

Prediction of the vibration state of the GTE turbine rotor taking into account the influence of the geometric accuracy of parts

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Abstract. The article deals with the problems of ensuring the vibration of gas turbine engines. A technique has been developed for assessing the level of vibration state depending on the geometrical errors of parts and assembly units. The studies of the level of vibration state are presented depending on the following geometrical parameters: eccentricity of the inner hole of the shaft and eccentricity of the supports. A regression dependence of the level of vibration velocity on the considered geometrical errors is formed.

1. Introduction

Gas turbine engines are objects of the highest category of complexity, the quality of which imposes high demands. Particular attention is paid to the vibration state of gas turbine engines, which has an impact on many other quality indicators, including service life and reliability. A high level of vibration reliability of turbine units is achieved through the implementation of a whole range of activities at all stages of their life cycle. An important step to achieve a given level of vibration state is the assignment of tolerances on the geometric parameters of parts and assembly units. It is known that geometric errors cause vibration, due to the occurrence of induced imbalance. Production can be characterized by the appearance of geometric errors. An important task is to estimate the occurrence of vibrations for specific geometrical errors [1].

One of the most significant causes of imbalances in the GTE turbine rotor is not concentric seating surfaces of the middle and rear supports, which is achieved in the process of centering. Thus, there is a mismatch of the landing circle with the axes of the disk rotation. Since the balancing technology involves balancing the rotor assembly, the misalignment of the supports is not taken into account in the process of balancing the rotor. Thus, the misalignment is a direct influence on the imbalance of the rotor. Also, an imbalance is caused by the displacement of the inner hole of the shaft relative to its seating bases due to two reasons. The first reason is the effect of misalignment of the damper and cup under the bearing, as well as the gap in the bearings. The influence of the misalignment of the inner bore of the shaft on the displacement of the center of mass of the rotor is eliminated in the process of balancing the rotor assembly when using technological bases. However, when assembling a balanced rotor together with a stator, additional eccentricities arise, caused by the misalignment of the supports, the damper and the bearing cup. The listed misalignments lead to the appearance of an additional imbalance, since the symmetry of the rotor with respect to the axis of rotation is broken [2-4].



When solving such problems at production, the capabilities of existing methods and means of vibration diagnostics and monitoring are often insufficient, and there is a need to develop and implement fundamentally new methods for studying vibration characteristics to predict and eliminate emerging defects at minimal cost.

This paper describes the methodology for assessing the level of the vibration state depending on the geometrical errors of parts and assembly units. The technique includes the use of CAE - packages to create computational CAD models for predicting the vibration state depending on geometrical errors. An analysis of the capabilities of the well-known CAD/CAE packages revealed the limited capabilities of the software tools allowing to evaluate the vibration state. In this regard, an algorithm was developed that allows calculating the mass center in the ANSYS system and analyzing it based on the export of stl-files to third-party applications. In the developed technique, programs written in the MATLAB language were used [5, 6].

2. Modelling methods

The method of forecasting the vibration state of the rotor of a low-pressure turbine is designed to determine the predicted values of geometric parameters based on the results of calculations in the ANSYS software package based on the permissible deviations of the geometry of the assembled parts. The modeling of the forecasting process can be divided into the stages presented in figure 1.

