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ANALYSIS OF VIBROACOUSTIC PROPERTIES OF THE 250-C20R/2 RRC (ALLISON) ENGINE IN THE SUPPORT SURFACE OF THE COMPRESSOR

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Abstract

The paper presents an analysis of the levels of vibration on the compressor in the support surface of the American RRC Allison 250-C20R engine built into the SW-4 Puszczyk helicopter. Then, it presents the association of occurring vibrations with their source of origin, and also the comparison of their values with the limit values specified in the operating manual of the helicopter. The methodology of the conducted research and analyses are explained. The essential elements preceding the research, such as determining time courses, on the basis of which the most important parts to conduct the detailed analyses of changes of the basic parameters and compliance with technical conditions, are defined. Moreover, the theoretical issues in terms of determination and description of the characteristic parameters of mechanical vibrations are briefly presented. The typical terms used in the procedures of vibration, description and measurements are explained. The importance of the interpretation of measurements is quite significantly emphasised and the components of the main engine, which were subject to measurement, are indicated. The difficulties in the identification of the vibration due to the high probability of overlapping of vibrations coming from several elements are emphasised. Next, the methodology of measurement is described, in which, among others, mounting points of vibration sensors are presented. The final part of the paper is mainly a graphical presentation of the results, on the basis of which the conclusions are developed. The conclusions show a lack of decisive symptoms indicating the danger at the level of vibrations, and present the future directions of work, which will allow for a more detailed analysis.

Keywords: *vibroacoustic properties, engine vibration analysis*

1. Introduction

For several years, in the military aviation, a light, multifunctional helicopter, SW-4 Puszczyk, has been provided. It was designed by PZL-Świdnik from the August Westland group. It is ideal for transport as well as patrolling even places and for basic and advanced aviation training. Therefore, it is currently used for the training of young pilots in the Air Force Academy.

Fig. 1. SW-4 Puszczyk helicopter [1]

[1] http://timimodelfactory.blogspot.com/.

It has very good parameters and aviation characteristics, which make it safe and pleasant to flight manoeuvre. In addition, it is designed to enable training during the day and night, in conditions compatible with IFR (Instrumental Flight Rules) and the use of the NVG goggles (tactical goggles). As a drive unit the American turbo-prop engine 250-C20R/2 Allison (Fig. 2) was built in it.

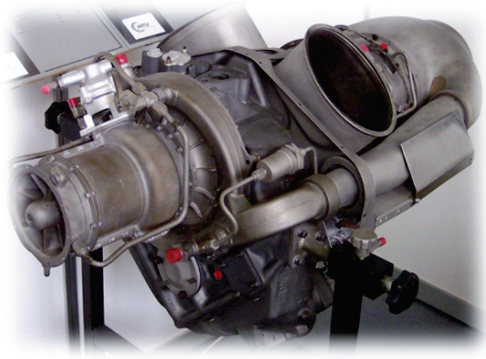

Fig. 2. RRc Allison engine model 250-C20R/2 [2]

During the exploitation of the SW-4 helicopter, the existence of vibrations in the support surface of the compressor was found. Therefore, a research was conducted, the purpose of which was to identify the source of these vibrations and to compare them with the limit values.

2. Research methodology

The research was conducted by a selective method, based on the data provided by the qualification tests in the SW-4 Puszczyk helicopter's flight.

Firstly, the basic time courses of the change in the recorded operating parameters were determined. On this basis, the most important parts to conduct the detailed analyses of change of the basic parameters, and compliance with the technical conditions defined in the Operating manual of the helicopter, were determined.

The graphical imaging specifying the levels of vibrations in a function of the *f* frequency was determined, and on this basis, the dynamics of their changes was specified. Frequency is the number of vibrations per unit of time, expressed in Hertz:

$$f = \frac{1}{T} \quad [Hz], \tag{1}$$

where: T – period, otherwise the time interval after which the vibration is repeated.

