ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2808

ANALYSIS OF MIDDLE RANGE FREQUENCY VIBRATION OF AIRCRAFT RECIPROCATING ENGINE

Tomasz Goliasz
Jacek Czarnigowski

Lublin University of Technology
Faculty of Mechanical Engineering, Department of Thermodynamics
Fluid Mechanics and Aviation Propulsion Systems
Nadbystrzycka Street 36, 20-618 Lublin, Poland
tel.: +48 81 538-42-45, fax: +48 81 538-47-4
e-mail: tomaszgoliasz@poczta.onet.pl, j.czarnigowski@pollub.pl

Abstract

The authors investigate into vibration characteristics of ASz-62IR-16E aircraft engine. The focus of empirical tests was on the middle frequency vibration range (1000-7000 Hz) that corresponds to vibrations caused by air-fuel mixture combustion process, and defining root mean square of the detected vibration and the amplitude − frequency function. The tests were conducted for seven characteristic engine speeds. Vibrations were measured along three axes of local Cartesian coordinate system. Results indicate directions, frequency ranges and scale of strongest vibrations. The work is a part of identification tests and is intended to provide input for redesign of the engine ignition system.

In particular, ASz-62IR-16E engine in test bed, coordinate system for the experiment − designation of axes, sensors mounted on the engine block, comparison of root mean square of full detected range of vibrations (RMS), spectral analysis of vibration for characteristic engine speeds, vibration peaks for all engine speeds, vibrations attributable to combustion process are presented in the article.

Keywords: *vibration, aircraft, radial engine, identification*

1. Introduction

Constructing airframes and aviation engines requires that the design teams analyse factors, which determine durability and safety. One of the most significant factors that affect the design of aircraft elements and subassemblies are vibrations generated by the engine. Reduction of their amplitude, acceleration and speed is expected to extend time between overhaul of engines and airframes, as well as reduce cost of condition-based maintenance [1, 2]. The main cause of engine vibrations is processes during work of engine but most of all processes, which are consequences of the air-fuel mixture combustion process [3]. Accurate control of combustion process significantly improves vibration characteristics in wide range of frequencies. The source of low frequency vibrations (up to 500 Hz) is cyclical character of the combustion processes [3], together with its nonuniformity and unrepeatability [4]. Vibrations of higher frequencies derive from speed and fluctuations of the combustion processes [4].

Precise control of combustion process implies control of at least some part of the engine vibration profile and, as a consequence, provides protection of the engine and airframe against excessive loads. However, combustion process is not the only source of vibrations. The engine, together with its complete equipment and in relationship with the airframe it is mounted on, needs to be designed to avoid resonance within normal operating range. Therefore, complete characteristics of vibrations (including those combustion-related) and their relationship with operation conditions should be checked before any engine design decisions are taken.

The aim of the study was to determine the effect of engine speed on middle frequency vibrations generated by combustion processes for a particular type of radial engine. The study is a part of broader project to modernize this engine.

2. Object of research

The tests were conducted on the ASz-62IR-16E aviation engine manufactured by the WSK PZL Kalisz S.A. It is a four-stroke unit of nine cylinders in radial setup, air-cooled with electronic fuel injection control system and magneto ignition. Tab. 1 lists main parameters of the engine, and Fig. 1 presents the object of research in the test bed.

Tab. 1. ASz-62IR Specification [6]

Parameters	**Values**
Engine diameter	1380 mm
Length	1130 mm
Dry engine mass	567 kg (±2%)
Cylinder diameter	155.5 mm
Stroke	174.5 mm
Displacement	29.911 dm3
Compression rate	6.4±0.1
Maximum power at 2200 rpm and PK=1050 mmHg	1000 KM (735 kW)
Power rating at 2100 rpm, PK=900 mmHg	820 KM (603 kW)
Power rating at h=1500 m	840 KM (618 kW)
Power (2030 rpm & PK=830 mmHg)	738 KM (543 kW)
Power (1930 rpm & PK=745 mmHg)	615 KM (452 kW)
Power (1770 rpm & PK=665 mmHg)	492 KM (362 kW)
Average fuel consumption	200 dm3/h
Maximum fuel consumption	330 dm3/h
Weight to Power Ratio	0.57 kg/KM (0.42 kg/kW)
Power to Displacement Ratio	33.43 KM/dm3 (24.58 kW/dm3)

Fig. 1. ASz-62IR-16E engine in test bed

3. Methods

The tests were conducted in the test bed equipped with the following instruments:

I. Three high-frequency accelerometers (type PCB M621B40):
- sensivity: (±10%) 10 mv/g (1.02 mV/(m/s2),
- frequency range: (±10 %) 204-1080000 cpm (3.4-18000 Hz),

- frequency range: (±3 dB) 96-1800000 cpm (1.6-30000 Hz),
- measuring range: ±500 g (±4905 m/s2).