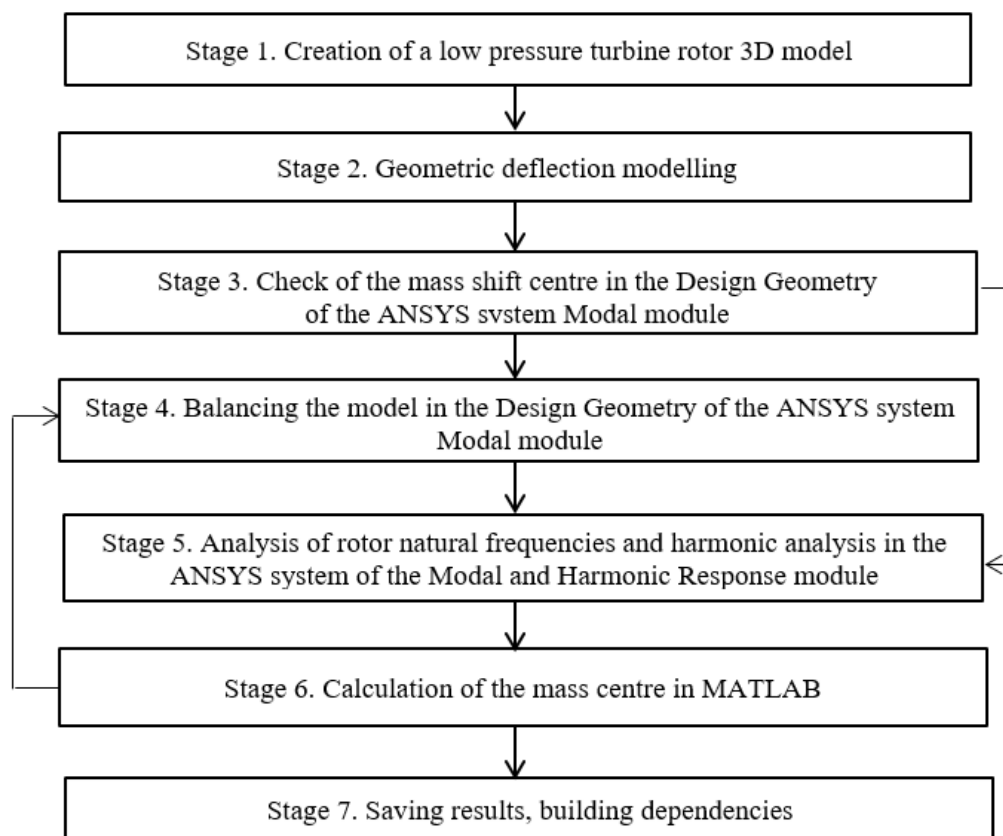


Figure 1. Methods of assessing the dependence of the rotor vibration state on the geometrical errors of parts and assembly units.

For calculations in the CAE package, a simplified 3D model of the third stage low pressure turbine was created (figure 2). This assembly unit consists of three parts: the shaft, the spacer and the disc.

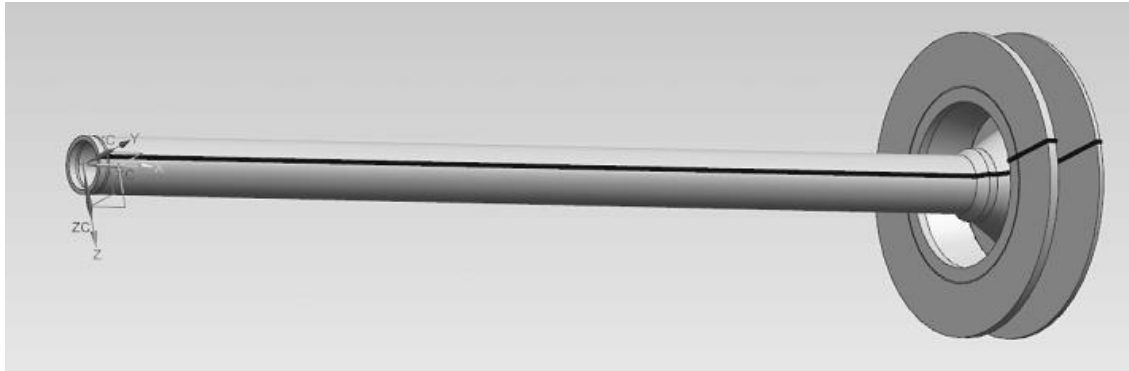


Figure 2. 3D model for calculation taking into account geometric deviations.

In accordance with the flowchart, the CAD-part model is imported into the ANSYS software package, where the geometrical deviations of the parts are simulated (figure 3), the boundary conditions are set simulating the rotor fixation in a parametric form and the operating conditions are specified, in particular, the rotor rotation.

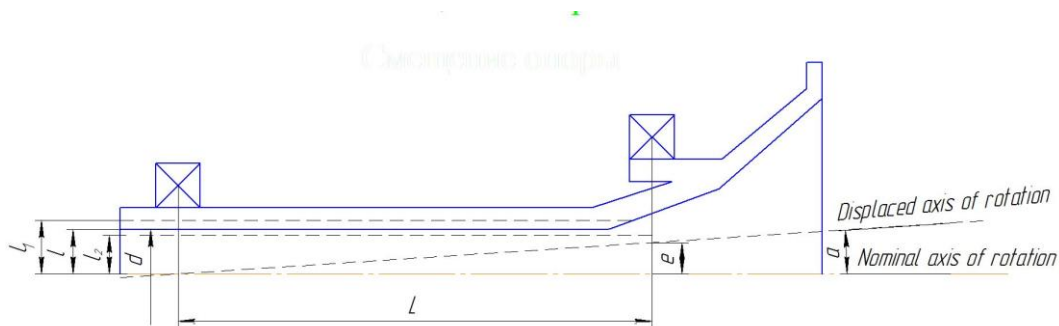


Figure 3. Simulation of the rotor geometric deviations .

Figure 3 shows the simulation of the rotor geometric deviations for two cases: 1) the displacement of the inner bore of the shaft: d is the diameter of the inner bore of the shaft; l is the nominal distance from the main axis of the rotor to the inner bore; l_1 , l_2 are the maximum and minimum distances from the main axis of the rotor to the offset inner hole; 2) support displacement: α is support displacement angle; L is the distance between the supports, mm; e is the value of non-parallelism of supports, mm.

Then, a series of calculations is performed using variable parameters in the module [7]. Since it is not possible to estimate the result of the center of mass displacements in the ANSYS software package, after each calculation, the model is saved in *.stl format and then imported into the MATLAB system to calculate the center of mass and unbalance [8,9].

3. Results

A study of the vibration level state depending on the following geometrical parameters was conducted: eccentricity of the inner hole of the shaft and eccentricity of the supports. Simulation of errors of geometric parameters was carried out in the ANSYS Workbench.