For information purposes, it is appropriate to cite a few terms used in the procedure of measurement of vibrations:

- acceleration – the rate of vibration's speed changes along the specified axis;
- shift – specifies the position change (in mm), typically measured from a medium position (or rest position) and relates to linear motion, but it may also concern the rotational motion;
- speed – refers to the rate of the shift change in time along the specified axis, the speed of motion (typically measured in mm/s);
- cycle – an interval of time during which a series of repetitive activities terminates (in case of vibrations, it is one complete vibration);
- frequency – measuring the vibration response, expressed in hertz (Hz);
- Hertz (Hz) – a unit of vibration frequency; in relation to the frequency, cycles per second are sometimes used;
- discrete frequency – measuring the vibration response at only one frequency;
- overall value – the measurement of vibrations at all frequencies, read on the counter reading the average value.

[2] http://en.wikipedia.org/wiki/Allison_Model_250.

Speed and acceleration (as defined above) are values, which characterize every motion. Speed is the first derivative of the deflection with respect to time, and acceleration is the second derivative of the deflection with respect to time:

$$v = \frac{dy}{dt} = A \cdot \omega \cdot \cos(\omega t), \tag{2}$$

$$a = \frac{d^2y}{dt^2} = -A \cdot \omega^2 \cdot \sin(\omega t), \tag{3}$$

where: ω – angular velocity,
ωt – vibration phase,
A – vibration amplitude,
y – deflection – variable in time – $y = A \cdot \sin(\omega t)$.

In order to record the basic parameters, an additionally built in measurement chain with the use of vibration sensors was used.

It was also necessary to become familiarised with the procedure of vibration research, which is essential in order to conduct their proper assessment, identification of sources and analysis of existing vibration levels, so that corrective actions can be developed in the next step.

The continuous engine exploitation with high levels of vibrations causes excessive engines and parts' wear, and may contribute to its damage and premature replacement.

Vibrations may be a result of many factors, such as the method of installation, individual properties of particular parts, normal wear, servicing, maintenance or abnormal exploitation conditions. By measuring the frequency and the level of vibration, and then comparing the measurements with the known vibration factors, such data may be identified for the purpose of obtaining information in the suspected area of the engine and requirements to conduct corrective actions.

Vibrations are mechanical oscillations or motions around a point of reference. The vibrations caused by the engine are generally observed at a frequency equal to the n_1 or n_2 rotor speed, rotational speed of the toothed gear, the meshing frequency of the toothed gear or the speed of the bearing shift. In some cases, the vibration occurs also as a harmonic component or multiples of the fundamental frequency.

In order to measure vibrations, sensors (transducers) in which the motion of vibrations is converted into the electric signal are used. These sensors can be calibrated on the basis of the vibration shift (amplitude), acceleration or speed. Speed is the most important measurement of vibrations in the Allison 250 engines.

Vibration level should be controlled regularly (as determined by the Manufacturer's research), which ought to be recorded in the relevant documentation. In case of the occurrence of significant deviations (changes), a more precise inspection of such an engine should be conducted.

The controls should be performed in a specific way – the sensors built in the vertical axis in the compressor, in the diagonal box and turbine. The data should be recorded for several specific rotational speeds n_1 speed during the ground training of the helicopter.

Currently, for the Allison 250 engines, the average limitations for discrete frequencies are 2.54 mm/s (1 inch/sec) with an overall average of 3.81 mm/s (1.5 inch/s).

3. Data interpretation

The ability to interpret data is a very important element of measuring. Firstly, it should be determined if the vibration is from the airframe or engine. A rotational speed below 6 000 rotations/min. (100 Hz) is usually associated with the airframe because the smallest rotational speed is reached by the input power shaft with 6 000 rotations/min. (with the exception of some auxiliary drives).

The analysis of the vibrations is usually conducted as follows:

- the frequency of vibrations and the speed amplitude of the main peak values of vibrations on the cards with diagrams should be specified,
- the sources of vibrations should be identified.

