The use of thin-walled milling in the technological production processes of aviation structural elements

Wykorzystanie frezowania cienkościennego w procesach technologicznych produkcji lotniczych elementów konstrukcyjnych

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The use of HSM technology in the technological processes of milling and machining elements of aircraft structures made from (among other materials) aluminum alloys makes possible the production of elements with complex shapes, appropriate levels of precision workmanship, as well as surface roughness and waviness. The efficiency of the machining process is also a crucial factor, allowing it to compete with other manufacturing technologies. The achievement of these effects consists of many factors related to the machining process: machine tools and their rigidity, machining parameters, type of processed materials, as well as machining tools. The requirements for the tools used are related to the workpiece material and its specific properties, as well as the extreme machining conditions used (especially cutting speed v_c and efficiency of the cutting process).
KEYWORDS: HSM, HSC, High Speed Milling, High Speed Cutting

Zastosowanie technologii HSM w procesach technologicznych frezowania konstrukcji lotniczych wykonanych m.in. ze stopów aluminium, umożliwia produkcję elementów o skomplikowanych kształtach, odpowiednim poziomie precyzji wykonania oraz chropowatości i falistości powierzchni. Istotnym czynnikiem, pozwalającym konkurować z innymi technologiami wytwarzania, jest również wydajność procesu obróbki. Na osiągnięcie tych efektów składa się wiele czynników związanych z procesem obróbki: obrabiarki i ich sztywność, parametry obróbki, rodzaj obrabianych materiałów, a także narzędzia obróbkowe. Wymagania stawiane stosowanym narzędziom są związane z materiałem obrabianym i jego specyficznymi właściwościami, a także ekstremalnymi warunkami obróbki (zwłaszcza prędkością skrawania v_c i wydajnością procesu skrawania).
SŁOWA KLUCZOWE: HSM, HSC, frezowanie z dużą prędkością, cięcie z dużą prędkością

Introduction

In aircraft structures, the decisive criteria for their work are appropriate strength, stiffness, lightness, and reliability. As has been demonstrated in the conducted research ensuring a particularly appropriate lightness of a structure requires the use of special technological methods allowing one to shape thin-walled structures. Some features, such as rib walls, require a thickness of 0.5 mm, or even less, to be used. According to the adopted concept of making these elements with the HSM technology, it is advisable to perform machining at cutting speeds v_c, which guarantee reduction of the cutting force, maintenance of the required surface roughness, as well as dimensional and shape tolerance, especially concavity of the surface, as well as high efficiency. Making thin-walled surfaces can be precarious due to the risk of their detachment from the base surface during processing, which may result in their complete destruction. The workpieces must therefore be firmly clamped. Under industrial conditions, it is necessary to achieve the appropriate efficiency of the milling process. Due to the cutting forces, the depth of cut and the feed per cutter blade should be limited. An effective way to increase the efficiency is to increase the cutting speed and the rotational speed of the spindle, with the diameter of the tool limited by design considerations [1–5].

Research

The research was conducted using an HES810 electromagnetic spindle by Nakanishi Inc. (the latest design solution), equipped with an ultra-precise high-speed motor. It is a chip that includes a DC brushless motor and a microprocessor-based control unit. The system

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is able to reach a maximum speed of 80,000 rpm and an output power of 350 W. The solution uses bearings with ceramic material. The air taken in is used to both cool the motor and protect the spindle from incoming contaminants.

The tests were carried out on samples made of aluminum alloy 7050. The roughness of the machined surface was tested with the parameters determined in the preliminary tests, using the rotational speed of the tool n from 20,000 up to 80,000 rpm the cutting depth $a_p = 0.2$ mm and the advancing blade f_z equal to 0.03 mm (finishing) on the samples shown in Fig. 1 [5, 6]. The tool used was a carbide cutter with a ceramic coating with a diameter $d = 6$ mm. These parameters

