How to cite this article:
Authors: Leszek Bielenda, Wojciech Obrocki, Maciej Masłyk, Jan Sieniawski
Title of article: „Metodyka pomiaru amplitudy drgań pióra łopatki sprężarki silników lotniczych w próbie zmęczeniowej" („The methodology for measuring the vibration amplitudę of the blade of the aircraft engine compressor in the fatigue test")
Mechanik, Vol. 91, No. 3 (2018): pages 230-232
DOI: https://doi.org/10.17814/mechanik.2018.3.38

The methodology for measuring the vibration amplitude of the blade of the aircraft engine compressor in the fatigue test

Metodyka pomiaru amplitudy drgań pióra łopatki sprężarki silników lotniczych w próbie zmęczeniowej

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Results of comparison research of various sensors types used in the fatigue tests for aircraft engine compressor blade vibration amplitude measurement were analysed. Following sensors were tested: inductive, capacitive, eddy-current, laser and vibration. Presented were sensors characteristics and their shortcomings. Additional test stand instrumentation was designed and made, including mounting bracket.
KEYWORDS: measurement of vibration amplitude, inductive sensor, capacitive sensor, eddy current sensor, laser head, vibration sensor

Compressor and steering rotor blades belong to the critical components of turbine engine construction. Their operational reliability depends on the safety of engines and aircraft. Therefore, engine manufacturers have to control their strength properties already in the manufacturing process. Compressor blades are exposed during operation to varying bending and torsional loads from the aerodynamic forces of the stream of flowing gases and variable tensile loads induced by centrifugal force. The analysis of the literature data and the results of own research show that the damages of the blades are most often caused by the action of bending forces. Witek [1-3], among others based on the tests of compressor rotor blades after exploitation, showed that the main cause of their fracture are mainly variable bending loads.

At present, steel compressor blades in the production process are subject to fatigue strength assessment. The basis for the fatigue test $N_G = 5 \cdot 10^6$ cycles is accepted in these tests. The fatigue test is conducted for randomly chosen blades (samples) and its result is generalized according to the accepted algorithm of analysis and statistical inference [4].

Fatigue tests for a large number of cycles are time-consuming and modern methods of determining the fatigue strength of the blades affect the cost of their production.

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That is why research on a new method is being carried out, allowing first of all to shorten the time of the fatigue test and its full control.

Research methodology

The paper deals with the development of a methodology for measuring the vibration amplitude of a blade of an aircraft engine in a fatigue test in the conditions of a large number of cycles. The basic subassembly of the test bench is the electro-dynamic vibration exciter model V-830 (4) from LDS (tab. I, fig. 1). The stand was additionally equipped with: a climatic chamber (1), enabling the introduction of changes in the environment, including humidity and temperature from -80 to 180 °C; a power amplifier (2) and a computerized sample control system (3). The research was carried out at the Research and Development Laboratory for Aerospace Materials and the Department of Materials Science at the Faculty of Mechanical Engineering and Aeronautics at Rzeszow University of Technology.

TABLE I. Technical characteristics of electrodynamic vibration exciter LDS V-830 [5]

Maximum force in a sinusoidal cycle, kN	6,78
Resonance frequency of the pulsator head, Hz	3100
Maximum speed of the pulsator head, m/s	2
Maximum head acceleration, m/s^2	1176,7
Maximum displacement of the head, m	0,0254
Weight of the pulsator, kg	616
Maximum mass of tested object, kg	160
Working frequency range, Hz	5÷3500

Fig. 1. Test stand for fatigue testing of compressor blades: 1 - climatic chamber, 2 - power amplifier, 3 - computer control system, 4 - electrodynamic vibration exciter

Fatigue tests and vibration amplitude measurements were carried out for the first stage compressor vanes of the length and width of the blade respectively: 53 and 22 mm. The TF-3 strain gauges with a 3 mm measuring base were mounted on the upper surface of the blade at a fixed distance from the lock - 8 mm (fig. 2). The developed and performed auxiliary equipment of the test stand (fig. 3) enabled fatigue testing of the blade for a large number of cycles. The blade (5) is fixed in the holder (1) by means of the clamping screw (3). The stand has been supplemented by a vibration sensor (2), a laser head (4) and a light microscope (6).