Vibrations from the engine occur with the following rotational speeds of main components of the engine:

- rotational speed of the turbocharger n_1,
- rotational speed of the power turbine n_2,
- rotational speed of the starter generator,
- rotational speed of the output shaft,
- rotational speed of the special motor-driven equipment.

Vibrations from the airframe are mainly:

- rotational speed of the helicopter rotor,
- transition speed of the rotor blade and its multiple,
- speed of drive shaft of the tail rotor,
- rotational speed of the tail rotor,
- transition speed of the tail rotor blade and its multiple.

Identification is also possible on the basis of calculations, which are conducted with the use of a speed chart (methodology described in the manual and technical service of the Allison 250-C20R engine).

It is quite difficult to identify vibrations occurring on the body of the compressor (in the vicinity of the support). There is a high probability of overlapping of the vibrations from a few elements. For example, in case of disorders of the n_1 speed, it is advisable to check,

- the cables of the analyser of the vibration spectrum and sensor, in order to make sure that all the equipment works properly and is appropriately calibrated,
- the operating equipment, due to potential damage and failures,
- the compressor, i.e. its technical condition, mounting to the turbine, etc. as well as damage with foreign bodies (which is usually accompanied by acoustic changes – noise),
- the main shaft bearings or if there are no signs preceding its damage (metal shavings in the oil, etc.),
- the coaxial alignment of the front support, compressor and gear box,
- the shift of the shaft connecting the turbine with the compressor

and many other elements.

Finally, if as a result of all possible tests, repairs or replacements of defective elements according to the relevant recommendations, excessive vibrations do not stop, please contact the Allison company.

4. Methods of measurement

The measurement of engine vibration in the support surface of the compressor was performed during the flight of the SW-4 helicopter, using a sensor mounted in the position (1) shown in Fig. 3.

In order to record the vibrations, a B&K 4371 sensor was used. The vibration sensor was mounted to the support made in accordance with the manufacturer's recommendations given in p. 3-16 of the GTP 5232-5 document. The signal obtained from the vibration sensor was amplified using two three-channel ENDEVCO amplifiers of 133 type and numbers AP-14, AP-15 and three one-channel B&K amplifiers of 2635 type and numbers 1690192, 1690199, 1690237.

The measuring vibration signals (listed in Table 1) were recorded with the SONY recorder of the SIR 1000i type and No. C32040 with the digital data record on a magnetic tape of the CN 120 type. The analysis of data was performed using a B&K frequency analyser of the 2034 type and No. 1217100.

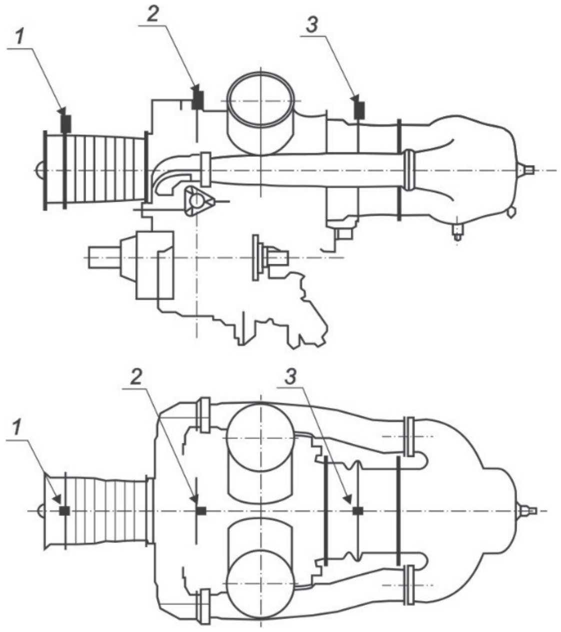

Fig. 3. The layout of places for mounting the vibration sensors of the 4371 type on the engine: 1 – body of the compressor, 2 – body of the drive box, 3 – turbine

Table 1. List of measurement points during ground training of the engine

Item	Stages of the ground training - rotational speed of the turbocharger's rotor n_1 [%]
1	60
2	65
3	75
4	80
5	85
6	90
7	92

The complete accuracy of the measurements, taking into account the characteristics of the sensors, amplifiers, resolution of the measurement system, sampling and mechanical calibration of measuring circuits shall be at least 5% of the measured value.