II. Signal amplifier: EC Test System PA 3000.

III. Measuring system: National Instruments cDAQ-9178 chassis with two 9215 BNC measuring cards:

- 4 simultaneously sampled analogue input channels,
- 16-bit resolution,
- 100 kS/s sample rate per channel,
- maximum voltage range: -10 V to +10 V,
- maximum accuracy of voltage – 0.003 V.

Sensors were located on the engine block in configuration allowing vibrations to be measured in three directions. Orientation of axes (Fig. 2) was set as follows:

- X axis – vertical, perpendicular to the axis of propeller rotation,
- Y axis – axis of propeller rotation,
- Z axis – perpendicular to the axis of propeller rotation.

Measurements were taken for seven values of engine speed (measuring points): 600, 1670, 1770, 1910, 2030, 2100, 2200 rpm. At each point, assuring the engine was brought to a steady state, the measures were taken for 15 seconds of continuous sampling with frequency of 50 Hz. Data collected this way were analysed by means of a custom-created application developed in LabVIEW environment. The application was to filter vibration frequencies generated by the combustion process at combustion chambers out of the whole range of vibrations related with engine operation. The range of filtration was set between 1000-7000 Hz.

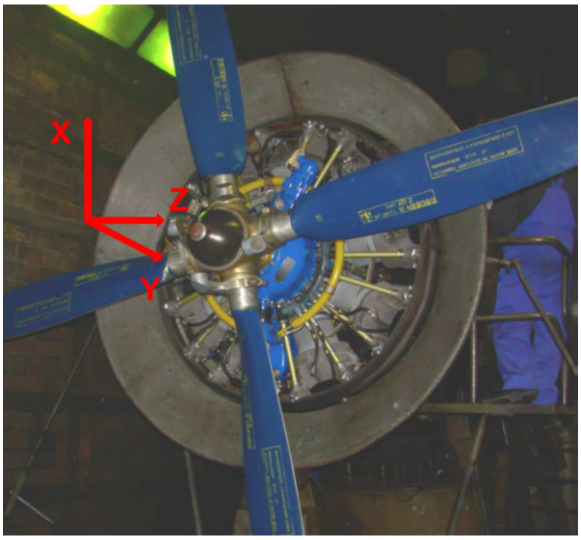

Fig. 2. Coordinate system for the experiment − designation of axes [7]

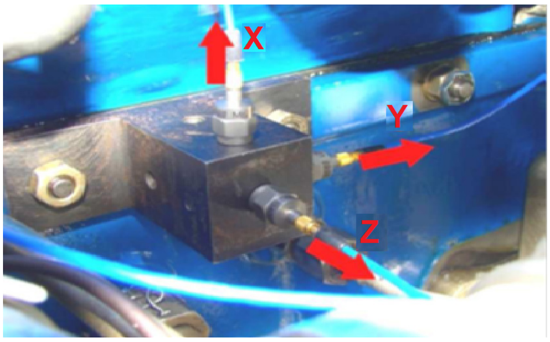

Fig. 3. Sensors mounted on the engine block

Results were analysed to determine the following characteristics:

1. Root mean square (RMS) of the full range of vibrations;
2. Fundamental frequency for full range of vibrations;
3. Spectrum of vibrations for frequency range 1000-7000 Hz;
4. Root mean square (RMS1) for frequency range 1000-7000 Hz;
5. Maximum amplitude of vibrations for frequency range 1000-7000 Hz;
6. Frequency corresponding to maximum amplitude for frequency range 1000-7000 Hz.

4. Results and discussion

Assuming that the root mean square of amplitude is an overall measure of scale of vibrations, the authors compared the root mean square of full-detected range of vibrations, RMS, and root mean square for vibrations attributable to the combustion of fuel-air mixture in combustion chambers (1000-7000 Hz), RMS1, for the previously mentioned characteristic engine speeds. The results are presented in Fig. 4. In general, the higher the engine speed, the higher the root mean square of vibrations amplitude along each axis of the local coordinate system.