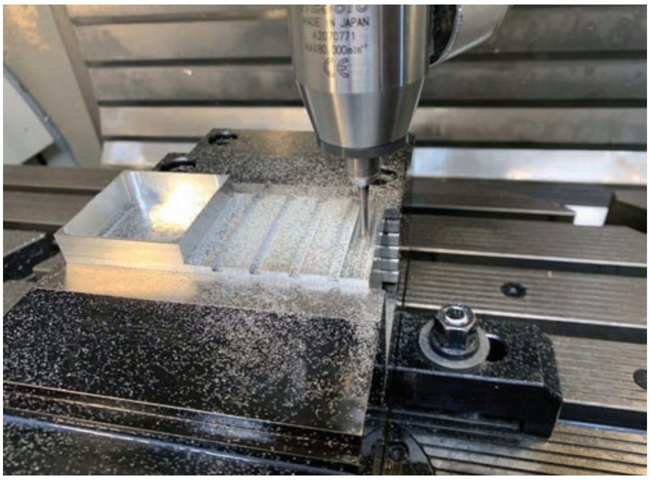


Fig. 1. Tests of the milling process of 7050 aluminum alloys with a spindle speed of 20,000÷80,000 rpm

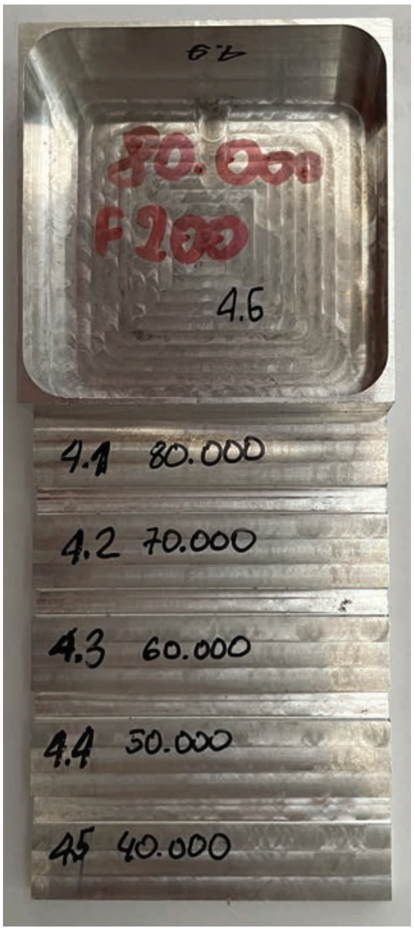
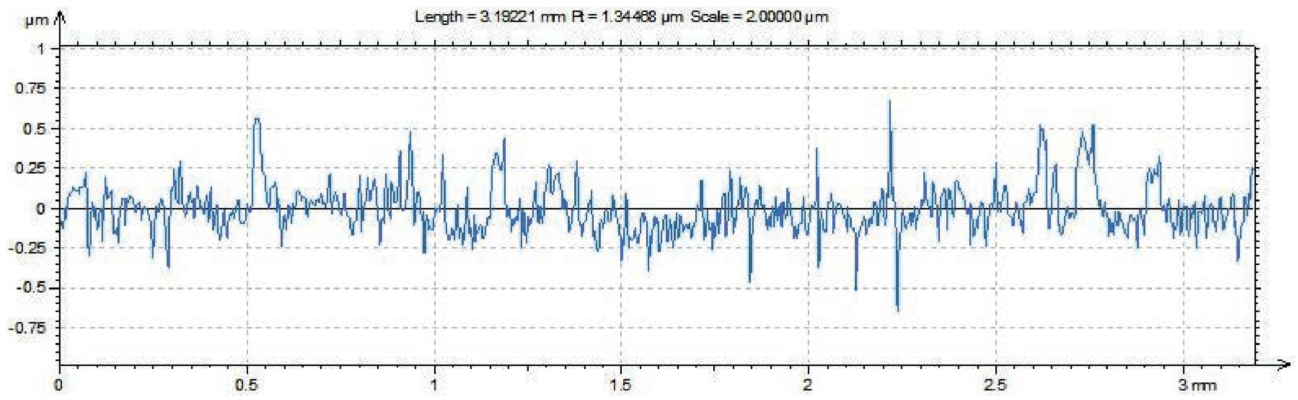


Fig. 2. A sample made of 7050 aluminum alloy, machined at cutting speeds v_c from 753.6 m/min (over 4.5) to 1507 m/min (over 4)



