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IMPACT OF THE VIBRATION AMPLITUDE ON THE FATIGUE LIFE OF COMPRESSOR BLADES WITH MECHANICAL DEFECTS

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Abstract

In this paper, the results of an experimental fatigue analysis of the compressor blades with the mechanical defects were presented. Before the fatigue test, the blades were damaged in order to simulate the foreign object damage. In this operation, the v-notch was created by hitting the hard object into leading edge of the blade. The similar kind of damage occurs when the small particles as stones or sandy grains are sucked to the engine inlet and next have a collision with the rotated blade. As a result of the impact, both the plastic strains and also the initial stresses occur in the vicinity of the notch. These stresses have a large influence on the number of load cycles to crack initiation. During the experiment, the blades were entered into transverse vibration with the use of Unholtz-Dickie TA-250 vibration system. The crack propagation process was conducted in resonance conditions. During the fatigue test the blades were periodically bent. In investigations, the different vibration amplitudes of the blade were considered. During the fatigue test, the crack length was monitored with the use of non-destructive fluorescent penetrant method. The amplitude of the blade tip displacement was controlled using the Polytec PSV H-400S laser scanning vibrometer.

The main aim of this work is analysis of influence of the vibration amplitude on the fatigue life of the compressor blade of the turbine engine. The results of presented investigations are important from the research and also from the practical point of view and have an influence on safety and reliability of the turbine engine.

Keywords: *turbine engine, compressor blade, v-notch, resonant vibrations, fatigue life*

1. Introduction

Compressor blades are one of the most important components of aero engine. They compress of air, which is next mixed with fuel and used in combustion process. The blade of axial compressor during the work (Fig. 1) is subjected to the high rotational velocity and the large centrifugal force acts on the compressor components. The operational speed of rotor of small turbine engines achieves 50000 RPM. Centrifugal forces cause that a large radial stress occurs in the blade.

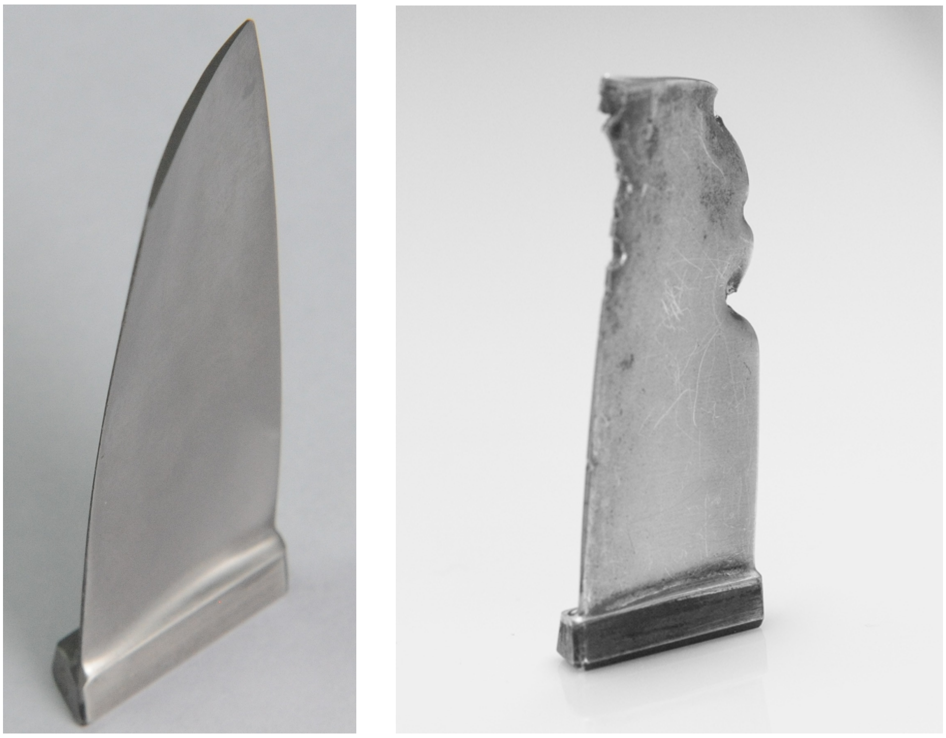
The axial compressor blade (Fig. 2a) has a small cross-section area. The small thickness of the profile causes that the blade is susceptible to resonant vibration, which can be excited by unbalanced rotor or non-uniform air pressure in the compressor passage. During the work of the engine, especially close to the ground, the compressor blades are also susceptible to foreign object damage (FOD). FOD is often caused by small objects (stones, sand grains) sucked to the inlet channel of engine. FOD often causes mechanical defects (notches) located often on the attack edge of the blade (Fig. 2b). These defects accelerate the fatigue process of the compressor blades.