A considerable increase of RMS (over 10 times) was observed between the speeds of 600 and 2200 rpm for vibrations measured in directions X and Z. As for axis Y, the increase of RMS was lower: above the speed of 1400 rpm, vibrations grew only twice.

As for vibrations attributable to the combustion process, the increase of root mean square of amplitude with growing engine speed was also observed, but it was lower than in the case of RMS. For engine speeds up to 1900 rpm, characteristics of RMS1 were similar to that of RMS. However, at greater speeds, RMS1 reacted only slightly to speed increase.

As comes from the above observations, the combustion process has a significant impact on the scale of total vibrations of the tested engine at lower engine speeds, whereas at higher speeds more vibrations are generated by cyclicity of the combustion process, movement of crankshaft, pistons and connecting rods, and movement of timing gear system elements. Moreover, combustion process related vibrations have a significant share in the whole vibration spectrum. Generalizing observations at all characteristic engine speeds, RMS1 amounts to about 80% of RMS for vibrations in directions X and Y, and about 60% in direction Z.

Figure 5 presents the spectra of vibrations (amplitude-frequency function) of filtered signal RMS1. The spectra were prepared separately for vibrations measured along each axis X, Y, Z of the local coordinate system, and at particular characteristic engine speeds.

Analysis of the spectra indicates that there existed particular vibration frequency ranges (1400-2200 Hz, 2800-4500 Hz and 5300-6200 Hz) where amplitudes were significantly higher. These amplitude peaks were observed at most engine speeds and in all directions.

In particular, in axis X, where the highest amplitudes were observed, vibration amplitude grew with increase of engine speed up to the speed of 2200 rpm. Comparing spectra at different speeds, amplitude peaks were shifted towards higher frequencies with increase of engine speed (Fig. 5). A possible cause of this finding is acceleration of combustion process due to in-cylinder pressures growing with engine speed.

Peaks in axis Z (Fig. 7) were most numerous, but of low values. Peak amplitudes in this direction grew exponentially for engine speeds between 20130 and 2100 rpm, to stabilize at higher speeds.

The highest amplitudes of combustion process-attributable vibrations were observed for vibrations in direction X, lower – in direction Y, and the lowest – in direction Z (Fig. 5-7). The difference in amplitudes observed for X and Z is of several orders of magnitude. Interestingly, most amplitude peaks of vibrations in axis X corresponded to peaks in axes Y and Z at similar frequencies, but many peaks in axis Z had no match in axes X and Y.

This indicates that horizontal vibrations are low when compared with vibrations in the vertical plane XY. The vibrations due to combustion process are generated mostly along axis X, but their effect is also vibrations in other directions.