ISO 4287			
Amplitude parameters - Roughness profile			
Rp	0.390711	µm	Gaussian filter, 0.8 mm
Rv	0.292129	µm	Gaussian filter, 0.8 mm
Rz	0.682840	µm	Gaussian filter, 0.8 mm
Rc	0.295066	µm	Gaussian filter, 0.8 mm
Rt	0.978260	µm	Gaussian filter, 0.8 mm
Ra	0.0939827	µm	Gaussian filter, 0.8 mm
Rq	0.124926	µm	Gaussian filter, 0.8 mm
Rsk	0.659644		Gaussian filter, 0.8 mm
Rku	4.25825		Gaussian filter, 0.8 mm
Material Ratio parameters - Roughness profile			
Rmr	100.000	%	c = 1 µm under the highest peak, Gaussian filter, 0.8 mm
Rdc	0.187500	µm	p = 20%, q = 80%, Gaussian filter, 0.8 mm

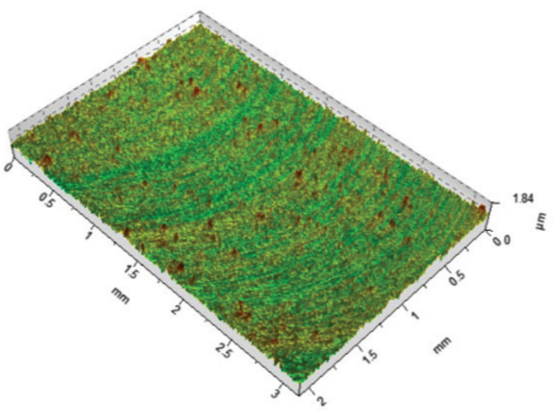
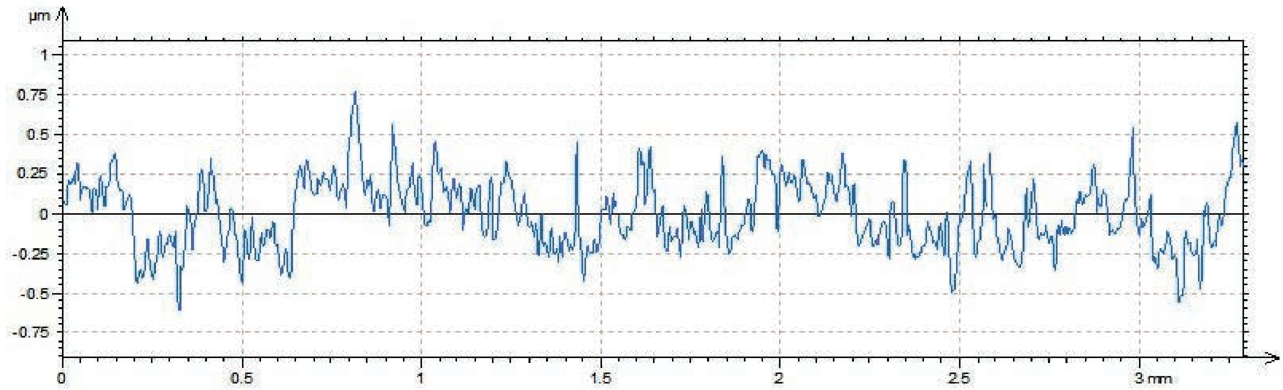


Fig. 3. The results of roughness tests of the treated surfaces: area 4.1 at a speed of v_c = 1507 m/min



ISO 4287			
Amplitude parameters - Roughness profile			
Rp	0.537298	µm	Gaussian filter, 0.8 mm
Rv	0.397799	µm	Gaussian filter, 0.8 mm
Rz	0.935097	µm	Gaussian filter, 0.8 mm
Rc	0.426165	µm	Gaussian filter, 0.8 mm
Rt	1.04220	µm	Gaussian filter, 0.8 mm
Ra	0.141267	µm	Gaussian filter, 0.8 mm
Rq	0.174695	µm	Gaussian filter, 0.8 mm
Rsk	0.439934		Gaussian filter, 0.8 mm
Rku	3.11414		Gaussian filter, 0.8 mm
Material Ratio parameters - Roughness profile			
Rmr	98.9664	%	c = 1 µm under the highest peak, Gaussian filter, 0.8 mm
Rdc	0.295568	µm	p = 20%, q = 80%, Gaussian filter, 0.8 mm

