Using a microphone to perform technical condition vibroacoustic diagnostics of a gas turbine engine's bearing supports

Alina Romanova[1*], *Aleksey* Zubko[1], *Dmitry* Balakin[2], and *Sergey* Zvonarev[1]

[1]Moscow Aviation Institute, 125993 Volokolamsk highway, 4, Moscow, Russia
[2]Moscow Power Engineering Institute, 111250, Krasnokazarmennaya street, 17 Moscow, Russia

Abstract. Ensuring product quality, due to the special requirements for reliability in the aviation industry, is the main and primary task. For successful and trouble-free operation, it is necessary to monitor the technical condition of all systems, especially the most critical ones, such as engines. The technical condition of the gas turbine engine directly affects flight safety. Bearing supports are considered one of the most important transmission components, which are most susceptible to wear and damage. The goal of this work is to develop a method for conducting vibroacoustic diagnostics that addresses the challenges related to the inaccessibility of the studied unit and the change in vibration vector during engine operation, which significantly impairs the informativeness of vibration sensor measurements.

1 Introduction

The use of diagnostics provides increased safety during the operation of the gas turbine engine. Technical diagnostics allows you to determine the condition of the diagnostic object with the specified accuracy. The result of the diagnosis is the assessment of the condition that determines what exactly is wrong in the object of study as well as the causes of the malfunction.

Many studies have been conducted on the topic of vibroacoustic diagnostics. Some of this research supports the prospective use of vibroacoustic diagnostics for defect detection. Most of the methods are based on the analysis of a vibroacoustic signal in a private domain through the use of the Fourier transform [1]. However, there are other ways. For instance, in [2], a unique approach is proposed, which combines both classical signal processing methods (optimal filtering, wavelet transformation, Hermitian transformation) and medical practice techniques (rhythmogram and scattergram). This represents a fundamentally new direction in assessing the condition of bearing supports. The peculiarity of the above methods is that they do not take into account the quality of registration of the vibroacoustic signal, as well as the influence of third-party sources. And this, in turn, may affect the correct assessment of the state of the object under study. For example, based on the research by I. V. Ivshin [3], it can be concluded that vibroacoustic diagnostics may have difficulties in identifying incipient

* Corresponding author: rommalinaa@mail.ru

defects in various components due to the masking of fault characteristics by parameters of other components. In the study by R. V. Birukov and Yu. V. Kiselev [4], the difficulty of accessing the research object is highlighted. The authors acknowledge that vibrations from the bearings to the sensor location experience attenuation. However, they do not explore the possibility of bringing the vibration sensor closer to the research object

Methods of vibration diagnostics have shown the greatest efficiency. However, it should be noted that the diagnosis of engine components, such as bearing supports located in hard-to-reach places, is associated with a number of technical problems. One of these problems is the difficulty of registering a vibroacoustic signal due to factors affecting the attenuation of the vibration amplitude. The presence of elements contributing to the attenuation (damping) of vibration is important to ensure the minimization of contact stresses of bearing parts. Nevertheless, during diagnostics, such factors become an obstacle to the effective capture of the vibroacoustic signal, which ultimately reduces the accuracy of the diagnostic method used. The distance from the vibration source to the installation site of the vibration sensor also plays an important role. Most commonly, piezoelectric vibration sensors are used as measuring instruments, and velocity sensors are also quite common, which are installed on the engine's casing. The value of the vibration amplitude directly depends on the removal of the sensor from the vibration source. Accordingly, the greater the distance, the smaller the amplitude of the signal and the less diagnostic signs of malfunction will appear. As a result, it can be concluded that the existing methods of conducting vibration diagnostics of bearing supports of gas turbine engines, as a complex mechanical system, have little effectiveness in determining the diagnosis. To obtain information about the technical condition of bearing supports, it is necessary to develop an approach that allows assessing the technical condition with high reliability and at the stages of the least damage development.

