Monitoring the state of power plants’ friction pairs on the basis of single-coil eddy-current sensors

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Abstract. The tasks of “on-line” assessment of the state of friction pairs of high-power power plants are considered. They are based on the use of clusters (groups) of original single-coil eddy-current sensors. It is proposed to use the information about the presence of wear particles in the lubrication system of the power plant and the axial displacement of the shaft in a radial thrust bearing as the main monitored parameters. A brief description of the methods for obtaining the information about the desired parameters and the tools that implement them is provided.

1. Introduction
Gas turbine engines (GTE) are one of the most typical representatives of high-power power plants, which are widely used in aviation, land, and marine engineering. Experience operating GTE in Russia and the world shows that a significant number of power plant incidents are caused by the failure of lubricated friction assemblies.

It is stated in [1] that the total number of GTE failures associated with friction assemblies may exceed 30%. In turn, it follows from the materials of the meeting of the association «Union of Aeronautical Engineering» [2], as well as the reports of the IAC on the investigation of the causes of aviation accidents (according to the media publications [3-5]), that the presence of wear particles (debris) in GTE’s lubrication systems is one of the reasons leading to engine damage. Therefore, it can be recognized that on-board diagnostics of the friction units of power plants is an urgent task.

It is obvious that the development of appropriate methods and tools of «on-line» monitoring of state parameters of the bearing assemblies will allow not only to timely detect the bearing’s damage and the occurrence of a precautionary state of the power plant, but also to estimate the residual life of a friction pair at any given time.

A solution based on eddy current measurement methods is possible. It is proposed to use the axial displacement of the shaft in the radial-thrust bearing (RTB) and the presence of the wear particles in the oil of the power plant lubrication system as the diagnostic parameters for evaluating the friction pair’s state.

This article summarizes the methods for evaluating the state of friction pairs and describes the generalized structure of the monitoring system. The proposed technical solutions are based on the use of the original single-coil eddy-current sensors (SCECS) and their cluster compositions, which ensure reliable operation under real operating conditions of GTE [6].
2. The assessment of friction pairs’ state

Rotors of power plants are involved in the conversion of energy and due to large mass and high speeds of rotation have a significant power effect on bearing assemblies in rotor supports. In general, one of the bearings is radially thrust (RTB) and perceives axial and radial loads, while the second is radial, perceiving only radial loads and allowing the rotor shaft to move in the axial direction to compensate for temperature effects.

Obviously, the shaft in the bearing will shift in the direction of the axial force with the wear of the RTB. And the wear of the RTB can be estimated by comparing the axial displacement of the shaft at any given time with its initial position at a power plant’s operation launch.

The cluster methods for measuring the radial and axial displacements of the power plant’s structural elements, based on the SCECS groups [7-9], can be used to determine the axial displacement of the shaft in the RTB. Fig. 1 shows the positioning of a cluster of two SCECS designed to measure the axial displacement of the shaft.

![Diagram of SCECS positioning](image)

**Figure 1.** Positioning of the SCECS on the power plant’s stator to measure the axial displacement of the shaft.

SCECSs are installed on the stator of the power plant above the blade row of the impeller with a specified offset in the direction of the axis of the rotation (Z). The sensing elements (SE) of both SCECS are oriented parallel to the blade tip. In this case the geometric center (g.c.) of the SE of the first SCECS has the offset along axis $X$ relatively to the g.c. of the blade by the amount that is equivalent to $-\Delta x/2$, and the g.c. of the second SCECS - by the amount that is equivalent to $+\Delta x/2$, where $\Delta x$ is the range of all possible axial displacements of the shaft in the RTB.

Each of the SCECS is connected to a measuring circuit (MC), which provides an analog signal in the form of voltage pulses at the moments when the blade tips pass under the SE of the corresponding sensor. The time diagrams of the changes in the output signals of the MC of both SCECS in the absence and presence of the shaft’s axial displacements are shown in fig. 2, $a$ and $b$, respectively. The diagrams show that the blade tip is located at an equal distance from the centers of the SEs of the SCECS1 and SCECS2 when the tip passes the sensitivity zones of both sensors on the condition that there is no axial offset. Therefore, the amplitude of the signals at the outputs of MC$_1$ and MC$_2$ will be approximately the same and will depend on the value of the radial gap to the end of the blade.

