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STRAIN DISTRIBUTION OF AIRCRAFT ENGINE COMPRESSOR BLADE SURFACE APPLYING NUMERICAL AND EXPERIMENTAL METHODS

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S u m m a r y

Paper contains an analysis of the 1st stage compressor blade strain distribution. Boundary conditions analysis was presumed for blade clamped in the fatigue holder. Strain distribution verification was performed for blade fundamental frequency. Numerical method results were verified with experimental (strain gauge) method.

Keywords: compressor blade, strain distribution, MES, fatique, strain gauge

Analiza odkształceń łopatek sprężarki silników lotniczych z zastosowaniem metody numerycznej i eksperymentalnej

S t r e s z c z e n i e

Artykuł przedstawia analizę rozkładu wartości odkształceń łopatki 1. stopnia wirnika sprężarki. Warunki brzegowe dla prowadzonej analizy przyjęto dla przypadku zamocowania łopatki w uchwycie maszyny wytrzymałościowej w próbie zmęczeniowej. Weryfikację rozkładu wartości odkształcenia wykonano dla pierwszej postaci drgań własnych łopatki. Wyniki analizy odkształceń metodą numeryczną weryfikowano w badaniach eksperymentalnych.

Słowa kluczowe: łopatki sprężarki, rozkład odkształceń, MES, próba zmęczeniowa, tensometria

1. Introduction

Deformable structures can be tested experimentally or by applying theoretical methods: analytical and numerical. Experimental methods are time and cost consuming. Labor intensity of those methods is noticeable during design work, where various design variants are being analyzed. Hence research using theoretical methods is commonly used, primarily numerical methods [1].

Theoretical research is based on conceptualization of proper mathematical description and solving the problem afterwards [2]. As for many practical problems of mechanical design, a reliable mathematical model can be formed,

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unfortunately exact analytical solutions are not known. A simple example of such issues is the determination of stress concentration factors.

Experimental research can be divided into various groups in terms of: method, test object type, test area or test location. The solid body submitted to external forces undergoes a deformation and distances between each of its points are changing [3]. The body distortions provide information regarding its internal stresses. Therefore the stresses can be calculated knowing physical connection among stress and deformation [4].

Strain gauge technology concentrates on measurement methods of solid deformation. Strain information is provided by sensors called strain gauges [5]. Stresses are determined using physical relation. Prime measurement magnitude is the distance between extremes section points, which length modification will determine the solid deformation. This length is called the strain gauge base.

Strain gauges can be divided into:

- electrical (resistance, inductive, electrodynamic, piezoelectric, capacitive)
- mechanical (mechanical, mechanical-optical, pneumatic)

2. Methodology and material

2.1. Numerical method

Numerical calculation was performed to determine the blade surface deformation distribution for its fundamental frequency. Boundary conditions analysis presumed the case where blade is fixed in fatigue holder.

FEM model was made using Tetrahedral and Hexahedral mesh elements. To achieve low calculation error the elements were concentrated for adhering blade and holder surfaces (Fig. 1 and 2).

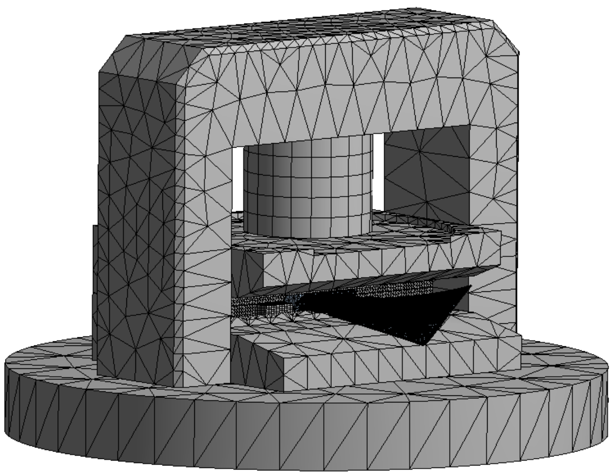

Fig. 1. Blade holder discrete model

Fig. 2. Blade discrete model

Holder along with tooling restrained on the bottom of the holder (F-Fig. 3). To clamp blade in the holder a pair of forces loading clamping device and holder were used – piston effect. A pair of forces applied on the cylinder side face (A and B-Fig. 3). Force value was determined using iterative feedback (40 kN – based on calculation). On cylindrical surface (C-Fig. 3) boundary condition enabling axial movement were applied – other directions movement was been blocked. Blade and holder contact was realized using contact elements providing friction coefficient of 0,2. The only boundary condition in harmonic analysis was acceleration value, applied to the restraint surface (F-Fig. 3).