This article is dedicated to researching the potential of closer placement of the sensor to the object of study, in order to increase the informativeness of the diagnostic signs of the signal. For this research, a technical microphone was chosen as the most promising device for non-contact vibroacoustic signal capture. Within the framework of this article, an experiment is presented aimed at confirming the assumptions about the possibility of effective use of a technical microphone. The results of this experiment provide important evidence and support the theoretical foundations of the implementation of this approach.

2 Using a technical microphone

During vibration diagnostics, the sensor is located on the engine casing. The vibration signal received by the vibration sensor is significantly weakened due to the presence of intermediate engine elements in the path of its propagation. The magnitude of the vibration signal from the bearing on the housing is reduced by about 30-40 times. This problem can be solved by using non-contact vibration measuring devices. This article examines the application of a technical microphone. The object under investigation, the bearing, rotates with a given frequency, generating the vibroacoustic signal. A vibroacoustic signal is a sound wave generated by mechanical vibrations. Sound waves propagate through the environment reaching the technical microphone. The technical microphone is equipped with a piezocrystal plate. When a sound wave applies pressure to this element, it undergoes deformation. Opposite charges are formed on the surfaces of the plate, creating a potential difference [5]. Thus, the movement of the piezocrystal is converted into an electrical signal, which is then transmitted to an amplifier and other equipment for further processing and analysis. To increase the efficiency of diagnostics of bearing supports, it is advisable to use a technical microphone with a narrow directional pattern. This sensor is focused on receiving sound waves with a certain angle of direction and has limited sensitivity to acoustic influences originating from outside. The aperture of the technical microphone is also important, that is, the size of the hole or opening in the microphone through which sound waves are received. The size and setting of the aperture determine the amount of sound energy that can be captured and converted by the microphone. The more acoustic energy the microphone can capture, the more accurate the measurement and analysis can be. At the same time, a large aperture leads to a wide angle of sound perception. This means that the microphone will register sounds coming from different directions. In this case, the received signal will contain information about the vibration of adjacent units and noise, which will complicate the process of analysis and diagnosis. In general, it is important that the microphone has an optimal aperture size. For a technical microphone that can be used for vibroacoustic diagnostics, the aperture size should be in the range from a few millimetres to 1 centimetre. This is related to the need for more precise microphone positioning and narrower directionality for specific measurements [6]. The technical microphone is capable of recording signals in a wide frequency range, from a few Hertz to 100 kHz.

The closer the receiver is to the object of study, the higher the accuracy of the data obtained. Attempting to bring standard signal recording sensors closer to the object of study is a complex and counterproductive process. The microphone also has the advantage of allowing diagnostics of nodes located in areas of the engine with limited access. Due to its mobility and compact size, the microphone can be placed in close proximity to the object of study, for example, inside the engine, without the need to disassemble the engine itself or deform its elements.

An equally important advantage of a technical microphone is its low sensitivity to changes in the vibration vector. A change in the vibration vector may occur due to the precession of the rotor [7],[8]. In the presence of unbalanced forces, the rotating rotor can cause bending of the shaft axis and displacement of its center of mass relative to the centers of the bearings, which leads to a change in the vibration vector. Accordingly, this leads to distortion of the vibration sensor signal and a decrease in its sensitivity, which can make it difficult to detect and diagnose a malfunction.

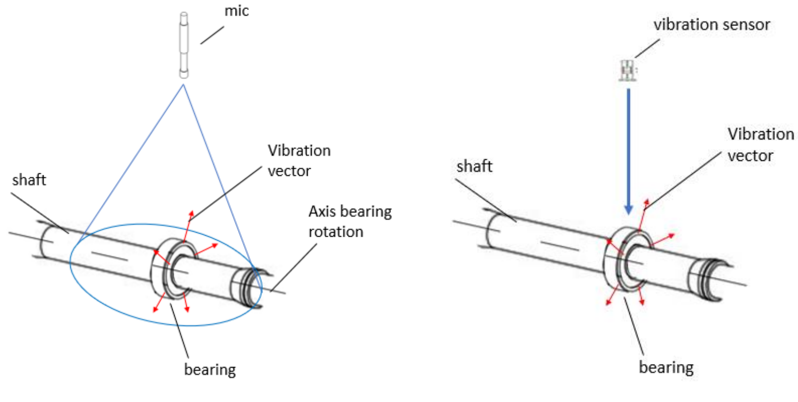


Fig. 1. Sensitivity of the sensor to changes in the direction of the vibration vector.

