Improving methods for predicting defects based on vibrography

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Abstract. The article is devoted to the broadband vibrodiagnostics of jet engines. The material discusses the main causes that affect the level of vibration of the engine. Using the methods for controlling vibrations in a wide frequency band, an analysis was made of the criteria that cause defects and their manifestations in a wide frequency band of vibrations. The author has studied the effect of defects in parts and assembly units on vibration levels in a wide range. Based on the data obtained, it was found that the results allow to determine the bottlenecks of the gas turbine engine with accuracy to the details of the assembly units. Key words: vibration, broadband diagnostics, jet engines.

One of the methods for controlling the quality of manufactured products is to predict the vibration effects of the engine and its structural elements, both when the product is delivered to the manufacturer and during its operation.

Currently, the system for evaluating and predicting the technical condition of the GT engine from the point of view of vibration monitoring is based on the assessment of the main (first) rotor harmonics using band-pass or servo filters of the equipment, as well as with vibration sensors that are used on engines. However, this approach does not allow an in-depth analysis of the technical condition of the engine.

Obviously, vibration signals measured by highly sensitive sensors are highly informative and may not reflect the properties of many structural elements of the engine. Any resource unit or assembly for a gas turbine engine is required. Rotors, thrust bearings, units, springs, drives, units, have a kinematic relationship with rotor installations. At the same time, it is necessary to determine the frequencies and forms of vibrations that affect the overall level of vibration. Special attention should be paid to the choice of installation location of vibration sensors on the engine, taking into account the mounting points of the brackets.

For this, the same vibration conditions of the engine, unit or assembly must be established. The output parameters of the frequency component associated with vibration can be a diagnostic sign of its malfunction or damage. Thus, it is important not only to correctly set the received vibration signals with sensors, but also to set the norms (permissible limits) for all available components.

Since 2005, hardware and software systems for the KVK-4-2 and KPA-134S broadband vibration monitoring systems, developed in conjunction with the SPC Vertical LLC LLC to provide support for testing the engines of the RD-33 (RD-33, RD-93 and RD-33MK).

Until 2017, the IVD-SF-3M for a more detailed and in-depth study of the causes of increased engine vibration.

It was decided to use the IVD-SF-3M equipment and the complexes of broadband vibration control in parallel. The KVKD-4-2 and KPA-134S complexes are connected to the BE-40-4M output unit of the IVD-SF-3M equipment and measure vibration through two channels from the MV-38 vibration sensors located on the front (Vk) and rear (VT) supports engine. Unlike standard devices, in the range up to 15 kHz.

Currently, vibration control is carried out by all necessary engines, including those that have undergone repair work, as well as on each cycle of bench life tests.

The use of vibration control systems allows normalization of acceptable levels of vibration speeds using separate controlled frequencies described in the instructions developed by our company’s
specialists. The manual contains criteria for evaluating the technical condition of the engine, including the maximum allowable vibration levels for rotor and multiple-motor components, their mutual combination, as well as diagnostic signs and suspected defects. Moreover, each defect is determined by the manifestation of several signs.

To increase the vibration level of engines can lead to:

1. Design features of the engine and test bench:
   - Rotor resonances (critical frequencies) within the operating frequency range;
   - Natural frequencies of structural elements in the operating frequency range and resonating with the rotors;
   - The quality of engine installation on a test bench, similar to its installation on an airplane, in terms of securing the suspension bearings (ball bearings).

2. Production defects: poor-quality manufacturing of parts and assembly units; poor assembly of the product.
   - Imbalance (mass imbalance);
   - Defects of units of fuel and oil systems;
   - Defective bearings;
   - Springs and drives propulsion system and aircraft box.

3. Defects manifested in the process of product operation:
   - Change in damping of rotor bearings (loss of stability) and the presence of skew;
   - Change of rigidity of a rotor of a gas generator;
   - Change the stiffness of the fan rotor;
   - Thermal imbalance (Impact of the rotor on the stator);
   - Attenuation in the support system;
   - Loosening of the coupler of rotor elements;
   - Banding of blades;
   - Destruction of rotor elements;
   - Vibro-burning.

Starting to assess the vibrational state of the engine, it is necessary to take into account the main forms of vibration of the rotors and their visualization in the spectrum:

a) the 1st harmonic characterizes the imbalance of the rotor, the displacement of the center of mass;
b) 2nd harmonic - a sign of skew;
c) 3rd harmonic - a change in the stiffness of the corresponding rotor.

It should be noted that on engines, RD-33MK, a frequently encountered defect associated with the operating time of the product is the destruction of brackets, tubes, etc., installed in area 1 of the fan support. This phenomenon is associated with the deformation of the external circuit generated by the second harmonic of the high pressure rotor. The solution to this problem is to reduce the level of 2HPR, the defect is constructive.
Another example of a structural defect is the resonance of the high-pressure rotor with the natural frequency of the rear support housing. We have carried out work to assess the natural frequencies of the vibrations of various supports. In the field of operating frequencies of the high pressure rotor, there are several ranges of natural frequencies of oscillations of the rear support. The task is to choose an instance that has its own frequency, as far as possible from the area of the operating range, as well as in the neat and careful installation of the cook. If these conditions are not met during the test, you can get the following picture - a sharp surge of vibration with a frequency of 1 WFD in a narrow range of the operating mode (see Fig. 2a, b).