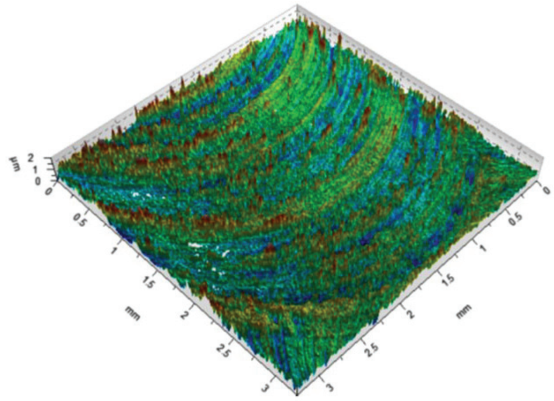


Fig. 4. The results of roughness tests of the treated surface: area 4.5 at a speed of v_c = 753.6 m/min

allowed for a cutting speed v_c from 753.6 to 1507 m/min (Fig. 2). The tests carried out on the samples allowed the researchers to obtain walls with a minimum thickness of $g = 0.8_{-0,-5}$ mm. The cutting process was stable, without any local tearing of the machined surface. The parts were fastened according to a method developed by the authors, which is currently patent pending.

The results of the roughness tests of the treated surfaces are shown in Fig. 3. The tests were carried out on samples shown in Fig. 1 and Fig. 2. Fig. 2 describes the spindle rotational speeds (e.g. 80,000 rpm) and the numbers of the surfaces where the roughness was measured (Fig. 3 and Fig. 4).

Treatment of the samples' flat surfaces with the face of the cutter allowed the authors to obtain the surface roughness as determined by the R_a parameter between $R_a = 0.078$ µm for $v_c = 1507$ m/min to $R_a = 0.14$ µm for v_c 753.6 m/min. In the case of processing flat surfaces with the side surface of the cutter, the surface roughness was greater. For the treatment of such surfaces with a cutting speed of $v_c = 1507$ m/min, a roughness of $R_a = 0.22$ µm was obtained. In terms of the research and cutting speed $v_c = 753.6 \div 1507$ m/min, the achieved roughness is satisfactory from a technological point of view. This is the roughness that is attained by using, for example, grinders. The use of HSM milling in the machining of aluminum alloys allows for resignation from the machining of cylindrical and flat surfaces by grinding [5–7].

Research on the dynamics of the milling process

Carrying out the machining process at very high spindle speeds (approx. 80,000 rpm) and cutting speeds v_c of approx. 1,500 m/min requires an assessment of the dynamics of the process and control of the state of the MHWT system, both of which can have a very strong influence on the quality of the obtained surface and process efficiency. The definition of the permissible processing areas is defined by, among other things, the so-called bag curves. In the conducted research, a high-speed HES810 spindle and a shank cutter with a diameter of $d = 6$ mm were used. Before starting the tests, the radial runout of the tool was checked, which at the point of its greatest protrusion showed a value of about 0.02 mm. In order to assess the dynamics of the milling process, spindle vibration tests were carried out during machining [8–10]. The Microlog CMVA 60 system developed by SKF was used to conduct the study. The set of apparatus installed on the test stand is shown in Fig. 5 and Fig. 6.

The dynamic tests of the cutting process were carried out at spindle speeds of $n = 40{,}000$; 60,000; and 80,000 rpm. The tests were carried out both in free running mode (without loading the spindle with