Linear model represents steel with Young's modulus 200 GPa and Poisson's ratio 0.3. Conjugate numerical analyses – structural and harmonic were performed. Harmonic analysis allowed determining deformation state of the model for any vibration frequency.

2.2. Experimental method

Three 1st stage compressor blades were prepared for their surfaces strain distribution measurement using strain gauge technology. Strain gauges were glued to suction face surface.

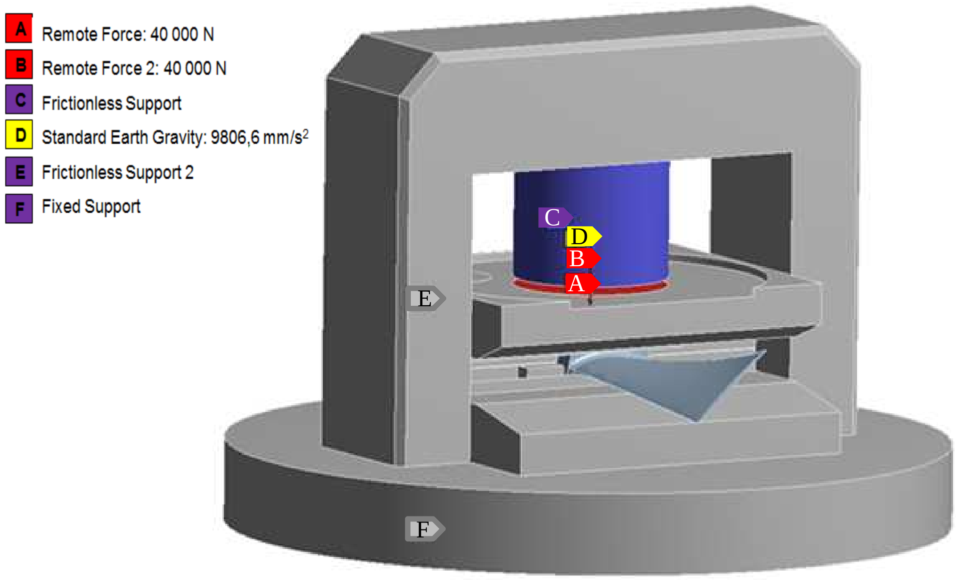

Fig. 3. Holder model with boundary conditions

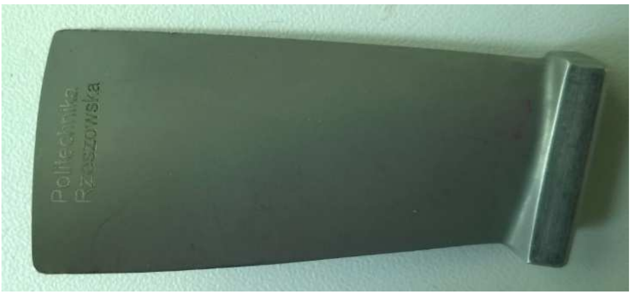

Fig. 4. 1st stage aircraft engine compressor blade

Blade strain distribution measurement was performed using electrical strain gauges. Deformation measurement with resistance strain gauge base conductor resistance change effect due to its deformation in accordance with examined solid deformation [6]. Strain gauges stuck in compliance with Vishay technology [7].

Specification of used strain gauges (Fig. 5):

- foil area – 1 mm^2
- resistance – 120 Ω
- constant K – 2,15

Research was performed at room temperature. Blade young's module – E = = 198 GPa.

Fig. 5. Resistance strain gauge

Strain gauges location was selected on numerical analysis basis. Sensors stuck to blades using a technical cement. Three blades were used for this purpose due to the mass and size of a single strain gauge. Strain gauges stuck to the blades surface in parallel to the blade root rows:

- 1st blade – A, B, C section
- 2nd blade – D, E, F section
- 3rd blade – G, H, I section

Each measurement line contained seven strain gauges. A total of sixty three strain gauges (on three blades) covered approximately 80% of blade suction area The first line stuck from the blade root side. All sections on three blades covered cumulatively two thirds of blade surface (Fig. 6)

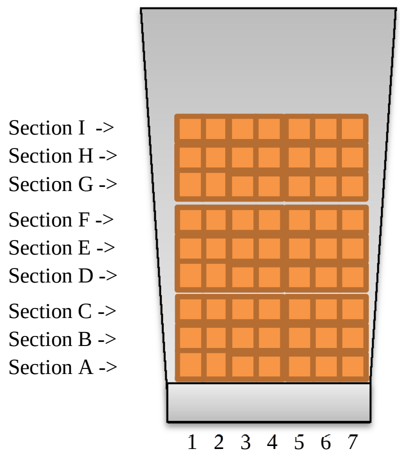

Fig. 6. Strain gauges joint location on blade surface

Instrument leads used for strain gauges were not insulated. Due to their amount additional insulated leads were soldered. Heat shrink isolated tubes were used to secure possible strain gauges shorting (Fig. 7.)