In contrast to primary transducers, such as an accelerometer, which have sensitivity in two directions – mainly (longitudinal) and transverse [9], the microphone picks up vibrations in the air space, so it is less sensitive to changes in the vibration vector. (see Fig. 1)

Based on the above, this study offers a new approach to vibroacoustic diagnostics. This approach involves replacing standard sensors for signal registration with a narrowly directional technical microphone. The use of this technique is to optimize the placement of the microphone as close as possible to the object under study, which allows you to obtain accurate and undistorted data. It is especially important that the use of a narrowly focused microphone minimizes the impact of changes in the vibration vector on the measurements obtained.

3 Experiment. Diagnostics of bearings on the test stand using a microphone

To demonstrate the effectiveness of the developed approach, the method was tested. This experiment is aimed at confirming the operability of the new method. Purpose: To develop diagnostic signs that allow to determine the condition of bearing supports, as well as to identify possible malfunctions in them, based on the received vibroacoustic signal.

An inter-rotor bearing was used as an object of research. The inter-rotor bearing is one of the most vulnerable elements of two-shaft aircraft engines. This is due to the difficult conditions of its operation, such as high mechanical loads perceived by the bearing, as well as frequent changes in its operating modes. [10]

The experiment was carried out at the SP-180 bearing input control stand. [11] (see Fig. 2)

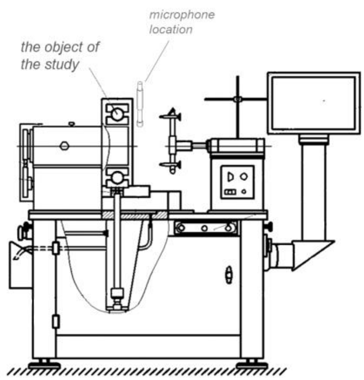


Fig. 2. Scheme SP-180 Bearing Input Control Stand.

A transition bushing of corresponding size is installed on the housing. The diameter of the bushing matches the inner diameter of the bearing. A load of 15 kg is applied. The test rig is rotated at a speed of 3000 revolutions per minute. Prisms of the radial load application mechanism and the axial load application clamping mechanism are brought into contact with the outer ring of the bearing. Compressed air is supplied to the pneumatic cylinders of the load application mechanisms, generating the necessary force on the cylinder rods, and then the bearing is set into rotation.

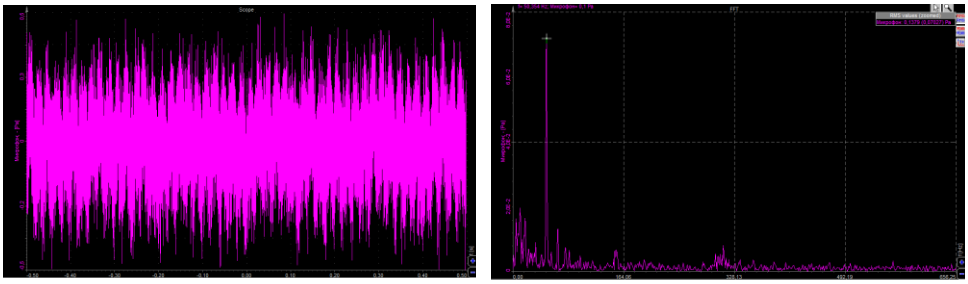
A technical microphone measured the bearing parameters, and the data received was transmitted to a vibration analyzer for analysis. The received signal was presented in the time and spectral domain using the DEWESoftX program.