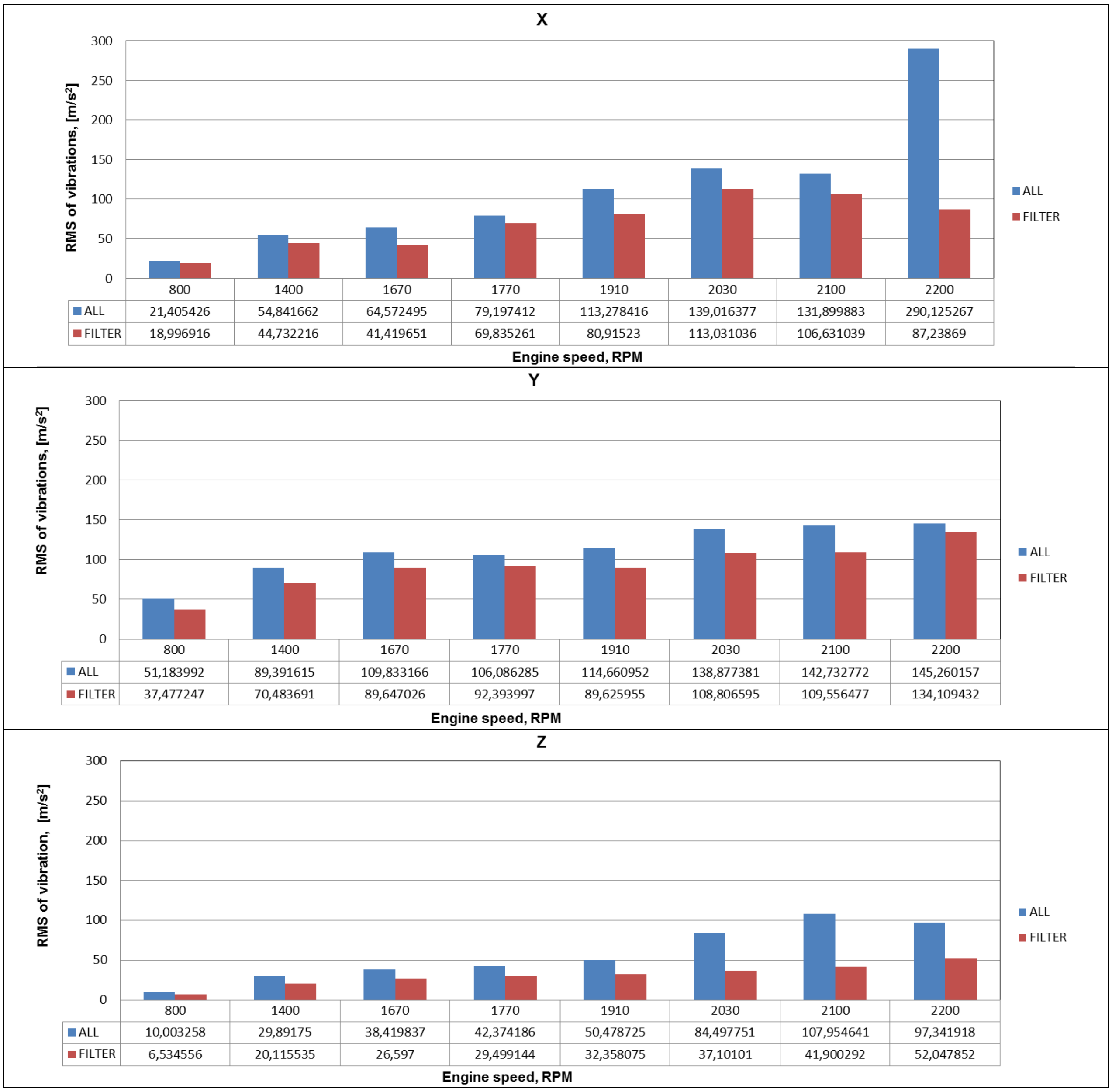

Fig. 4. The comparison of root mean square of full-detected range of vibrations (RMS) and root mean square for range of vibration between 1000-7000 Hz – those vibrations that are generated by the combustion of fuel-air mixture in combustion chambers (RMS1)

Isolated amplitude peaks were observed in each spectrum of vibrations in all three directions. The peaks are attributable to knocking. In the course of normal combustion process, the spark ignited flame moves steadily with the speed of about 30-60 m/s embracing more and more volume of compressed air-fuel mixture. In the case of knocking, the flame does not spread in a uniform way. Mixture ignition starts concurrently at many places within the combustion chamber and the flame forefront speed may be several hundred meters per second. The effect is a shockwave generating high loads that propagate through connecting rods to crankshaft and bearings. Moreover, abnormal course of combustion causes overheating of exhaust valves and piston buttons. Thus, knocking reduces power and potentially leads to engine damage. Knocking may be caused by wrong ignition settings. If ignition starts too early, the pressure within combustion chambers is too high; causing the forces acting on the crankshaft bearings to raise significantly, and the power is higher. With late ignition, the effectiveness of engine is lower and the engine is less flexible for changing of working engine parameters [8].