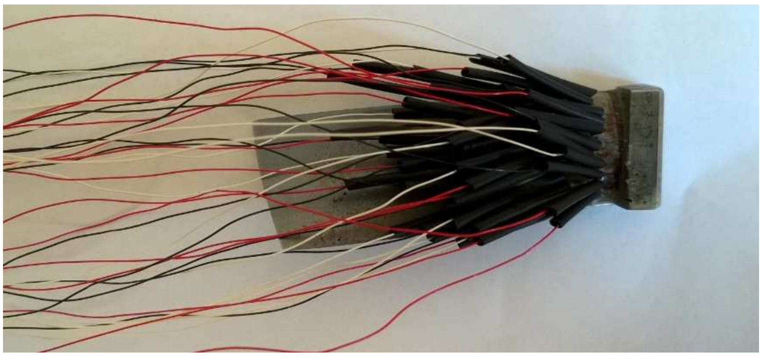

Fig. 7. Instrumented blade for deformation distribution measurement

The holder for compressor blade mounting was designed and manufactured. The holder jaws clamp was provided by hydraulic cylinder. The grip was bolted to the electrodynamic shaker – LDS 830V (Fig. 8).

Fig. 8. Blade in a hydraulic holder mounted on the electrodynamic shaker

Test data was monitored and recorded using following systems:

- shaker table vibration measurement (three axial accelerometers and three signal conditioners – IEPE, Delta Tron, ICP);
- displacement measuring laser of blade surface at a 2 mm distance from the blade tip;
- digital camera microscope connected to computer for blade tip displacement measuring;
- strain gauges measuring blade surface strain distribution during the test
- authorial electrodynamic shaker control system supported by National Instruments products and LabView software;
- authorial strain gauges data acquisition system supported by National Instruments products and LabView software;
- power amplifier and electrodynamic shaker.

The research was carried out using computer aided software supported by Lab View.

The research process [8, 9]:

1. Reference strain gauge connection to strain data acquisition system 9237.
2. Other strain gauges connection to strain data acquisition system 9237.
3. Shaker start-up.
4. Fatigue test system regulation to obtain blade resonance (blade fundamental frequency).
5. Stress value setting to 200 MPa.
6. Test data and stresses value record from each strain gauge.
7. System shutdown.

3. Results and Conclusion

Numerical calculation method results present blade effective strain field with marked characteristic stress values. Applied mesh of 1 x 1 mm dimension for proper blade area identification. Free vibration frequency (fundamental frequency) is equal 785 Hz. Strain distribution is different for blade suction and pressure side (Fig. 9).

Maximum blade stress value using experimental method was 215 MPa, recorded in the 5th strain gauge of C section (Table 1).