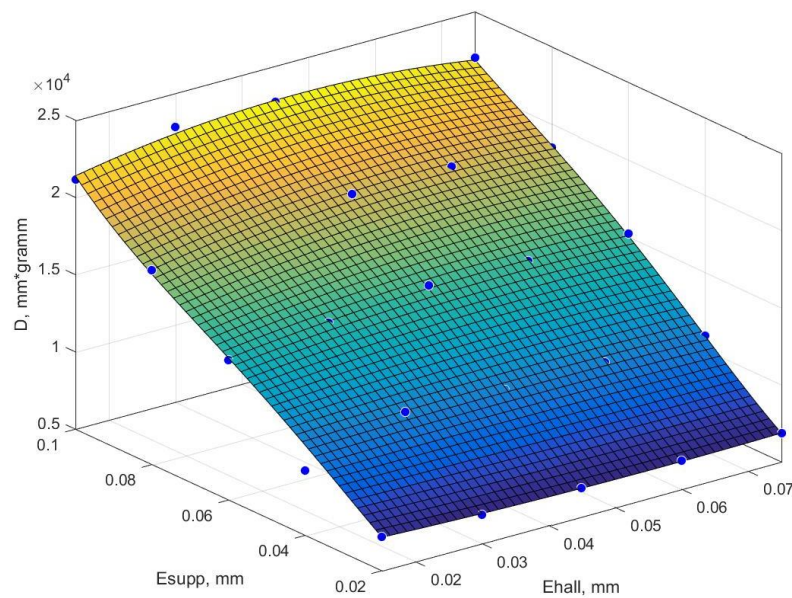
To offset the internal hole in the Design Geometry tab, the hole contour was drawn according to the specified dimensions, then it was parameterized. In order to offset only the hole, it is tied to the main axis of the rotor with the appropriate size. To offset one of the supports, a coordinate system was created in the Model tab, in the settings of which the angle α was specified, to which the offset will be made.

The calculations were carried out according to the plan of experiments (table 1).

Table 1. The plan of experiments and the results of the calculated imbalance (D , $\text{g} \cdot \text{mm}$)

Offset of the internal hole of the shaft (E_{hall}), mm	Support offset (E_{supp}), mm				
	0.015	0.03	0.45	0.06	0.075
0.02	7180.9	6846	6854	6866	6858
0.04	9201.21	11253.35	10897.7	10911	10911
0.06	14029.2	14723.8	15387.74	15174	15191.1
0.08	17561.9	17946.5	18988.6	19026.12	18509.1
0.1	21173	22782.2	22676.8	22369	22027

According to the results of the calculated imbalances, a regression dependence of the imbalance on the errors of the considered geometric parameters was constructed, which is presented in figure 4.

**Figure 4.** Graph of regression dependence of imbalance from the errors of the considered geometric parameters.

The obtained regression dependence of the imbalance on the errors of the considered geometric parameters is described by the following polynomial function [10]:

$$f(x, y) = p_{00} + p_{10} \cdot x + p_{01} \cdot y + p_{20} \cdot x^2 + p_{11} \cdot x \cdot y + p_{02} \cdot y^2 + p_{21} \cdot x^2 \cdot y + p_{12} \cdot x \cdot y^2 + p_{03} \cdot y^3 + p_{22} \cdot x^2 \cdot y^2 + p_{13} \cdot x \cdot y^3 + p_{04} \cdot y^4 \quad (1)$$

where p_{00} , p_{01} , p_{20} , p_{11} , p_{02} , p_{21} , p_{12} , p_{03} , p_{22} , p_{13} , p_{04} are polynomial coefficients (table 2).

Table 2. The values of the polynomial coefficients.

Coefficient	Values
p_{00}	4793
p_{10}	-5.269e+04
p_{01}	9.979e+04
p_{20}	7.168e+05
p_{11}	6.816e+05

p02	2.617e+06
p21	-2.574e+07
p12	4.113e+07
p03	-4.877e+07
p22	5.911e+07
p13	-3.049e+08
p04	2.769e+08

For the polynomial obtained during the approximation of the results of a simulation experiment, the coefficient of determinacy R^2 was calculated to be equal to 0.9978. The high value of the coefficient of determinacy R^2 indicates the possibility of using the obtained regression dependence to predict the magnitude of the imbalance.

4. Conclusion

The presented work is devoted to the development of methods for predicting the vibration state of the GDE turbine rotor, taking into account the influence of the geometric accuracy of parts. The above method allows to determine the predicted values of the geometric parameters according to the results of calculations in the software package ANSYS based on the permissible deviations of the geometry of the assembled parts. In the course of the research it was revealed that the partial dependences of the imbalance on the geometrical parameters: the eccentricity of the internal hole of the shaft and the eccentricity of the supports are linear. As a result of the study, a regression dependence of the imbalance on the errors of the considered geometric parameters, presented in the form of a polynomial, was obtained. Significantly small values of the considered geometric parameters have a significant impact on the magnitude of the induced imbalance, which increases the relevance of their consideration in the process of assembling and repairing gas turbine engines. The obtained regression dependencies will allow making technological decisions at the stage of assembling the GDE associated with the need to perform additional operations to improve the accuracy of geometric parameters.

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