Fracture problem of the compressor blades were analysed in works [1-13]. In many publications, authors considered this problem from the point of view of the fatigue of materials. In this paper, the attention is focused on the different research aspect.

The objective of presented investigation is to determine the influence of vibration amplitude on the fatigue life of the compressor blades with mechanical defects.

Presented results in this work of investigations concerned with the modal analysis of the compressor blades with defects are interesting not only from the research but also from the practical point of view. The modal analysis of the blades performed during the engine main inspection can indicate which blade has a fatigue crack and should be replaced.

Fig. 1. View of first stages of compressor



a) b)

Fig. 2. View of an undamaged blade (a) and blade after FOD (b)

2. Experimental investigations

The crack initiation and modal analysis of the blade were performed with the use of Unholtz-Dickie UDCO-TA-250 vibration system at Laboratory of Turbomachinery in Rzeszów University of Technology (Fig. 3). For control the amplitude of the blade tip displacement the laser scanning vibrometer POLYTEC PSV-H400S were used. To measure the crack length (a dimension in Fig. 4) a non-destructive fluorescent penetrant inspection was utilized (Fig. 5). In all tests, the intensity of excitation of 15 g was defined (where 1g equals 9.81 m/s^2). During the investigations, the first mode of transverse vibration was only considered. The blade consists the V-notch located on the attack edge, 3 mm above the blade lock. The notch was created by hitting of a hard object, which simulates a FOD. In preliminary phase of investigations the blade was tested in resonance conditions to the first fatigue crack appearance (to the crack length a = 1-2 mm). Such a length of the crack is achieved when the resonant frequency decreases at about 1%. This information was taken from previous experimental studies [14]. The blades are tested with different amplitude of vibrations. In investigations, the vibration amplitudes have the following values: 1.8, 2.1, 2.3 and 2.5 mm. The number of load cycles can be calculate by multiply of the resonant frequency and a time of the test. Obtained results of the experimental analysis were compared to the fatigue life of the compressor blade with V-notch created by machining (presented in work [13]).

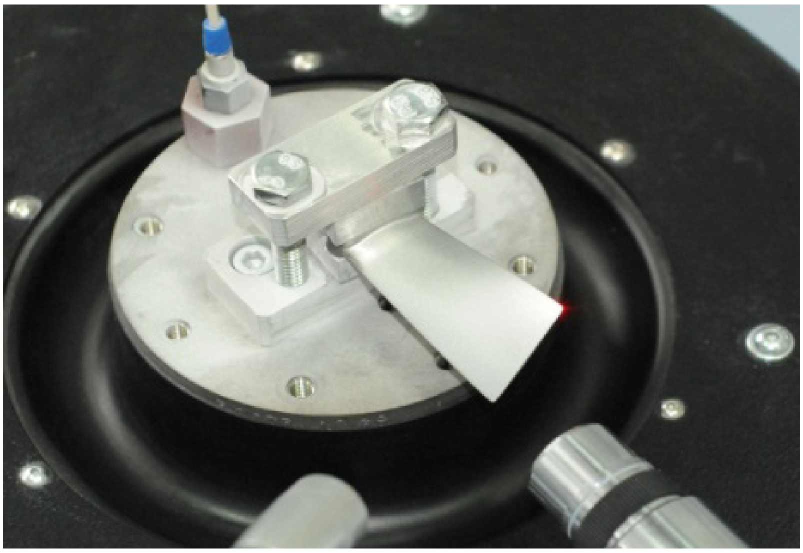


Fig. 3. Compressor blade during vibration test

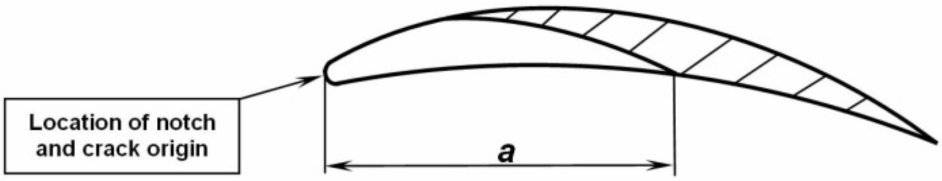


Fig. 4. Fracture of blade with crack length definition (a dimension)