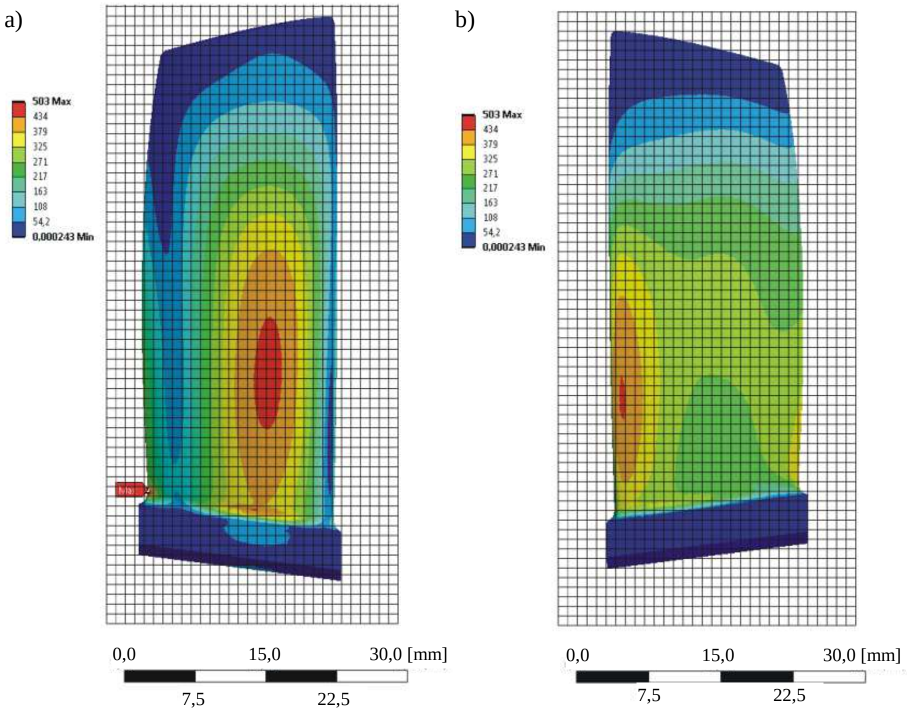

Fig. 9. Blade strain distribution on a) suction and b) pressure side

Table 1. Maximum stress values in each section, MPa

Column / Section	1	2	3	4	5	6	7
A	*30,6*	61,1	142,7	174,5	184,7	140,7	38,2
B	24,2	70,0	146,6	197,0	192,4	155,1	47,8
C	11,9	99,3	160,4	203,0	200,0	140,1	44,0
D	10,0	100,3	150,1	215,0	208,4	136,4	42,3
E	9,2	95,0	133,0	195,4	201,7	128,9	38,1
F	7,4	87,9	125,1	170,7	190,3	140,8	36,2
G	5,1	79,0	112,0	130,0	140,2	129,7	30,1
H	4,2	55,1	68,2	72,4	80,8	69,5	40,1
I	4,0	21,6	27,5	28,4	31,3	26,3	20,7

Experimental method data was analyzed using Diadem software to illustrate blade strain distribution. The blade strain distribution test results, obtained using numerical and experimental methods were compared (Fig. 10).

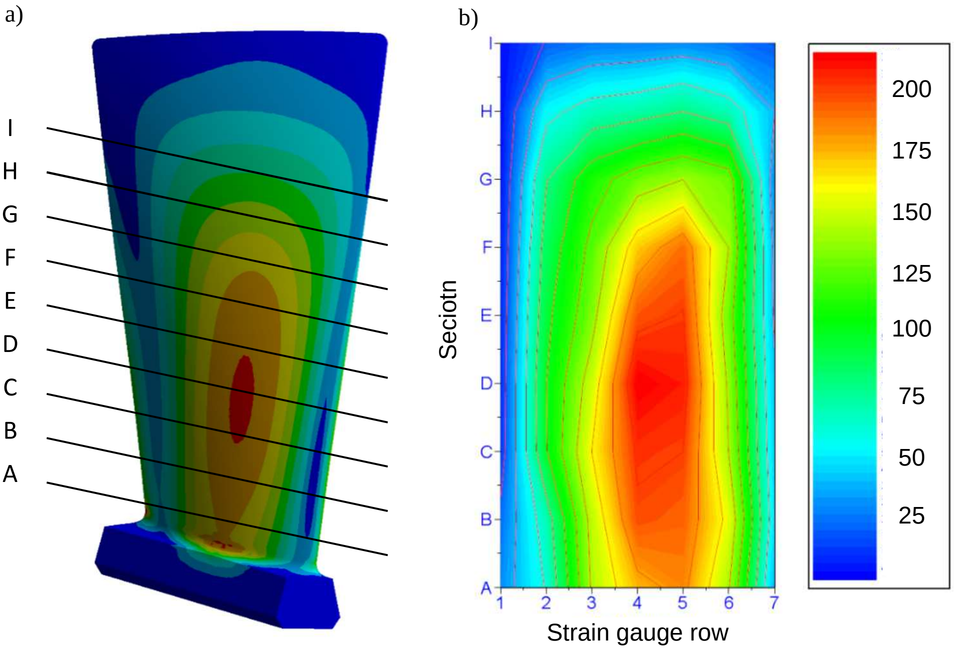

Fig. 10. Blade strain distribution comparison of a) numerical and b) experimental methods

Research results of numerical and experimental methods are strain distribution on aviation engine compressor blade. The maximum deformation is concentrated in the vicinity of blade root and one third of blade height, near to the leading edge. Strain distribution results acquired with experimental method are comparable to one from numerical method.

Acknowledgements

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