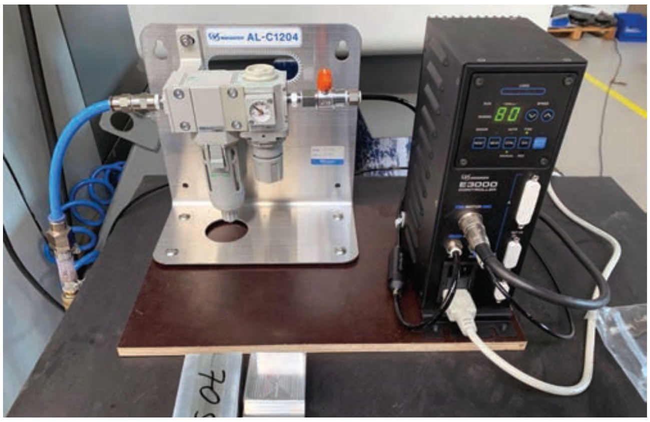


Fig. 5. Test apparatus for measuring spindle vibrations, type Microlog CMVA 60

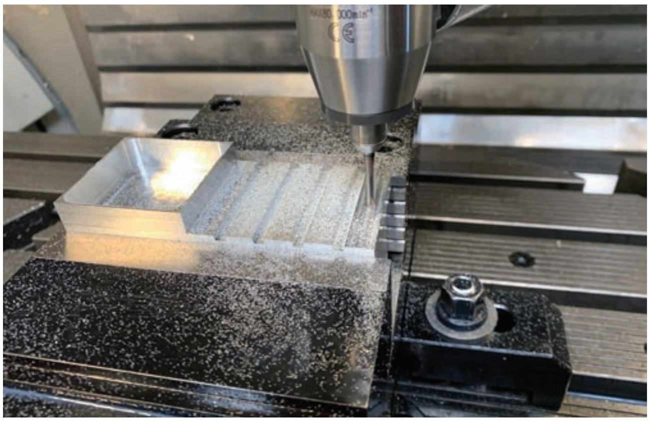


Fig. 6. Test apparatus for measuring spindle vibrations of the Micrologue CMVA 60 type during machining with rotational speeds of $n = 20{,}000 \div 80{,}000$ rpm

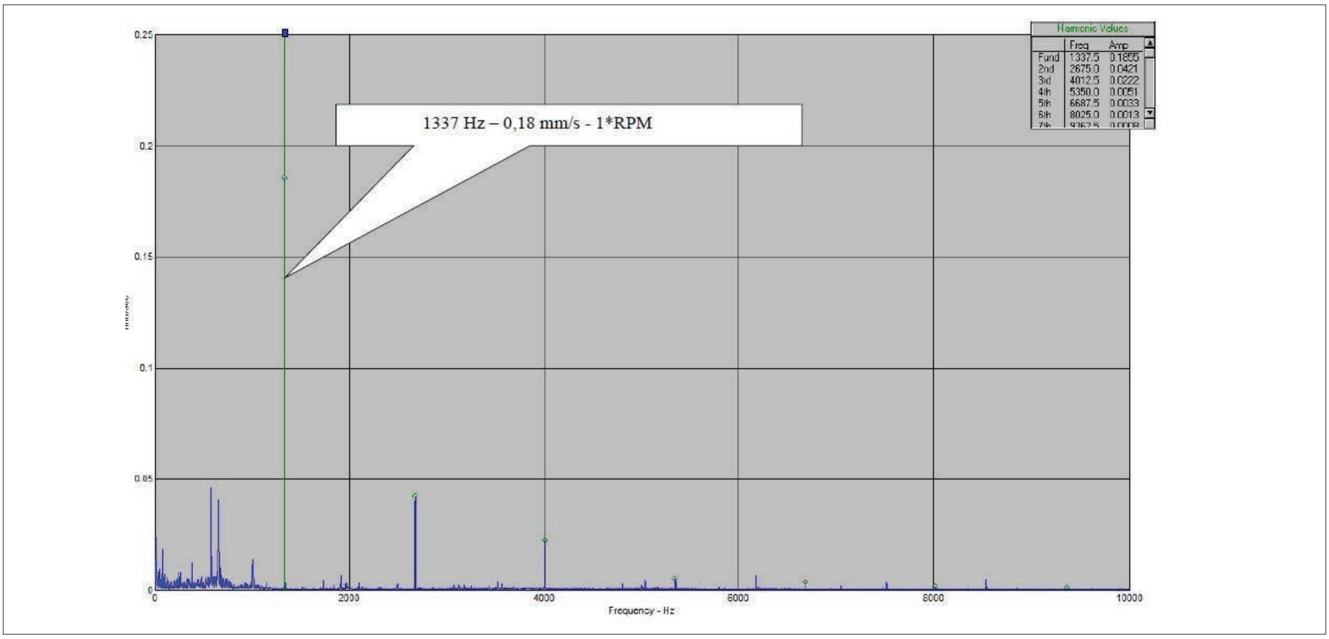


Fig. 7. List of spindle vibration velocity spectra in the range of 0÷10 kHz, $V = 0.23$ mm/s for the rotational speed of 80,000 rpm, no-load operation

