stereometry. These maps mainly allowed assessment of the malformation potential of the large beam exterior. Such defects can occur due to internal tensions produced in the part throughout the mechanical treatment phase [15, 16, 17]. Dimension evaluation showed that the irregularities of the linear measurements were within the forecast tolerances. The deformities of the workpiece occur primarily near the shorter axis of symmetry, and the shifts are symmetrical in the direction of the longer axis of symmetry. The biggest relative displacement value is 0.31 mm. Precise measurements are assured by the optical scanner, with a margin of error of ±0.25 mm. Nonetheless, this technique demonstrates – in a dependable way – what deformities should be foreseen in the machining of parts of a similar component. For an exacting assessment of the ribs' wall thicknesses, which are the most significant when considering structural durability, the walls were measured with a micrometer. The measurements were made at the ribs' points that were forecast to be most susceptible to malformations during the machining process – at the rib's base and at the rib's top.

To estimate the form, measurements and spatial displacements of the beam as a complete sub-assembly, the beam was evaluated on a control instrument that is used to study the beam present in current aircraft (Fig. 8). Research has shown that the beam measurements fall within the tolerances forecast in the technical documents. The measurements also met the local

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standard BN-85/3813-79, which was utilised for verifying unacceptable distortions and shapes.

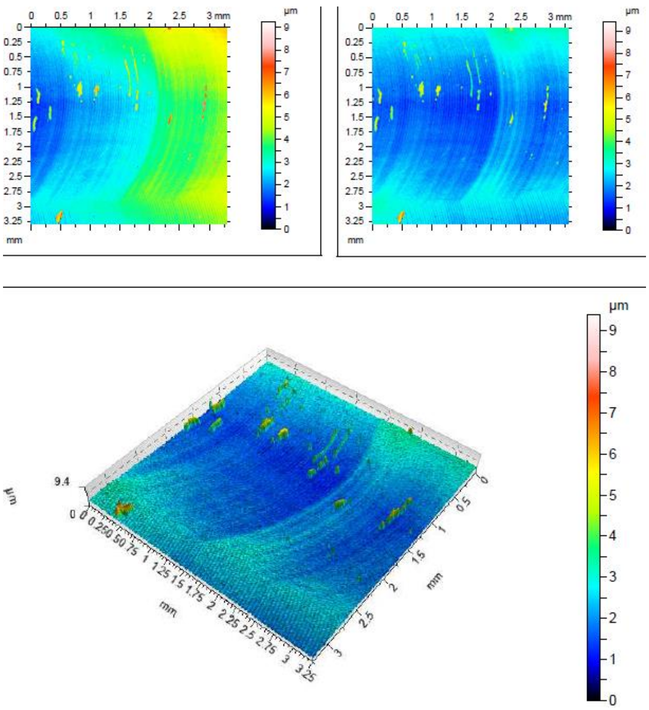

Fig. 7. Graphic representation of the roughness of the measured surface, Sa = 0.275 µm – arithmetic means of discrepancy of the surface's unevenness from the reference plane: (a) transition area between the machining marks; (b) homogeneous machining area; (c) view of the measurement zone

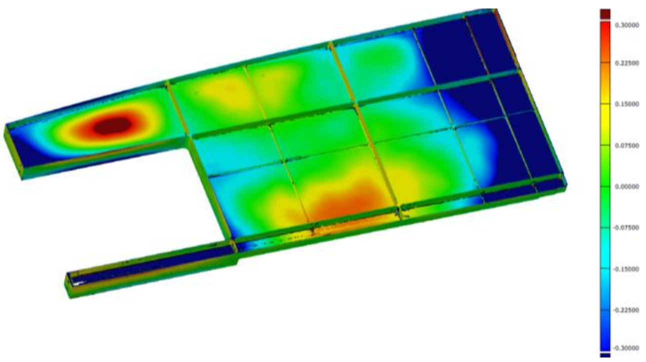

Fig. 8. The size of displacements of the beam elements measured by the GOM optical scanning method. The values of displacements reach positive and negative values due to the elastic stresses of the material after HSM treatment. The maximum brown values are due to wall thickness <1 mm of the pocket between the ribs with a relatively great height – 40 mm. HSM, high-speed machining

The application of HSM for thin-walled aircraft beams is achievable owing to the exactness of the workpiece and the machining potential of the Al7075 aluminium alloys. A suitable cutting parameter choice yields good surface waviness and roughness [1].