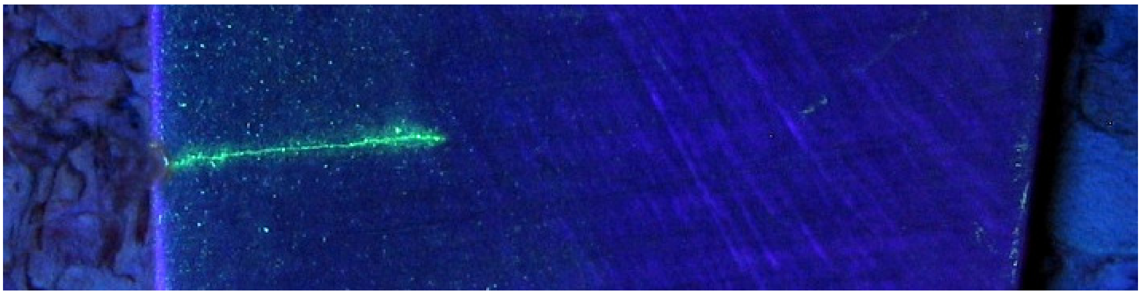


Fig. 5. View of fatigue crack in UV light (fluorescent NDE method)

The examinations have been conducted on the group of the blades of PZL-10W helicopter engine. The blades have been damaged by a series of hammer hits into intermediary chisel. After this operation the depth of the notch was equal to 0.5 mm while the angle of the notch – 90 degrees. The radius of notch fillet equals 0.05 mm. The angle between the attack edge and the cutting face of the chisel is 45 degrees.

The individual test results were averaged and presented in Tab. 1. Averaged value of resonant frequency is 817.6 Hz for I mode. The value of the resonance frequency of the blade in the case where the amplitude is equal to 1.8 mm and a notch was formed by machining is higher at about 3%. Maximum value of difference is observed in case when amplitude is equal to 2.3 mm. For this case of tests, a deviation of difference is equal to 4.1%. The small difference between the values of the resonance frequency shows the similarity of examined blades and will be the basis for comparing the results. The mass of studied objects were ranged from 15.6 to 16.4 grams.

In Tab. 1, the results of an experimental analysis were presented. All tests were performed in resonant conditions. The results in row no. 1 was taken from the work [13] in with the blades with the notch created by machining were tested. In the case of the vibration amplitude A=1.8 mm, the crack was initiated after N=0.144×10 the numbers of load cycles. The rows numbers 2-5 concern the blades with defects created by hitting (impact of a hard object). The amplitudes of vibration have the following values: 1.8, 2.1, 2.3 and 2.5 mm. The results from row no. 2, the vibration amplitude equals A=1.8 mm. The difference in the nature of the notch formation process has an infulence on increase of the number of load cycles to crack initiation. During the test the blade was subjected to resonance for 13 hours. After that the test was interrupted when the number of cycles was equal to 40 million. The number of cycles necessary for the crack initiation was not achieved. The same situation occurred in the case of the experiment described in the third row of the table (for the blade damaged by hitting). The vibration amplitude was equal to A=2.1 mm. After reaching 12 million of the load cycles the test was discontinued without the crack detection.

In the case of the blade damage by impact (A=2.3 mm, fourth row in Tab. 1) the crack was initiated after about 3.6 million of cycles. The increase of the vibration amplitude to the value A=2.5 mm caused a decrease of the number of load cycles for crack initiation to the value of 1.7 million. This value is at 47% smaller than the number of cycles for the crack initiation for the blade vibrated with the amplitude A = 2.3 mm.

Tab. 1. Summary of the results of experiment fatigue test

Test number	Amplitude of displacement	Resonant frequency	Test time	Number of load cycles	Crack appearance
	A, mm	F_{rez}, Hz	s	$N\times10^6$	(Y/N)
1	1.8	820	174	0.144	Y
2	1.8	815	49080	40	N
3	2.1	815	14730	12	N
4	2.3	821	4420	3.6	Y
5	2.5	817	290	1.7	Y

Tab. 2. The dependence between the crack length and the resonant frequency for the blades vibrated with an amplitude of A=1.8 mm (blade no. 1) and A=2.5 mm (blade no. 5)

Amplitude of displacement A=1.8 mm (blade no.1)		Amplitude of displacement A=2.5 mm (blade no. 5)	
Notch created by machining [13]		Notch created by hitting	
Crack length	Resonant frequency	Crack length	Resonant frequency
mm	Hz	mm	Hz
0.00	820	0.00	817
2.00	817	2.50	814
4.50	805	7.50	774
7.00	779	14.00	599
10.00	727	18.00	452
16.50	531		