The experiment was carried out in several stages. At the first stage, a technical microphone was used as a sensor for recording the signal. At the second stage, as vibration sensor was used - an accelerometer, which is used for standard vibroacoustic diagnostics of bearing supports.

Further, a comparative analysis of all records was carried out both in the time domain and in the frequency domain spectrum. Based on the analysis, conclusions were drawn about how effective the use of a technical microphone can be as a signal registration sensor for vibroacoustic diagnostics.

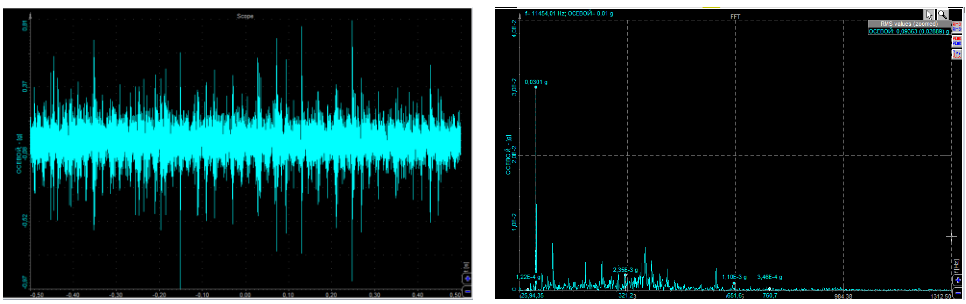
3.1 Analysis of the received data

This article presents a vibroacoustic signal obtained as a result of the operation of a serviceable bearing, both in the time domain and frequency domain. Figure 3 shows a recording obtained using a technical microphone, Figure 4 shows a recording obtained using an accelerometer.



a) b)

Fig. 3. Vibroacoustic signal got with microphone: a) time domain, b) frequency domain.



a) b)

Fig. 4. Vibroacoustic signal got with an accelerometer: a) time domain, b) frequency domain.

The time signal is a graph of the vibration change over time. It is presented in the form of a signal graph or time series, where time is displayed on the X axis, and the amplitude of oscillations is displayed on the Y axis.

Based on the data presented on the time domain graph, it is possible to calculate the PEAK factor and the swing range (peak-peak):

$$\text{peak factor} = \frac{\text{A peak}}{\text{A rms}}$$

A rms - the quadratic mean value (RMS) of the vibration acceleration amplitude;
A peak - peak value (PEAK) of the vibration acceleration amplitude

Swing Range (Peak-Peak) U_p is the difference between the largest and smallest values of the fluctuating magnitude in the time interval under consideration, or the difference between positive and negative amplitudes.

$$U_p = \frac{\text{max peak}}{\text{min peak}}$$

The calculation results for the two experiments are presented in Table 1.

Table 1. Calculations results.

Parameters	Technical Microphone	Accelerometer
Root mean square (RMS)	0,1373	0,1027

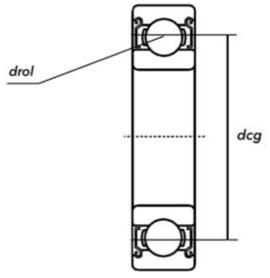
Peak factor	4,37	7
PEAK-PEAK	6	7,2

Consider the frequency domain. The conversion of the vibroacoustic signal from the time domain to the frequency domain occurs using the fast Fourier transform method. The Fourier transform decomposes a complex time signal into elementary harmonic components with different frequencies. The result is a spectrum that shows the amplitude of each frequency component of the signal. The spectrum is represented as a graph, where the frequency is plotted along the horizontal axis, and the amplitude or intensity of the signal is plotted along the vertical axis.

Based on the spectra obtained in the first and second stages, the rotor frequency has been determined. The rotor frequency, i.e., the inner ring rotation frequency of the bearing, from the first and second stages of the experiment, matches.

Rotor frequency $f_r = 50{,}35\ Hz$.

To calculate the rotation frequencies of the bearing elements, we will use the geometric parameters of the examined bearing (Fig. 5). The bearing is a radial-angular contact ball bearing 7017 A.