The axial displacement of the shaft will cause the blade wheel to be closer to one of the SCECS (in fig. 2 this is SCECS1) and, all other things being equal, the equality of the amplitudes of the output signals of the MC$_1$ and MC$_2$ will be breached. An analysis of the specified difference of the amplitudes at each turn of the blade wheel makes it possible to continuously monitor the value of the axial offset of the shaft associated with the RTP wear and generate the corresponding signals about the state of the bearing assemblies according to the specified settings.
The second method of evaluating the actual state of the bearing assembly, discussed in the article, focuses on the detection of the wear particles in the bearing lubrication system. Currently, there are known debris detectors in the oil that implement the eddy current measurement methods [1, 10]. The GasTOPS (Canada) real-time debris monitoring systems based on the MetalSCAN MS1000 and MS4000 sensors are good examples of such systems [11, 12]. At the same time, as shown in [13], the sensitivity of such sensors decreases as the diameter of the lubrication system pipeline increases and under certain conditions may not be enough to detect small wear particles. An alternative is a cluster SCECS with an orthogonal orientation of the SE contour to the monitored object (wear particle) [13].

In order to increase the conversion sensitivity, the general oil stream on the input of the sensor is split into \( N \) independent streams with a smaller cross-section area (fig. 3) [14].

Each independent stream is covered by a single current loop located in the pipeline of the engine oil system. The cross-section area of each of the \( N \) streams, on the one hand, should guarantee that it does not hold the wear particles (the sensor should not act as a debris filter) and, on the other hand, should ensure an acceptable sensitivity to the small particles. The total area of the cross-sections of all \( N \) streams should be equal to the area of the cross-section of the input flow.

Two heteropolar pulse signals (fig. 4) are formed at the output of the corresponding measuring transducer when the wear particle passes the SE contour. The amplitude value of the signals characterizes the size of the wear particle, the sequence of the signals polarities makes it possible to
determine the type of the particle (magnetic or non-magnetic), and the time interval ($\Delta t$) between the signals under certain assumptions makes it possible to evaluate the velocity of the particle movement in the oil stream:

$$v = \frac{\Delta k}{\Delta t},$$

(1)

where $\Delta k$ is the distance between the SEs in the sensor oil channel [15, 16].

![Figure 4](image1.png)

**Figure 4.** Digital code changes when a single wear particle passes the contours of the SE.

It should also be noted that the stream separation by the proposed method, in addition to increasing the sensitivity, also increases the probability of detecting single wear particles running in the same stream section of the general oil pipeline of the power plant's oil system.

### 3. Structure of the monitoring system

The generalized functional scheme of the System for Monitoring the State of Bearing Assembly (BASMS), which implements the methods described above is presented in fig. 5.

![Figure 5](image2.png)

**Figure 5.** Generalized functional scheme of the system for monitoring the state of bearing assembly

SCECS is the basis of the BASMS. The Debris Sensor (DS) with the SE in the form of a single coil covering the oil channel is used in the debris monitoring subsystem and the Radial Clearance sensor (RCS) with the SE as a segment of the conductor used in the shaft’s axial displacements monitoring subsystem. The MC in both subsystems converts the information parameters of the sensors (the SE inductance changes) into an analog electric signal in the form of a voltage, which is then normalized in the Unit for Generating a Normalized Signal (NSGU) to the level corresponding to the used Analog-to-Digital Converters (ADCs). The measurement information is then processed in the Diagnostic Characteristics Generating Unit (DCGU) and the presence of wear particles in the GTE lubrication system, the particle characteristics (magnetic properties, dimensions and the intensity of particles’ occurrence) as well as the shaft offset in the RTB are determined. An estimation of the residual resource of the bearing assembly can be given on the basis of the obtained information. This operation is performed in the Bearing’s State Diagnostic Unit (BSDU), which receives information from two subsystems. The BSDU is also assigned an emergency alarm function when the bearing life resource is reduced, and the bearing assembly is approaching a dangerous state.
4. Conclusions
This article proposes two ways of obtaining information for an on-line estimation of the state of friction pairs of high-power power plants. The proposed methods are based on the use of SCECOS and their cluster compositions. The information about wear particles in the lubrication system of the power plant and the axial displacement of the shaft in RTB were selected as the main monitored parameters of the bearing assembly’s state. A generalized functional scheme of the BASMS is proposed. It implements the discussed methods for monitoring the state of the bearing assembly.

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