For the analysis and further comparison of the obtained results with the data presented by the manufacturer in the diagram of vibrations, in part II of the GTP 5232-5 publication, the digital filtering was performed in order to reduce the analysed frequency band ranging from 40 Hz to 2000 Hz.

5. Research results

The course of the vibration speed during the whole flight training shows that take-off and landing are dominant in terms of the obtained unit changes in values of the achieved levels of speed vibrations in the body of the compressor.

The graphical imaging of the spectrum of vibration acceleration in a function of frequency shows the ranges for which there are characteristic peaks, which constitute the evidence of the highly dynamic nature of the vibration of the compressor's body. The frequency value enables to specify the source of vibrations and the proper attitude to the problem.

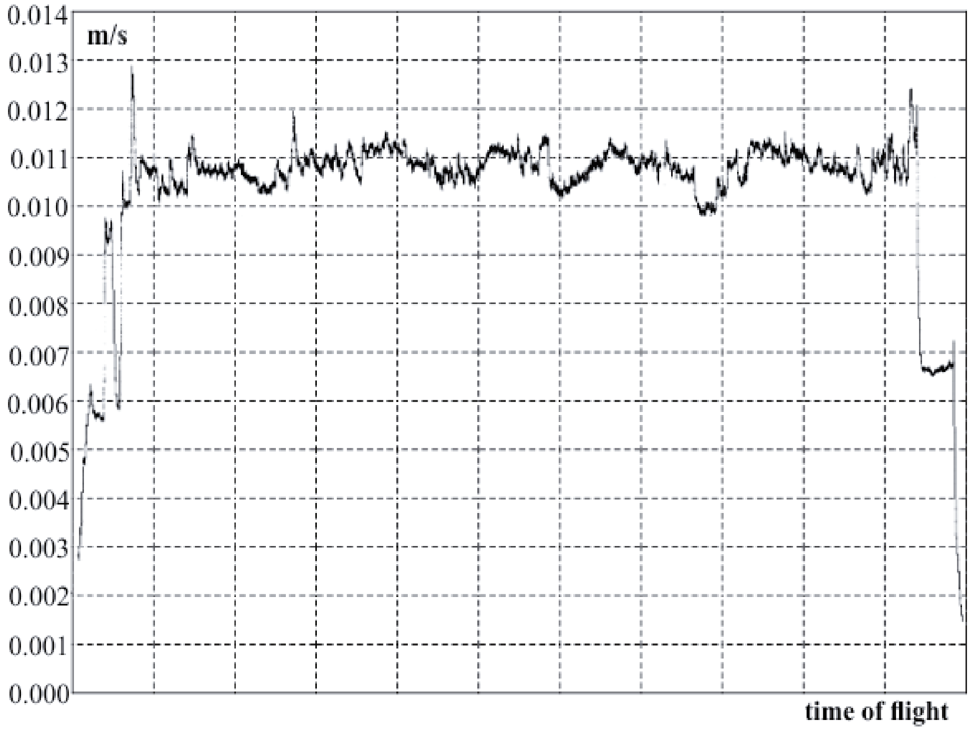

Fig. 4. Characteristics of the vibration speed change by the support of the compressor of the Allison 250-C20R engine during the flight