$d_{rol} = 10mm$ – rolling element diameter;
$d_{cg} = 128mm$ –d iameter of the circle passing through the centers of the rolling elements;
$z_{rol} = 28$ – number of rolling elements in the bearing.

Fig. 5. Angular contact ball bearing 7017 A.

1. Separator rotation frequency.

$$f_{cg} = \frac{1}{2} f_r \left(1 - \frac{d_{rol}}{d_{cg}}\right) = \frac{1}{2} 50{,}35 \left(1 - \frac{10}{128}\right) = 23{,}208\ Hz$$

2. Rolling frequency of rolling elements on the outer ring.

$$f_0 = \frac{1}{2} f_r z_{rol} \left(1 - \frac{d_{rol}}{d_{cg}}\right) = \frac{1}{2} 50{,}35 * 28 \left(1 - \frac{10}{128}\right) = 649{,}83 Hz$$

3. Rolling frequency of rolling elements on the inner ring.

$$f_i = \frac{1}{2} f_r z_{rol} \left(1 + \frac{d_{rol}}{d_{cg}}\right) = \frac{1}{2} 50{,}35 * 28 \left(1 + \frac{10}{128}\right) = 759{,}97\ Hz$$

4. Rolling frequency of rolling elements.

$$f_{rol} = \frac{d_{cg}}{2 d_{rol}} f_r \left(1 - \left(\frac{d_{rol}}{d_{cg}}\right)^2\right) = \frac{128}{2 * 10} 50{,}35 \left(1 - \left(\frac{10}{128}\right)^2\right) = 320{,}273\ Hz$$

Let's find the calculated frequencies in the spectrum.

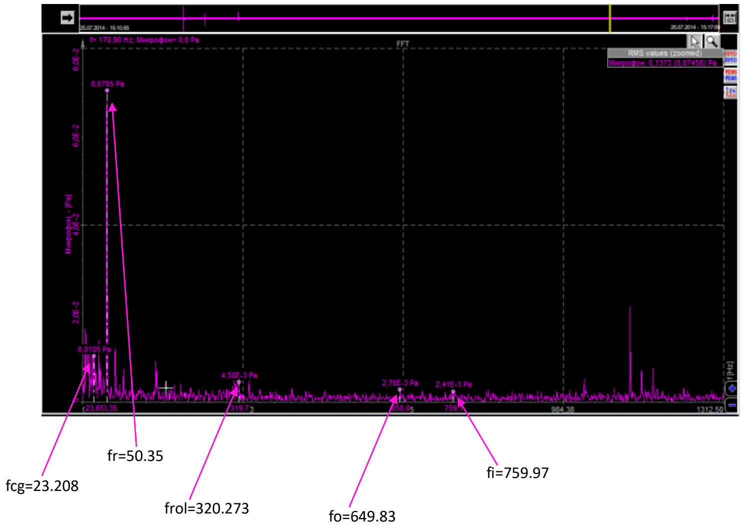


Fig. 6. The rotation frequencies of the elements of the investigated bearing for the signal obtained using the technical microphone.

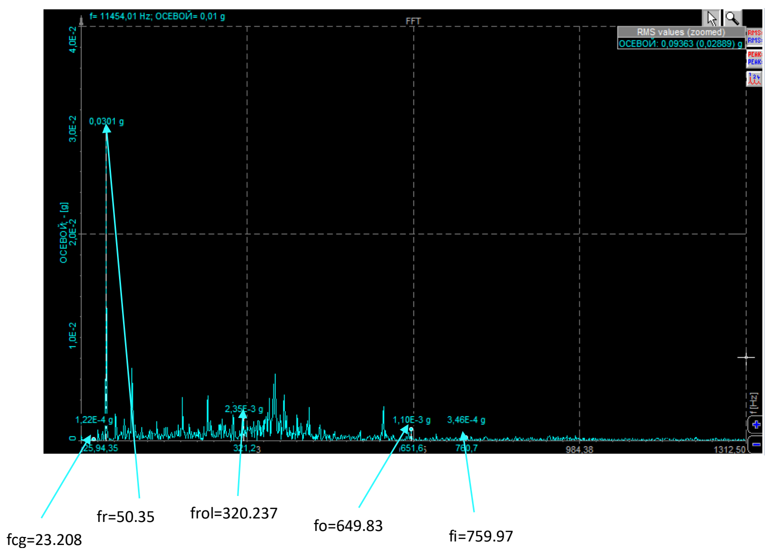


Fig. 7. The rotation frequencies of the elements of the investigated bearing for the signal obtained using the accelerometer.