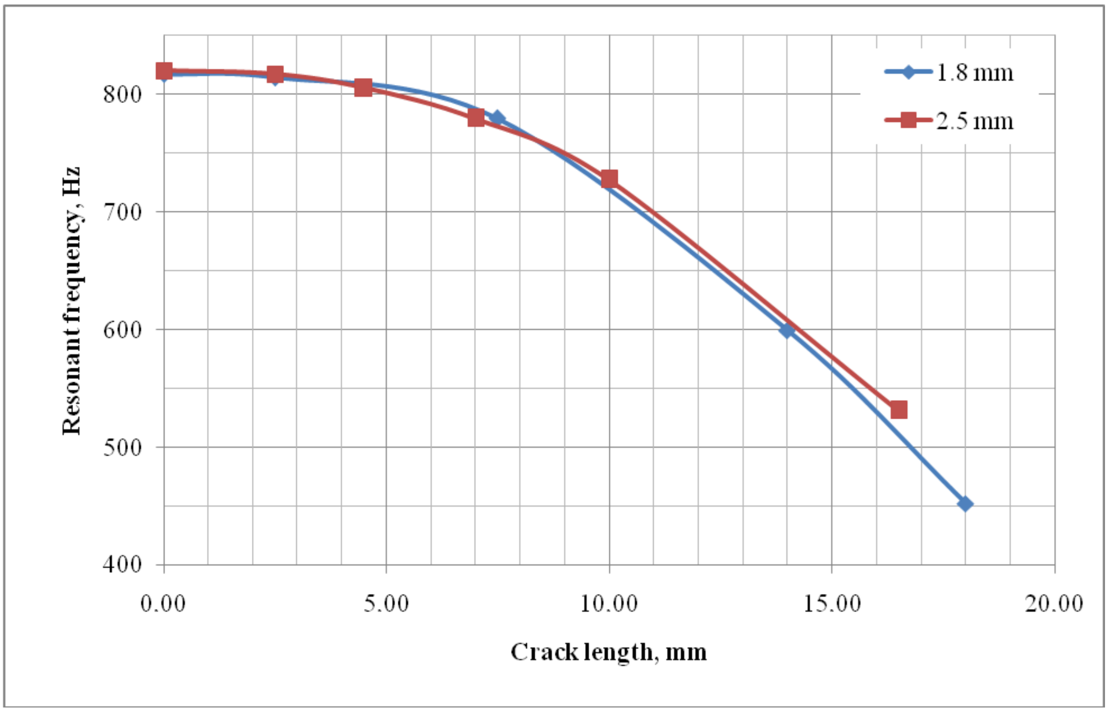


Fig. 6. Resonant frequency of the compressor blade as a function of crack length

Process of crack propagation for amplitude higher than 1.5 mm is not stable. It is difficult to perform of the tests for higher values of amplitude. The test should be repeated for the same load conditions in order to check reproducible of results. In Tab. 2 the information about the resonant frequency **as** function of the crack length were shown. An influence of the crack length an the resonant frequency is presented in Fig. 6. As seen from Fig. 6 there is a large similarity in character of two curves. A small difference in character of the crack propagation process in the first part of fatigue test was observed. The plastic strain and the initial stresses in the vicinity of the notch tip cause an increase of the number of cycles for the crack inititation. When the crack size is larger than radius of the plasticity zone, there is observed a similar crack growth dynamic.

Resonant frequency as a function of the crack length were shown on Fig. 6. As seen from this figure, the resonant frequency of the blade no. 1 (without the crack, a=0 mm) is equal to 820 Hz. After increase of the crack to the value 4.5 mm the resonant frequency decreases to the value of 805 Hz (relative decrease of resonant frequency at about 2%). When the crack length increases to 10 mm, the relative decrease of resonant frequency is about 11%.

3. Results and discussion

The initial stresses in the notch vicinity (obtained in results of hitting) cause siginificant increase of the number of load cycles to the crack initiation. The blade with the notch created by machining (for A=1.8 mm) the crack was initiated after $N=0.144\times10^6$ number of load cycles. The blade with the notch created by hitting (for the same amplitude, A=1.8 mm) was not damaged after $N=40\times10^6$ number of load cycles. In the blades with the notch created by hitting, crack initiation process was observed when the amplitude is higher than 2.1 mm.

For the blades with different types of the notch creation, the similar crack growth dynamic was observed. The plastic strain and initial stresses have an influence on the preliminary stage of the fracture process.

In the future, research works, the plastic strain and initial stress distribution obtained during the notch creation (by hitting) will be investigated.

Acknowledgement

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