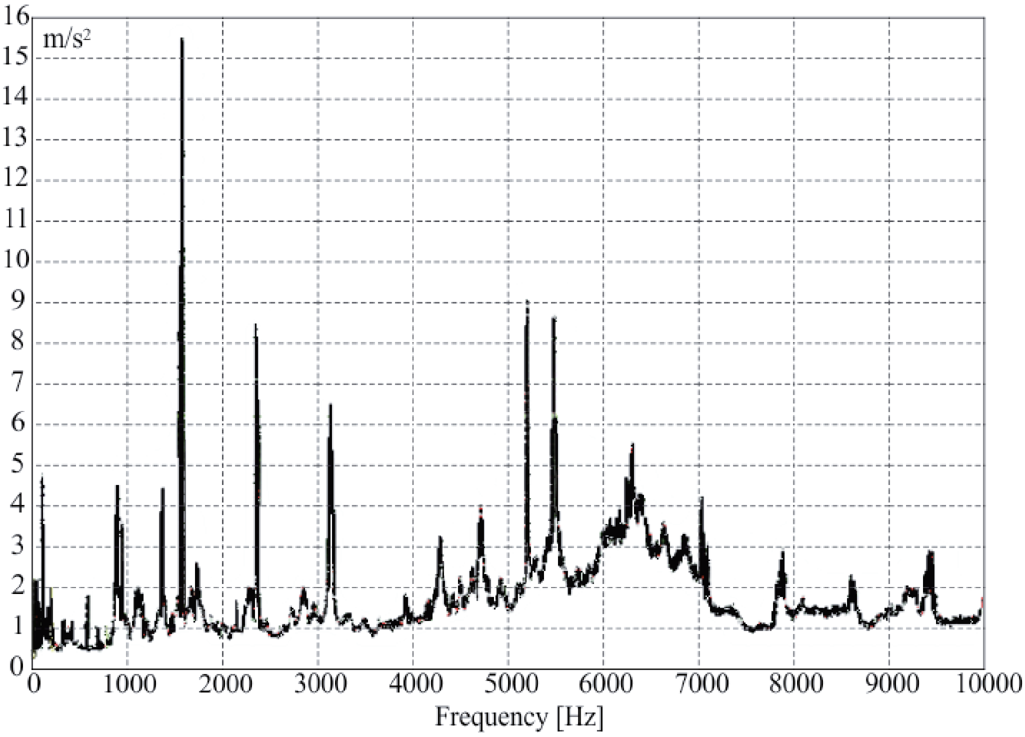

Fig. 5. The nature of change of the acceleration of vibrations by the support of the compressor of the Allison 250-C20R engine during the flight in the frequency function

Fig. 6, in turn, shows a selected spectrum of the vibration speed of the compressor body for the turbocharger rotor speed $n_1=90\%$.

The list of the maximum values of the medium deviation of the engine vibrations recorded in the ground training within the determined states of the engine's operation is presented in Table 3. Limitations of vibration defined in the GTP 5232-5 document, for the determined conditions of the engine's operation, are presented in the last line of Table 3.