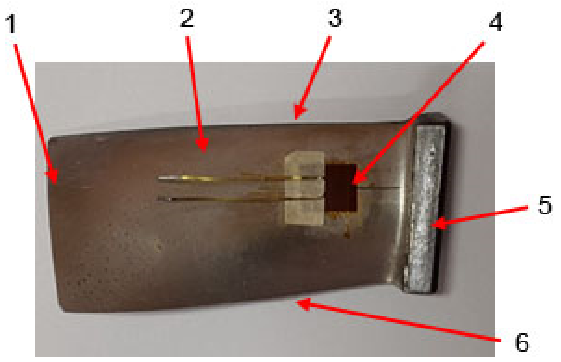

Fig. 2. Compressor blade with TF-3 strain gauge: 1 - blade tip, 2 – upper blade surface, 3 - leading edge, 4 – strain gauge, 5 – lock, 6 - trailing edge

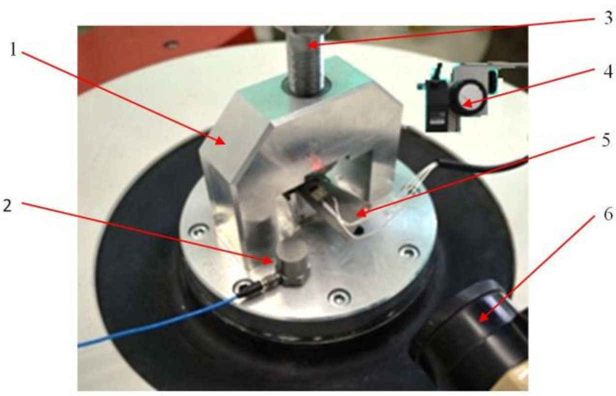

Fig. 3. Additional instrumentation used in the fatigue test: 1 - screw holder, 2 - vibration sensor, 3 - pressure screw, 4 - laser head, 5 - examined blade, 6 - light microscope

The control of the fatigue test of the blades is ensured by the developed proprietary control system. The National Instruments solutions were adopted as the basis of this system. The program controls the work of the pulsator, and at the same time ensures obtaining the required amplitude and frequency of the head vibrations. It allows to enter the blade into resonant vibrations. The constant value of the vibration amplitude of the blade is a condition for its constant dynamic load during the fatigue test.

During the fatigue test following quantities were measured: the amplitude and frequency of vibrations of the pulsator head and the displacement of the tip of the blade. The stabilized stress value on the upper surface of the blade was determined using a strain gauge.

Amplitude and frequency of vibration of the pulsator head was determined by means of a piezoelectric sensor attached to the handle of the spatula. Measurements of the amplitude of displacement of the tip of the vibrating blade were made using the optical method using a light microscope type PZO 21338. Continuous control of the movement of the tip of the vibrating blade was carried out using sensors qualified for measurement tests, among others inductive B&K MM-002, capacitive B&K MM-004 and eddy current blast Nevada 3300, and the Keyence LK-G402 laser head and the Endevco 22 vibration sensor.

Measurements of the blade deformation were carried out on the surface of the blade using a TF-3 strain gauge with a measuring base of 3 mm. Stress values in the elastic range were determined taking into account Hooke's law.

The basis of the developed measurement system were the sensors measuring the displacement value of the tip of the blade and the amplifier of the measured signal. The output signal for the displacement sensors was the voltage value. It was measured by a FLUKE 87V voltmeter. The use of a vibration sensor required a double integration of the output signal to obtain a displacement signal.

The vane blade during the fatigue test is subject to cyclic bending load to obtain a suitable stress value in its cross-section. It was assumed that the forced vibration frequency of the blade corresponds to the frequency of its own vibrations. Decrease in the natural frequency of the blade is a result of the changes in the surface layer of the blade and the initiation of fatigue microcrack and its propagation [6-11].

Measurements of vibration amplitude of the tip of the vane were carried out with the use of sensors with characteristic properties, including inductive, capacitive, eddy current, laser and vibration sensor (tab. II). The measurement results will form the basis of the comparative analysis and the determination of the criterion for selecting the type of sensor for the fatigue test.

TABLE II. Technical characteristics of sensors for measuring the displacement of the tip of the compressor blade in the fatigue test

Sensor type	Measurement distance, m	Working temperature, ºC	Working frequency, Hz	Remarks
Inductive sensor (Brüel & Kjær MM-002)	< 9 m	-150–250	< 2 k	dynamic
Capacitive sensor (Brüel & Kjær MM-004)	bd.	< 250	< 200 k	static and dynamic
Eddy current sensor (Bently Nevada 3300)	< 2 m	-35–177	< 10 k	static and dynamic
Laser head (Keyence LK-G402)	< 200 m	< 50	< 50 k	static and dynamic
Vibration sensor (Endevco 22 Picomin)	nd.	-73–149	< 12 k	dynamic

Research results and their analysis

As a basis for analyzing the value of the displacement amplitude of the tip of the blade during the fatigue test, the values of the output voltage were adopted, which were determined with the use of following sensors: inductive, capacitive, eddy current and laser. The dependence of the blade tensile stress on the output voltage was determined (fig. 4 and tab. III).

