Experimental study for choosing an active substance in a microcracks detection system in the turbine blade

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Abstract. In this work, an experiment was carried out that allows choosing an active substance in the system for early detection of microcracks in the blades of gas turbine engines. The aim of the work is to compare several active substances by measuring the signal generated by each of them at the same temperatures and concentrations of the active substance. A current signal is obtained by applying a voltage between two electrodes placed in a stream of hot gas. The strength of the electric current arising between the electrodes in the hot gas flow depends on the ionization of the gas caused by the active substance. The current signal is the main criterion for choosing an active substance. A study was also carried out on the effect of gas temperature on the strength of the signal caused by the active substance. This experiment is one of the main stages in the creation of a system for detecting microcracks in gas turbine blades.

1. Introduction

In gas turbine engines, the most loaded elements are the rotor blades of the first turbine stages. They operate at high temperatures and stresses from centrifugal forces and bending moments. Also, variable aerodynamic forces act on it. These factors lead to the risk of crack formation in them. Developing cracks are a hazard when the engine is running and can lead to an emergency situation. Timely crack detection is an important task in aircraft engine diagnostics. Currently, various methods are used for this, described in [1–6]. However, all these methods are applied in stationary conditions on the ground during engine inspections.

In works [7–9], a method for detecting microcracks in the blades of operating turbomachines is proposed and described. The proposed technology works as follows. Several thin-walled capsules with an active substance are located in the blade. At the origin of the crack, when it reaches the capsule with the active substance, the thin-walled shell of the capsule breaks and the active substance enters the flow path. After that the active substance is detected by the appearance of an electric current between the electrodes. The increase in the current is recorded with an ammeter.

2. Materials and methods

In the system for early detection of microcracks, the active substance is considered one of the most important factors affecting the success of this system and its effectiveness, since the magnitude of the recorded signal depends on it. Therefore, it is necessary to test several materials and select the most suitable one, which gives a clear and accurate indication for the formation of microcracks in the body of the turbine blade. One of the main conditions that were taken into account is the possibility of ionization of these materials at high temperatures. And when the active substance passes between the
electrodes, an electric current appears in the signal detection circuit, because of the attraction of various ions to the electrodes due to the high electric field, created by a large voltage difference. An experiment was carried out to select a suitable active substance. The scheme diagram for the experiment is shown in Figure 1.

![Figure 1](image1)

Designations: 1 - gasoline burner; 2 - pipe; 3 - place of active substance input; 4 - thermocouple; 5 - electrodes; 6 - voltage source; 7 – micrometer

**Figure 1.** Schematics of the experiment

The experimental stand consists of a stainless steel pipe 2 with a diameter of d = 8 cm with a thick wall h = 1 mm. A gasoline burner 1 is installed at one end of the pipe to give a hot gas flow. It can give a gas flow with a temperature of up to 800°C. A thermocouple 4 is installed in the pipe to measure the temperature of the gas flow and electrodes 5. The pipe has a hole 3 for introducing an active substance into the gas flow. A constant voltage is supplied to the electrodes from the source 6, which can be regulated. A micrometer 7 is connected to the electrodes to register the output currents. The active substance is added to the flow part through hole 3 at the initial section of the pipe to ensure its uniform mixing with the hot gas flow. The gas flow temperature is measured by a pre-calibrated thermocouple 4 connected to a voltmeter. The value of the gas temperature was determined according to the equation $T = 11.48 \cdot V^{-14}$, obtained during calibration, where $V$ is the voltage on the voltmeter.

Electrodes 5 were connected to a voltage source 6 (2000 V). When the gas flow with the introduced substance passes between two electrodes, different ions move between the two electrodes, which causes an electric current, which is measured by the micrometer 7. The image of the experimental stand is shown in Figure 2.

![Figure 2](image2)
We carried out six different active substances containing alkali and alkaline earth metals: potassium chloride (KCl), potassium monophosphate (KH₂PO₄), calcium nitrate (Ca(NO₃)₂), magnesium sulfate (MgSO₄), potassium nitrate (KNO₃) and sodium bicarbonate (NaHCO₃). The experiments were preliminarily carried out at a temperature of 600 °C, at the same concentration of all substances, which was 15 grams of active substance per 100 grams of solvent (water), injected into the flow path. This concentration was chosen because it ensures complete dissolution of all these substances.

The volume of the injected substance was 2 cm³ per second. The increase in the current ∆I between the electrodes was observed for 2-3 seconds. After that, the current dropped to its original value.

Electric current ∆I was measured each time when a new active substance was added. The experiment was repeated for each active substance at least seven times to ensure the results, and each time, the tube and electrodes were cleaned of any remaining active material that might have deposited on the walls of the tube and electrode.

3. Results and discussion
Table 1 and Figure 3 show the obtained results.

| Active substance | KCl | KH₂PO₄ | Ca(NO₃)₂ | MgSO₄ | KNO₃ | NaHCO₃ |
|------------------|-----|--------|---------|-------|------|--------|
| ∆I, µA           | 4   | 0.5    | 3       | 0.8   | 16   | 3.5    |

![Figure 3](image_url). The magnitude of the recorded current for various active substances

Note that (KNO₃) turned out to be the most effective than other materials, since the current was at least four times higher than the other substances. This allows us to select (KNO₃) as an active substance in the early detection of microcracks in a turbine blade.

It was shown in [10] that an increase in temperature affects the durability of gas turbine blades. It leads to an acceleration of crack growth and a decrease in the strength properties of blade materials.

Therefore, the influence of the gas flow temperature on the current obtained during signal registration was investigated. In this case, a concentration of 36 grams (KNO₃) in 100 grams of water was chosen, since it provides the highest degree of solubility of this active substance. The experiment was carried out at four different values of temperature and voltage between the electrodes of 2000 V. The obtained results are presented in Table 2 and in Figure 4.

| Temperature (°C) | 500 | 600 | 700 | 800 |
|------------------|-----|-----|-----|-----|
| ∆I, µA           | 2.5 | 21  | 500 | 2300 |
Figure 4 - Dependence of the current between the electrodes on the temperature of the gas flow

We can see from the results obtained that the temperature has a great influence on the strength of the resulting current.

4. Conclusion

Based on the research results, it can be concluded that:

1) it is advisable to use potassium nitrate as an active substance, since it gives the maximum value of the received signal;

2) the gas flow temperature is a significant factor influencing the signal value. With an increase in temperature from 600 to 800 °C, the signal value increases 110 times.

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