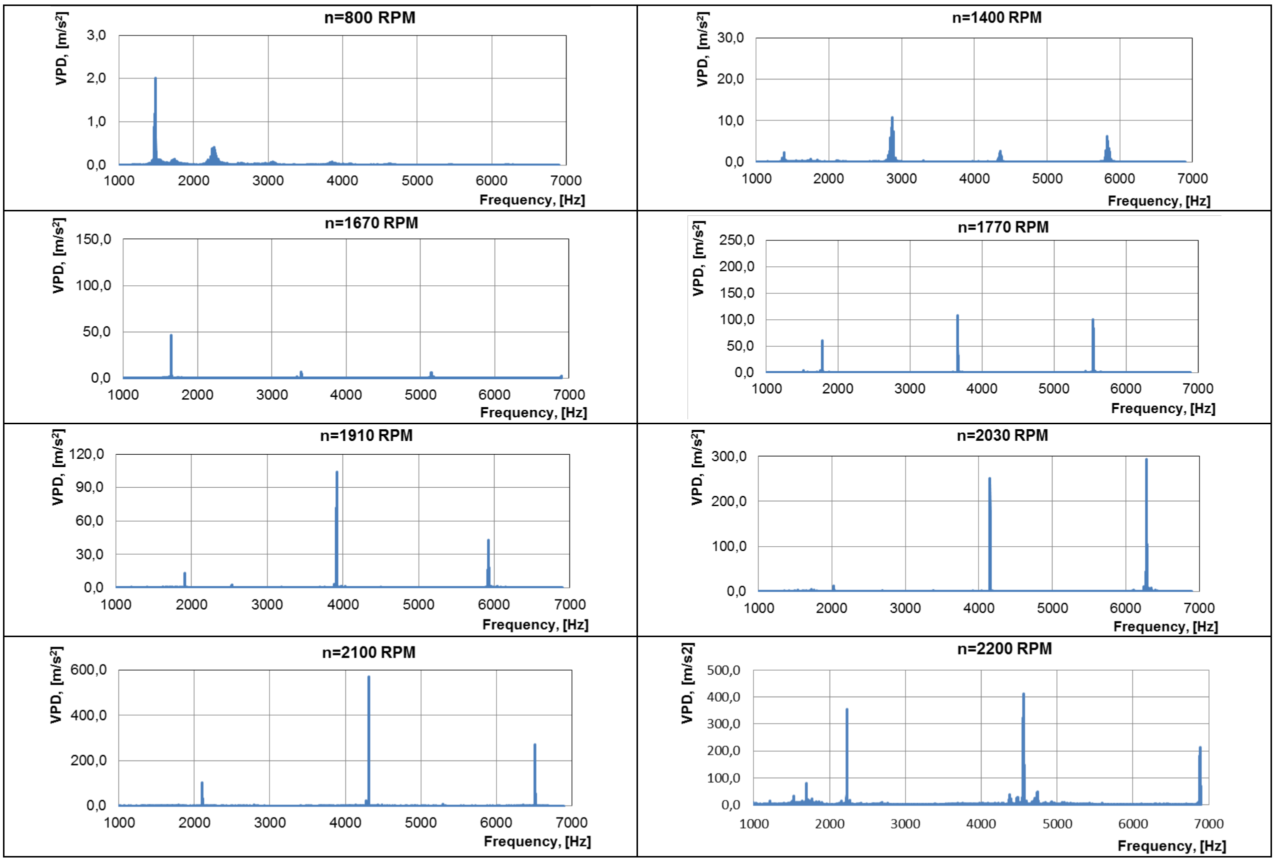

Fig. 5. Spectral analysis of vibration for characteristic engine speeds – axis X

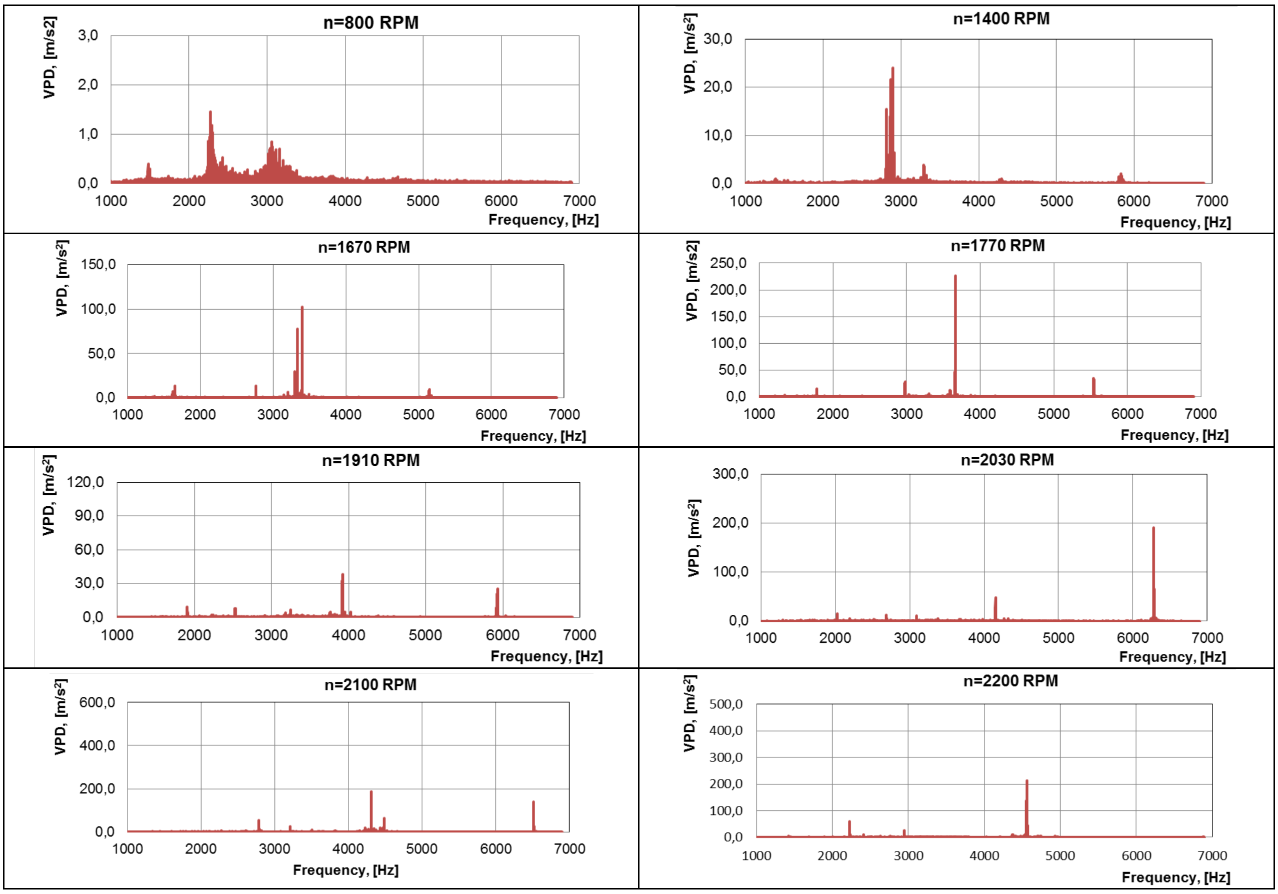

Fig. 6. Spectral analysis of vibration for characteristic engine speeds – axis Y

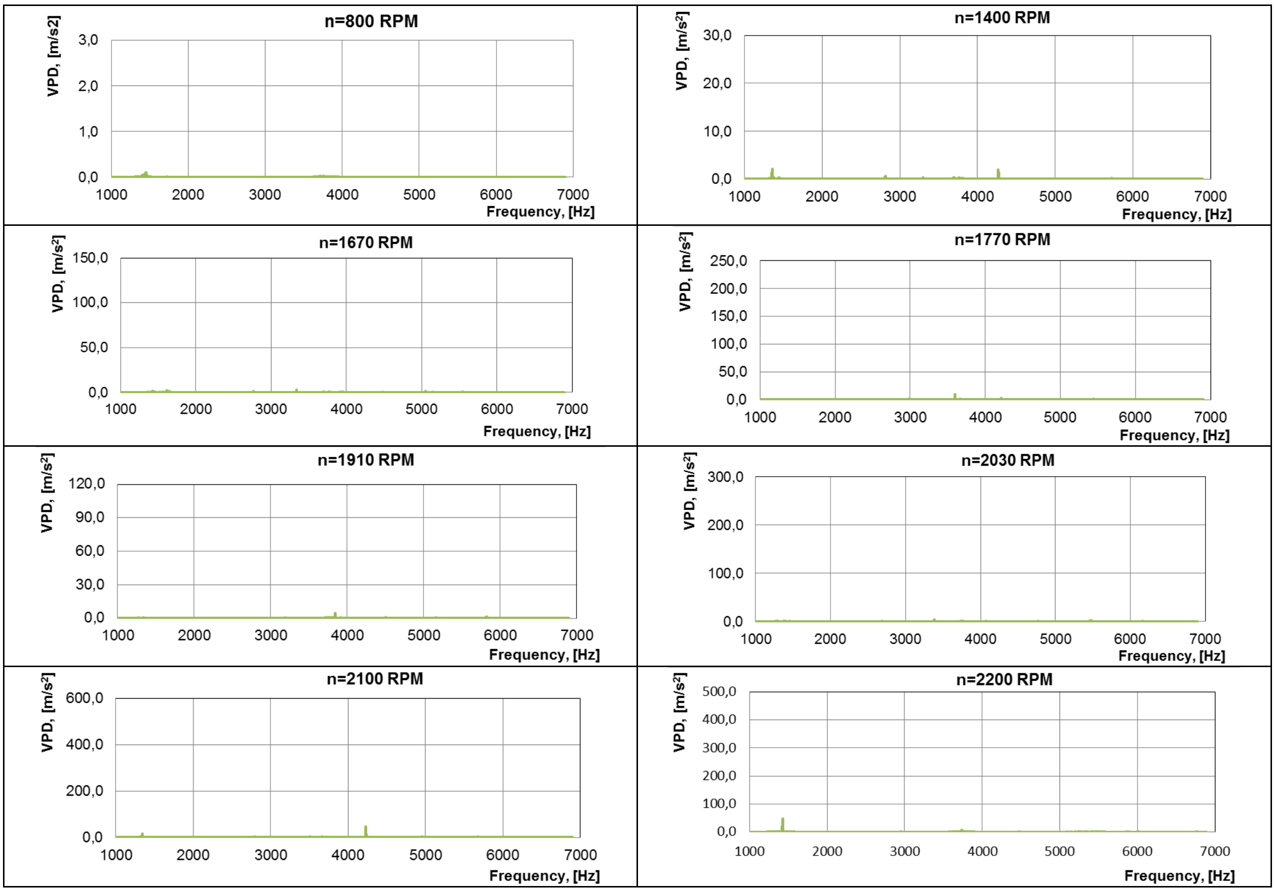

Fig. 7. Spectral analysis of vibration for characteristic engine speeds – axis Z

To find frequency ranges with most frequent vibration amplitude peaks, the amplitude-frequency charts were juxtaposed in Fig. 8.

It occurs that vibration amplitude peaks are concentrated in particular frequency ranges about 4000 Hz and 6500 Hz. As observed previously, the higher engine speed, the higher peak amplitudes. In the case of axis X, at 800 rpm, top amplitude was only about 2 m/s2, but at 2030 rpm, it grew to about 300 m/s2. The highest peaks occur at different