Preliminary analysis of the test results allows to conclude that in the assumed measurement range a proportional relationship was obtained - the characteristics of the blade root and output voltage values for eddy current, inductive and laser sensors and for measuring the length of deviations by means of a light microscope is linear. It was also found that the vibration sensor used to measure the displacement amplitude of the tip of the blade, mounted on the upper surface of the blade, influences the change of the resonant frequency of this amplitude. This frequency has been reduced from 833 to 800 Hz. It was also shown that the additional mass applied to the surface of the vibrating blade precludes obtaining tensile stress >70 MPa (fig. 5).

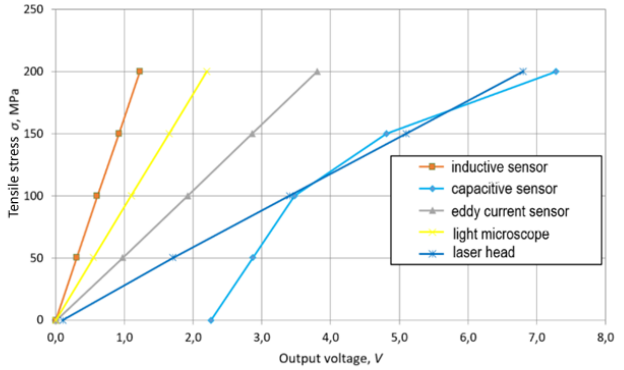

Fig. 4. Tensile stress in the blade depending on the output voltage for various types of sensors

TABLE III. Tensile stress in the blade depending on the output voltage for different types of sensors

Tensile stress , MPa	Blade tip displacement, mm	Output voltage, V			
	PZO microscope	MM-002 (capaciti-ve sensor)	MM-004 (inductive sensor)	3300 5 mm (eddy current sensor)	LK-G402 (laser sensor)
0	0,00	2,3	0,0	0,0	0,1
50	0,28	2,9	0,3	1,0	1,7
100	0,55	3,5	0,6	1,9	3,4
150	0,83	4,8	0,9	2,9	5,1

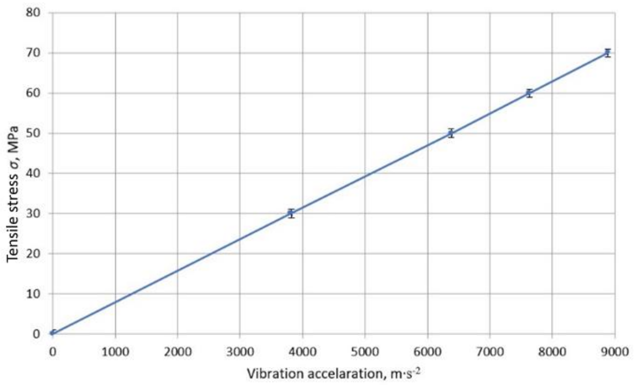

Fig. 5. Tensile stress in the blade depending on the acceleration of vibrations

TABLE IV. Tensile stress in the blade determined depending on the displacement of the tip based on the output signal of the Endevco 22 vibration sensor

Tensile stress, MPa	Standard deviation, MPa	PZO Microscope	Vibration sensor Endevco Model 22	
		Displacement, mm	Accelaration, $m \cdot s^{-2}$	Displacement, mm
0	0,55	0	0	0
30	0,47	0,165	3820	0,15
50	0,50	0,275	6381	0,25
60	0,41	0,330	7633	0,30
70	0,43	0,385	8889	0,35

Conclusions

The analysis of the test results indicates that to measure the amplitude of displacement of the tip of the blade in the case of a variable stress value a good solution is to use a laser head. It is characterized by a large range of measuring distance. It enables easy mounting of the sensor on the test bench in comparison to capacitive, inductive, inverter and vibration sensors. The disadvantage of the laser head is the low operating temperature - up to 50 °C (tab. II). The large distance between the examined blade and the laser head, however, allows measurement of the amplitude of its tip movement at a higher temperature than the temperature of the laser head. In addition, the use of a laser head allows the measurement of vibration amplitudes with frequencies up to 50 kHz.

It was also found that measurement of blade vibration amplitude during fatigue testing with the use of a vibration sensor is not possible in the whole measuring range. The vibration sensor, due to the additional mass introduced into the system, did not allow achieving the compressor blade stress level >70 MPa. It can be used when the mass of the tested object is much larger than the mass of the sensor.

The other types of sensors - capacitive, inductive and eddy current - were characterized by good stability of the output signal during the fatigue test. It was difficult, however, to accurately determine the distance between the sensor and the object. These sensors have a smaller measuring range than the laser head. However, during measurements at high ambient temperature they gain advantage and in such cases they should be chosen (tab. II).

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Translation of scientific articles, their computer composition and publishing them on the website www.mechanik.media.pl by original articles in Polish is a task financed from the funds of the Ministry of Science and Higher Education designated for dissemination of science.

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