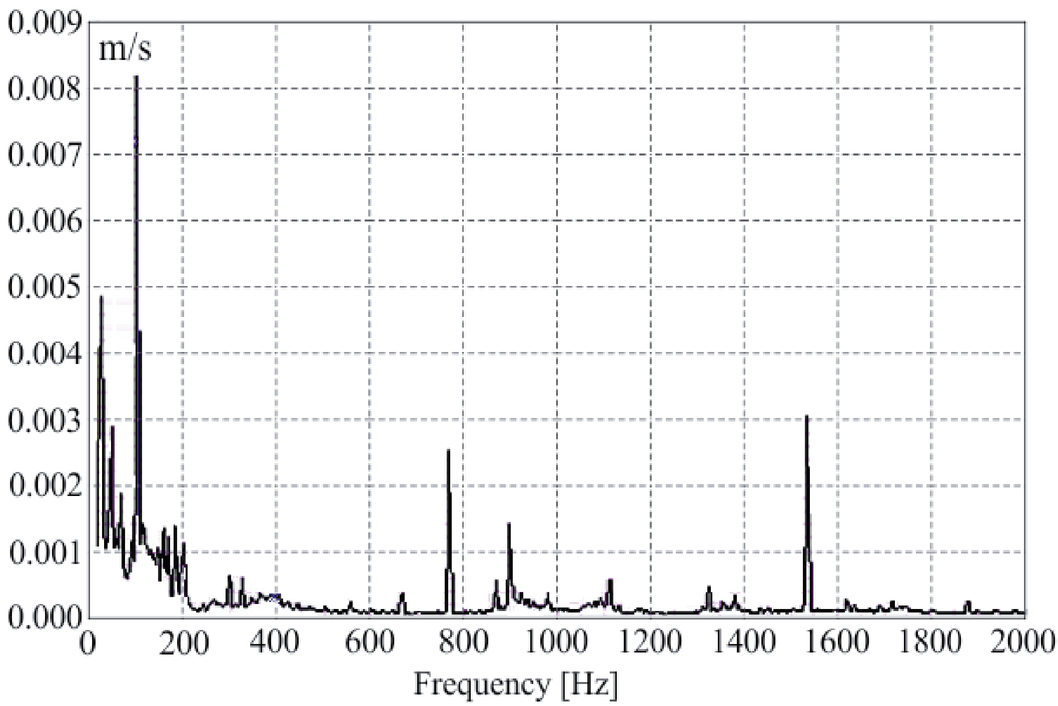

Fig. 6. The vibration spectrum Z_s of the compressor's body for the rotational speed of the turbocharger rotor n_1=90%

Table 3. The list of the maximum values of the medium deviation of the engine vibration

Item	Rotational speed of the turbocharger rotor n_1 [%]	Medium deviation of the avg. vibrations for the determined states	
		Body of the compressor (vertical)	
		mm/s	in/s
1	60	9.69	0,38
2	65	10.50	0.41
3	70	11.50	0.45
4	75	11.90	0.47
5	80	13.80	0.54
6	85	14.80	0.58
7	90	17.80	0.70
8	92	18.20	0.72
Max		18.20	0.72
Limitation by GTP 5232-5		38.10	1.50

The obtained results of the linear engine vibrations for the determined states meet the requirements of the manufacturer included in the GTP 5232-5 document in all tested operating states of the helicopter on the ground.

6. Conclusions

The conducted analysis of data from research during the SW-4 Puszczyk helicopter's flight, in the scope of vibroacoustic properties of the RRC (Allison) 250-C20R/2 engine, in the support surface of the compressor, showed no deviations from WT.

It is advisable to be fully convinced that there was no evidence suggesting an abnormal nature of work of the engine. Additionally, the data from several flights and in various flight configurations was analysed.

1. References

[1] Buchacz, A., Świder, J., Wojnarowski, J., Podstawy teorii drgań układów mechanicznych z symulacją komputerową. Układy dyskretne o jednym stopniu swobody. Wyd. Politechnika Śląska, 2011.
[2] Cemple, C., Drgania mechaniczne, wprowadzenie – wyd. 2. Wyd. Politechnika Poznańska, Poznan 1984.
[3] Kowalski, M., Zagadnienia diagnozowania turbinowych silników lotniczych z wykorzystaniem danych z pokładowych rejestratorów lotu. Zeszyt naukowy ITWL nr 31. Warszawa 2013.
[4] Kowalski, M., Kozakiewicz, A., Unstable operation of the turbine aircraft engine. Journal of Theoretical and Applied Mechanics. Vol. 51. No. 3. pp. 719-727. 2013.
[5] Kucharski, T., System pomiaru drgań mechanicznych. WNT. 2002.
[6] „Instrukcja użytkowania i obsługi technicznej wersji silnika 250-C20R – silnik – sprawdzenie/regulacja. Świdnik 2006.
[7] http,//timimodelfactory.blogspot.com/.
[8] http,//en.wikipedia.org/wiki/Allison_Model_250.