frequencies; however, the crucial frequency is about 4000 Hz. For this value, concentrations of peaks are most striking. At engine speeds above 2000 rpm peaks occur at frequency about 6500 Hz. This frequency is strictly related with knocking.

5. Summary and conclusions

The results of the experiment on a particular aviation engine of nine cylinders in radial setup point that vibrations generated by combustion process of air-fuel mixture within combustion chambers significantly contribute to absolute vibrations of the engine: in the vertical plane along axes X and Y, combustion-attributable vibrations were responsible for 80 percent, and along axis Z – 60 percent of root mean square of amplitude across the whole frequency range. Amplitudes of vibrations due to combustion process occurred to be strongly related with engine speed, and their values were high. Propagation of these vibrations is likely to generate loads on the airframe and particular elements of the aircraft. Therefore, the results should be considered while designing the structures to fix the engine to the airframe, as well as shaping subassemblies mounted on the engine. Moreover, providing a solution to reduce vibrations by improving combustion process is expected to provide savings on aircraft maintenance. Amplitude peaks observed in the spectrum of vibrations indicate to knocking – damaging for the engine, reducing engine efficiency and thus generating unnecessary operating costs. These results provide justification for further modification of the engine – its current configuration (equipped with an electronic fuel injection control system, but with magneto ignition) calls for improvement.