The presence of the 3rd harmonic, a level above the noise, there are multiples of it — loosening the nuts.

The presence of 1LPR - and 2LPR - problems with the intermediate shaft, landing on the necks is not provided.

As an example, the initial stage of bearing failure is characterized (Fig. 3):

The presence of a separator component in the vibration spectrum, the level of which is 0.5 of the first rotor harmonic and higher;

The presence of odd multiple-rotor harmonics of increased intensity;

The presence of skew on the rotor, characterized by the presence in the spectrum of subharmonics and combination harmonics;
Frequency manifestations corresponding to the rolling elements of the bearing;
The appearance of a higher noise level component of the outer and/or inner ring.
If we are considering an inter-shaft bearing, then attention should be paid to the state and
manifestation of the components of other bearings - 3 and 5 bearings.
With the further development of the defect, one can observe a shift of the extremum of the
separator frequency in the direction of lower frequencies from the calculated value, a violation of the
slip line of the rotors.

![Fig. 3a](image1)

The operation of the engine at rotational speeds at which a critical multiple of the critical frequency is located near the diagnosed frequency of the support separator 4 may contribute to the development of a defect on the bearing 4 and deformation of the bearing surfaces on the dampers of the bearing 5. When conducting tests with heated air at the inlet, the maximum RPM rotor speed is 101.5%. According to the calculations of Klimov OJSC [021002800P3.47], [021002800P3.48], the region of maximum bending vibrations of the NR rotor is in the range n2 = 78% and 97%, where the pathogen is the VD rotor and n1 = 103%, where the pathogen is the ND rotor. Long-term work with heating the air at the engine inlet in the range of critical rotational speeds: n2 = 98.5% and n1 = 101.5% contributes to more intensive development of the bearing surfaces of the damper 5 of the support and the appearance of a skew in the bearing 4 of the support.
The main reason for the increased running-in detected on the treadmill of the inner ring of the bearing is the misalignment of the bearing rings for more than 10 minutes, caused by the development of the bearing surfaces of the damper rings of the bearing 5 of the bearing mounted on the support with the nozzle, and the prolonged operation of the engine at the stages of heating the air inlet into the engine in the range of critical revolutions of rotation of the rotors and the region of maximum bending vibrations of the high pressure fuel rotor. When a skew occurs in combination with work in the field of critical revolutions, the stress level in the contacts of the rollers with the inner and outer rings has increased significantly, especially at the ends of the rollers, while the inner ring has shifted together with the fastening nut.

Thus, the criterion for the development of a defect is not only the presence in the vibration spectrum of a component that exceeds the established threshold level, but also the manifestation of other components of the spectrum.

The complexes of broadband vibration monitoring in real time provide the calculation and display in the form of parametric graphs and in the numerical representation of vibration levels, as well as the issuance of warning signals about threshold values for each element of the spectrum being monitored.

The materials obtained make it possible to determine the bottlenecks of gas turbine engines with accuracy up to assembly unit parts, which significantly reduces the time to search and eliminate deficiencies, and also allows the engine to be assembled taking into account the individual characteristics of the elements.

The implementation of the Instructions for controlling vibration in a wide frequency band, the established communication between the enterprise divisions - designers, the testing and assembly shops allow for completion of production to improve and improve the quality of products. Based on the results of the analysis of the databases of broadband vibration control obtained during bench tests, an Act certificate is drawn up indicating the identified diagnostic signs and a possible defect. After consideration by the specialists of the design department, the engine is disassembled and fault-free with troubleshooting or replacement of the structural element. In the future, when collecting statistics, the a priori probability of each of the encountered defects will be calculated and the calculation result will be displayed on the monitor of the diagnostic complex directly when analysing vibration signals, or in real time during the test.

In order to ensure the operation of RD-33 engines according to the technical condition and troubleshooting in operating organizations, our company, together with JSC "RSK" MiG", LLC SPC" Vertical "and a number of other co-developers, created and put into operation a unified engine monitoring system RD-33 (SKD-33). Along with the functions of parametric control of the engine, SKD-33 has the technical ability to monitor the vibrational state of the engine as part of the aircraft when it is being tested from standard and two additional vibration sensors, to accumulate information, form a vibration portrait, evaluate the trend and provide information in the process of testing the engine about a malfunction or development defect. The SKD-33 system is successfully used in a number of foreign countries (Slovakia, India), as well as in JSC RSK MiG and the operating organizations of the Russian Air Force. The data obtained with the use of SKD-33 make it possible to assess the technical condition of the engine before the manifestation of the defect and the failure of the engine.

For the RD-33MK engine installed on the MiG-29K or MiG-35 aircraft, preliminary work was carried out to control the vibration state using a complex similar to that installed on the test bench. However, the use of MV-38 type sensors mounted on remote brackets, and the presence of a signal conversion unit installed remotely from the signal source and operating under conditions of strong electromagnetic interference, do not allow diagnostics in the required frequency range. At the moment, research is underway on the manufacture of a mobile vibration monitoring complex using a new generation of sensors manufactured in Russia, operating in the range of vibration speeds from 5 to 15000 Hz and increased noise immunity. The signal conversion unit is minimized by weight and size characteristics, it is supposed to be placed in the immediate vicinity of the signal source. The software for the complex will include a defect localization matrix in accordance with the Instruction developed at our enterprise.
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