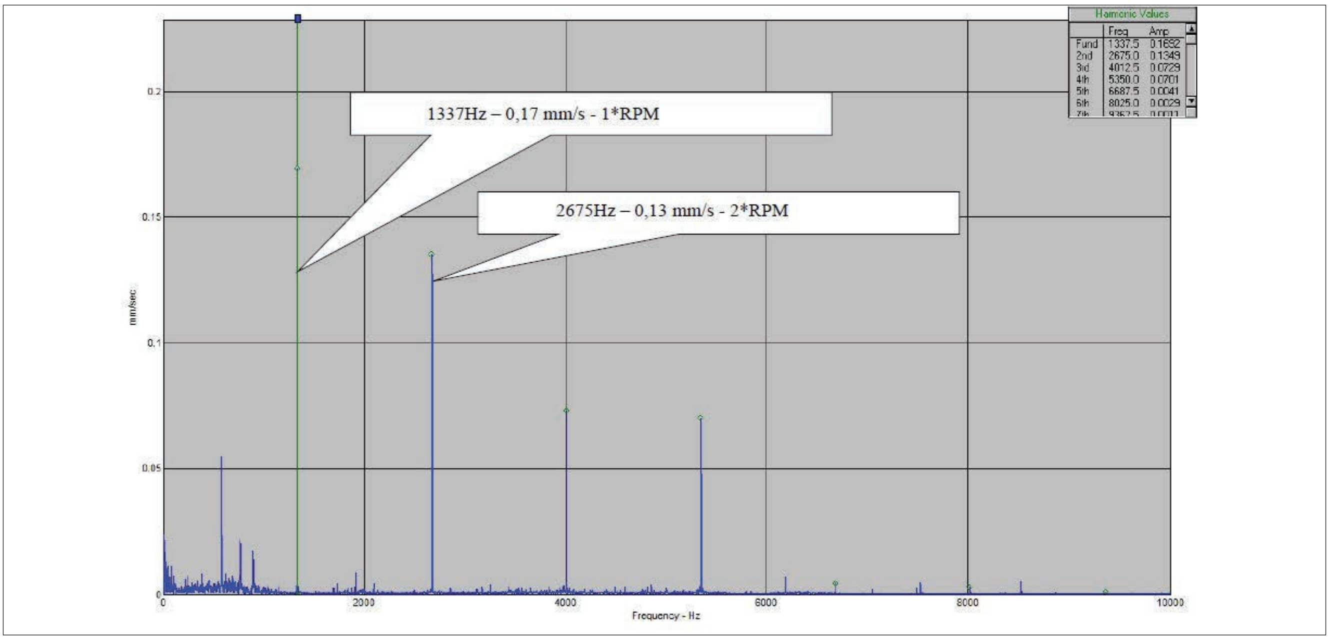


Fig. 8. List of spindle vibration speed spectra in the range of 0÷10 kHz, $V = 0.28$ mm/s for the rotational speed of 80,000 rpm, machining with a cutting depth of 0.05 mm at a feed rate of 100 mm/min

