

УДК 004.896

Leoshchenko S.¹, Pukhalska G.², Bezkhlibnyi D.¹

¹PhD student NU “Zaporizhzhia Polytechnic”

²PhD, assistant professor NU “Zaporizhzhia Polytechnic”

MODELLING OF BLADE OPERATING PROCESSES

When military helicopters and transport aircraft take off and are forced to land on a desert or simple runway, sand and dust cause erosion of the aircraft blades by solid particles, which leads to a decrease in compressor performance and structural integrity, which seriously affects engine reliability [1].

Paper [2] investigated the erosion wear of the gas-solid flow of a compressor blade in an aero-turbine engine. In the study, a test bench for testing the Ti-6Al-4V alloy for erosion wear was designed and manufactured. Particle velocities were tested using particle image velocimetry at different air pressures. The results showed that the wear areas are concentrated on the rotor blade's pressure surface, as well as on the stator blade's suction and pressure surfaces. The maximum wear concentration was observed near the leading edge of the 80% span and near the leading and trailing edges of the 95% span on the rotor blade [2].

In studies[3] were conducted to predict the erosion of gas turbine engine blades. The model of blade material erosion is based on three-dimensional modeling of particle trajectories in a three-dimensional turbine flow field. The trajectories provide a specific distribution of particle impact parameters on the blade surface. To increase the blade's resistance to erosion and reduce blade wear, the blades must be coated [3].

Paper presents the results of an experimental study of the erosion resistance of fibre-reinforced structural carbon fibre reinforced plastic used in the structural elements of a gas turbine engine. A methodology for characterising the process of gas-abrasive wear of thin-walled structures made of polymer composite materials has been developed. The factors that determine the level of abrasive impact of the dust-gas mixture formed during take-off and landing are found. A criterion for assessing the erosion resistance of a material is presented. The factors that determine the level of abrasive impact of the dust and gas mixture formed during take-off and landing are found. A criterion for assessing the erosion resistance of a material is presented.

Erosion is an important mechanism of wear of jet engine compressors. To predict the damage caused by erosion, it is necessary to determine the rate. The physical model presented in [4] offers a new approach to adapt the erosion-induced wear mechanisms to any geometry of the compressor blade.

As an object of research, the blades of the first stage of the compressor of the TV3-117 engine, made of VT8 alloy, which have operational damage to the blade feathers of the engines, were selected.

The study was carried out on two engines that were operated under the same conditions, but have different operating times and, accordingly, different degrees of blade damage. For the study, 20 blades without gross mechanical damage were selected from the two engines.

To build regression models, we first selected informatively significant features (using stepwise regression methods). The selection of features allows us to discard uninformative features that complicate the model and introduce erroneous data that reduce the accuracy of the model. After that, regression models were built using the selected groups of features.

The study of blade geometry consisted of measuring the chord, C1, C2 in sections A2-A2.....A8-A8. In the original data $x_1, x_4, x_7, x_{10}, x_{13}, x_{16}, x_{19}$ – chordal value in different sections; $x_2, x_5, x_8, x_{11}, x_{14}, x_{17}, x_{20}$ – thickness of the leading edge; $x_3, x_6, x_9, x_{12}, x_{15}, x_{18}, x_{21}$ – thickness of the trailing edge; x_{22} – hardness of the trailing edge, HRC; x_{23} – yield strength of the initial material, MPa; x_{24} – tensile strength, MPa; y_1 – total operating time; y_2 – operating time before 1 repair; y_3 – frequency of natural vibration of the blades, Hz.

Regression models of blade service life and natural oscillation frequencies were constructed.