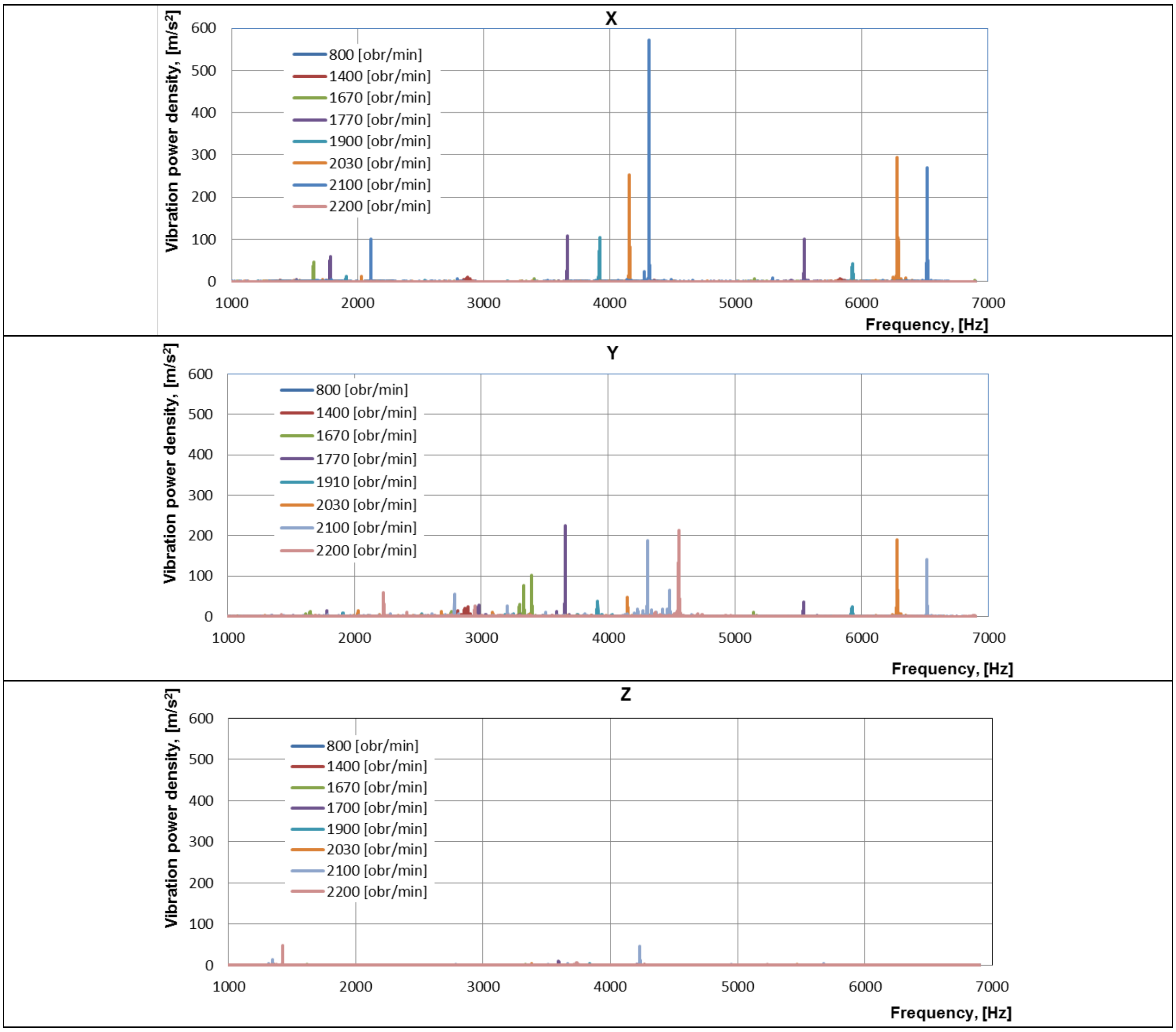

Fig. 8. Vibration peaks for all engine speeds, vibrations attributable to combustion process (1000-7000 Hz)

References

[1] Kijewski, J., *Silniki spalinowe,* Wydawnictwo Szkolne i Pedagogiczne, Warszawa 1997.

[2] Głowacki, P., Łukasik, B., *Aviation piston engines on-condition maintenance – proposal*, Combustion Engines, 3, 162, 2015.

[3] Wajand, J. A., Wajand, J. T., *Tłokowe silniki spalinowe*, Wydawnictwo Naukowo-Techniczne,

[4] Litak, G., Wendeker, M., Krupa, M., Czarnigowski, J., *A Numerical Study of a Simple Stochastic/ Deterministic Model of Cycle-to-Cycle Combustion Fluctuations in Spark Ignition Engines*, Journal of Vibration and Control, 11: 371-379, 2005.

[5] *Instrukcja użytkowania silnika lotniczego ASz-62IR-16E*, Wytwórnia Sprzętu Komunikacyjnego, PZL Kalisz.

[6] *Instrukcja obsługi silnika lotniczego ASz-62IR-16, ASz-62IR-M18*, WSK PZL-Kalisz.

[7] Raport nr 001/2014 *Analiza drgań kolektora paliwowego silnika ASz-62IR-16E – badania stanowiskowe*, Politechnika Lubelska, Wydział Mechaniczny, 2014.