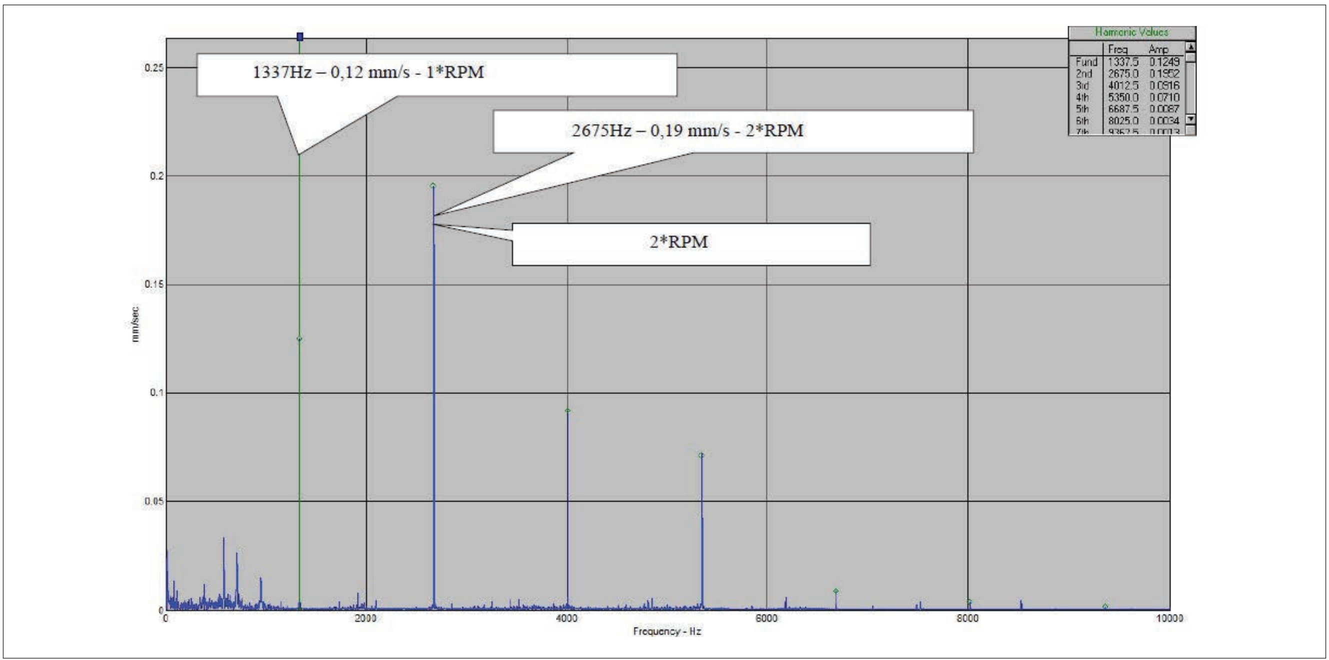


Fig. 9. List of spindle vibration speed spectra in the range of 0÷10 kHz, $V = 0.3$ mm/s for the rotational speed of 80,000 rpm, machining with a cutting depth of 0.10 mm at a feed rate of 100 mm/min

cutting forces) and under load. The machining was carried out with a minute feed $f_m = 100$ mm/min and cutting depths a_p equal to 0.05; 0.10; and 0.15 mm [11–14]. Radial runout of the unloaded tool was 0.02 mm. The results of the tests are shown in Figures 7–9. The obtained results allowed the researchers to indicate safe areas of the spindle operation with selected machining parameters, especially the dominant vibration frequencies and the corresponding amplitude velocities. These parameters should be especially favored during machining. The highest spindle vibration amplitude velocities occurred at the spindle rotational speed of $n = 40{,}000$ rpm. An increase in the spindle speed caused a decrease in the amplitude speed. An increase in the spindle load (greater cutting depth a_p) resulted in an increase in the amplitude of the vibration frequency. Detailed characteristics are presented and described in Figures 7–9 [15–20].

Conclusions

The tests of processing samples made of 7050 and 7075 alloys confirmed the correctness of the selection of the machining tools. The machining process performed ensured both good quality of the machined surfaces (R_a up to 0.32 μm) and stable machining, which was manifested in the absence of surface waviness in the workpiece.

The selected tools worked well both with the face of the cutter as well as with the side surface, up to a height of $h = 2÷3\ d$ (cutter diameter). No visible changes were noticed on the rake and tool flank surfaces, related to the occurrence of built-up edge and tool wear. It is advisable to use tools layered coatings especially when machining with cutting speeds v_c of about 2000 m/min and higher. The dynamic tests of the cutting process were carried out under the spindle speeds of $n = 40{,}000$; 60,000; and 80,000 rpm both in idle run (without loading the spindle with cutting forces) and under load. The machining was carried out with a minute feed $f_m = 100$ mm/min and cutting depths a_p equal to 0.05; 0.10; and 0.15 mm. The results of the tests are shown in Figures 7, 8, and 9. The obtained test results allowed the authors to indicate safe ranges of spindle operation within selected machining parameters, especially the dominant vibration frequencies and the corresponding amplitude velocity. These parameters should be particularly preferred during machining.

The highest spindle vibration amplitude velocities occurred at the spindle rotational speed of $n = 40{,}000$ rpm. An increase in the spindle speed caused a decrease in the amplitude speed. An increase in the spindle load (greater depth of cut a_p) resulted in an increase in the amplitude of the vibration frequency. Detailed characteristics are presented and described in Figures 7–9.

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