Linear regression models of the second order with a first-order term:

$$y_1 = -50,81 - 11616,91 x_{13} + 11774,24 x_{19} - 12941,78 x_3; x_{13} + 8294,39 x_3; x_{16} + 4332,86 x_3; x_{19} + 26582,52 x_{13}; x_{15} - 6700,64 x_{13}; x_{16} - 1653,66 x_{13}; x_{17} - 50,81 x_{13}; x_{18} - 1594,87 x_{13}; x_{19} + 353,01 x_{13}; x_{20} - 27506,72 x_{13}; x_{21} - 26828,98 x_{15}; x_{19} + 14604,59 x_{16}; x_{17} + 8490,52 x_{17}; x_{19} - 13196,27 x_{17}; x_{20} - 7295,96 x_{19}; x_{21} + 27928,12 x_3^2 + 11444,33 x_{13}^2 + 4471,35 x_{16}^2 - 1037,9 x_{19}^2$$

$$y_2 = -211,77 - 3660,12 x_{13} + 3709,69 x_{19} - 4077,55 x_3; x_{13} + 2613,30 x_3; x_{16} + 1365,15 x_3; x_{19} + 8375,31 x_{13}; x_{15} - 2111,16 x_{13}; x_{16} - 521,02 x_{13}; x_{17} - 16,01 x_{13}; x_{18} - 502,49 x_{13}; x_{19} + 111,22 x_{13}; x_{20} - 8666,50 x_{13}; x_{21} - 8452,97 x_{15}; x_{19} + 4601,45 x_{16}; x_{17} + 2675,10 x_{16}; x_{19} - 4157,73 x_{17}; x_{19} - 2298,73 x_{17}; x_{20} + 8799,27 x_{17}; x_{21} + 3605,75 x_3^2 + 1408,78 x_{13}^2 - 327,03 x_{16}^2 - 1143,78 x_{19}^2$$

$$y_3 = +102428,81 - 12147,18 x_{13} + 4986,58 x_{19} - 4614,65 x_3; x_{13} + 2141,45 x_3; x_{16} + 2381,85 x_3; x_{19} + 5371,39 x_{13}; x_{15} + 750,30 x_{13}; x_{16} - 4343,15 x_{13}; x_{17} - 22,36 x_{13}; x_{18} - 274,72 x_{13}; x_{19} + 24,94 x_{13}; x_{20} - 1565,90 x_{13}; x_{21} - 5462,51 x_{15}; x_{19} + 5648,81 x_{16}; x_{17} + 177,70 x_{16}; x_{19} - 1287,82 x_{17}; x_{19} - 1117,12 x_{17}; x_{20} + 1595,23 x_{19}; x_{21} + 3339,80 x_3^2 + 43,50 x_{13}^2 - 540,16 x_{16}^2 - 29,66 x_{19}^2$$

The obtained regression models show that during the operation of helicopter engines, the geometry of the blade inlet and outlet edges in the sections A6-A6.....A8-A8 has the greatest impact on the engine life and the frequency of blade natural oscillations. Therefore, special attention should be paid to measures that can minimise the erosion wear of blade edges and extend the engine service life.

REFERENCES

1. Di Wang Solid Particle Erosion / Wang Di, Yang Zhen // *Advances in Turbomachinery*. – 2023. – Режим доступа: <https://www.intechopen.com/online-first/85507>
2. Li Chao Study on the erosive wear of the gas-solid flow of compressor blade in an aero-turboshaft engine based on the Finnie model / Chao Li, Guangfu Bi, Jian Li, Zezhong Liu // *Tribology International*. – 2021. – № 163. – С. 1057–1077.
3. Tabakoff W. Blade Deterioration in a Gas Turbine Engine / W. Tabakoff, A. Hamed, V. Shanov // *International Journal of Rotating Machinery*. – 1998. – № 4. – С. 233–241.
4. Lorenz M. Prediction of Compressor Blade Erosion Experiments in a Cascade Based on Flat Plate Specimen / M. Lorenz, M. Klein, J. Hartmann, C. Koch, S. Staudacher // *Frontiers in Mechanical Engineering*. – 2022. – № 8. – Режим доступа: <https://www.frontiersin.org/articles/10.3389/fmech.2022.925395/full>