3.2 Conclusions from the experiment

Based on the conducted experiment and detailed analysis of the data obtained during tests with a serviceable bearing, a comparative evaluation of the results was performed. In the course of this experiment, where recordings of the serviceable bearing were compared, obtained using a microphone on the SP-180 stand and a conventional vibration sensor on the same stand, it was revealed that the parameters in the time domain exhibit minor differences at a level of a few units, which still characterize the bearing's condition as serviceable. The rotor frequency in both cases coincides and is $f_r = 50{,}35\ Hz$. The rotational frequencies of the bearing elements were calculated and found in the spectrum for both signals. This allows us to conclude that the microphone has a certain advantage over traditional vibration sensors. This advantage lies in the sensor's ability to register signals based on acoustic pressure, independently of the direction of the vibration vector. This conclusion also confirms the idea that using a microphone instead of a traditional vibration sensor significantly enhances sensitivity in the process of vibroacoustic diagnostics, enabling more effective detection of faults.

4 Conclusion

Existing methods of diagnostics of internal engine components, such as bearing supports, have limited efficiency and instability. Therefore, in order to obtain information about the technical condition of bearing supports, a new approach to diagnostics is needed, providing higher reliability and the ability to assess their condition at the early stages of damage development. Analysis of current trends in vibroacoustic diagnostics indicates the prospect of using technical microphones to achieve the goals set. The conducted experiment in the course of this study confirms that the use of a technical microphone in the vibroacoustic diagnostics of bearing supports is an effective tool for detecting and analysing their condition. Such kind of vibroacoustic diagnostics should be conducted during ground maintenance in the cold idle mode.

References

1. A.V. Barkov, N.A. Barkova, Vibration diagnostics of machinery and equipment Vibration analysis, textbook (2004)
2. D. Balakin, V. Shtykov, A. Zubko and others, *Principles of Diagnosing: The Technical Condition of the Bearings of the Gas Turbine Engine Supports Using Rhythmogram and Scatterogram,* Advances in Turbomachinery, (2022)
3. Ivshin I.V. *Diagnostics of GTE Turbine Blades Using a New Vibroacoustic Method*, Aviatsionnaya Tekhnika, (2009)
4. Biryukov P.B., Kiselev Yu.V. Proceedings of the Samara Scientific Center of the Russian Academy of Sciences, **18**, 1(2), (2016)
5. R.R. Lukmanov, A.V. Savelyev, A.A. Kopylov, Natural and Technical Sciences, No. **6**, (2008)
6. J.M. Sachar, H.F. Silverman, Conference: Acoustics, Speech, and Signal Processing, Vol **5**, (2001)
7. S. Wang, J. Zhou, *Vibro-acoustic characteristics of gear-rotor-bearing coupled system under multi-source excitation*, Low Frequency Noise Vibration and Active Control, Vol. 0(0), (2022)
8. M. E. Podolsky, S. V. Cherenkova, Theory of mechanisms and machines**, 12.** 1, (2014)
9. V. N. Kostyukov, A. P. Naumenko, *The basics vibroacoustic diagnostics and monitoring machines*, Omsk State Technical University, (2011)
10. M. E. Vostrikov, A. A. Krylov, , Bulletin of the RGAT named after P. A. Solovyov**, 2** (61), (2022)
11. Vibration diagnostics and Balancing, Stand for input control of rolling bearings SP-180M, http://www.diamech-2000.com/bearing_testing.html (2004)