In the case of machined walls having a height-to-thickness ratio <30, the effect of the structure's deformity on the part's parameter precision is negligible, and it still lands within the tolerances of the milling machine. For larger walls' slenderness, this impact starts to become noticeable and should be reduced by proper selection of the cutting velocity (workpiece feed rate, cutting depth).

Maintaining dimensional-shape precision throughout the machining process necessitates an appropriate choice of the technological bases to secure the mounting technique for the workpiece. In composite spatial components, some extra foundations ensuring mount solidity should be utilised and later removed during the final processes. The final HSM application permits the manufacturer to reduce the work machining hours.

The finished part is an integrated structure that replaces the same parts currently manufactured using plastic processing of individual parts (38) and then assembling those using fasteners. The entire manufacturing time for individual elements of the beam was >5 times that of the suggested HSM method. Augmenting the advantages resulting from the lowered manufacturing time of the beam, other benefits of the suggested technology are the quality and precision of the fabrication, in addition to the desirable roughness class of the part surfaces [18, 19].

During the machining process around the tip of the cutting tool, a plastic deformation of the workpiece is created, which, after removing the factor causing it, causes the formation of compressive residual stresses in the surface layer (Fig. 9). In addition, during cutting, heat is generated (related to, among others, friction), leading to large differences at temperature and thermal stresses exceeding the yield point of the material and, consequently, to tensile residual stresses in the surface layer. In fact, all these factors influence the state of residual stress, but their intensity may vary. However, it is assumed that after machining, the surface layer is dominated mainly by mechanical stress (pressure) and – acting in the opposite direction – thermal stress (temperature). The mechanical model corresponds mainly to machining, while the thermal model is characteristic of abrasive machining and the high-speed machining of HSC. The residual stress after machining occurs at depths of several tenths of a millimetre.

The residual stresses arising during the cutting process depend on many factors, including the following:
– depth of cut
– feed
– cutting speed
– the geometry of the cutting tool
– cooling conditions
– properties of the processed material and
– degree of wear of the cutting tool.

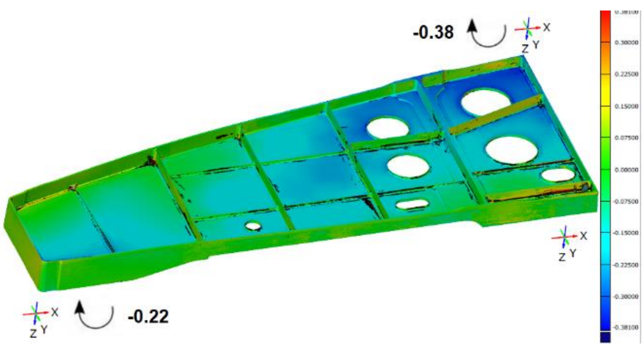

Fig. 9. The deformation of a thin-walled element caused during machining on a five-axis machine tool CNC measured in external points

5. SUMMARY

The tests of machined samples and elements of aircraft constructions made of alloy 7075 using the HSM method confirmed the overall suitability of this machining method in the manufacture of thin-walled airframe structures. First of all, HSM allows one to make components with a tolerance of 0.05 mm, which is satisfactory for such parts.

Application of the HSM method to thin-walled elements (thickness: 0.8–2.5 mm) results in changes in the state of the top layer (stresses, plastic deformations), followed by displacement of thin walls at the level of 0.6 mm, which should be considered during thin-wall machining of ribs and large free surfaces. This phenomenon can be partially counteracted by supporting the surfaces treated with elements of high stiffness.

The tests were conducted at a cutting velocity of Vc = 830 m/min for roughing and Vc = 1,200 m/min for finishing machining, respectively. In any case, the cutting process was very stable. No vibrations were observed, which caused a degradation of the surface quality of the worked part, especially surface undulation and roughness. Surface roughness of Ra = 0.6–2 μm was obtained, with higher values referring to the middle points of free surfaces (plate with dimensions of 300 mm × 300 mm) and lower values with higher stiffness values. From the point of destination of the workpieces, such surface roughness is satisfactory. In comparison to the classic milling method, the HSM method gives results of 10% better surface quality at 5–10 times thinner wall thickness of the processed npockets, i.e. with a thickness of up to 0.6 mm. The proper choice of machining settings provides the desired roughness and waviness of the machined surface needed for the product grade for the aerospace industry. In addition, the use of HSM provides the production of thin-sided integral aircraft structures with sufficient accuracy, including the machining of high-strength aluminium alloys Al7075.

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