Investigations of heat exchanger elements at tests

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Abstract. A method for modeling the thermal state and a method for conducting research on plate heat exchanger elements for an aircraft gas turbine engine using the developed test equipment during thermocyclic tests are proposed. The analysis of the operating conditions of the heat exchanger is carried out and the most thermally stressed sections of the heat exchanger are identified. Optimal inductor designs are selected. The methods and boundaries of the effective control and thermal state in the elements of the heat exchanger are determined. Studies have shown the possibility of using high-frequency induction heating when testing sections of a heat exchanger for thermocyclic durability. The results of testing elements of a plate heat exchanger for a gas turbine engine are presented.

1. Introduction

One way to increase the efficiency of aircraft gas turbine engines (GTE) is to increase the air temperature at the inlet to the combustion chamber by utilizing the heat of the gases leaving the turbine. For this purpose, a heat exchanger is located behind the turbine. One of the options for the heat exchanger is a structure assembled from a separate profiled plates (Figure 1). Flows of gas and air flow through a grate of a heat exchanger shared by plates. Heated air enters through the central manifold and plates, flowing between them perpendicular to the direction of gas flow (moving on the other side of the plate) and heated air is vented through the extreme collectors. When operating in the nominal mode, the gas flow temperature at the inlet to the heat exchanger is 600 °C, and the air temperature is 200-250 °C. However, during start-up and during take-off, the “burn” mode occurs, when air is not supplied to the heat exchanger and the gas temperature reaches 650 °C. The duration of the regime is 10 minutes. Analysis of the design shows that the largest temperature differences in the “burn through” mode occur in site 1 (Figure 1) in the inner ribs of the central air supply manifold at the moment of air supply with a temperature of 200 °C. A shutdown moment can also be dangerous when cold air is introduced into a heated heat exchanger. In this case, the site 2 on the Figure 1 (outer ribs of the heat exchanger section) is dangerous.
2. Test method and research results

Many scientific papers are devoted to various studies of heat exchangers [1-5]. Testing and investigations of heat exchangers and their elements is possible on various types of testing equipment that simulates the conditions of their work in the gas flow of the gas turbine engine. It can be gas-dynamic stands or installations with high-frequency heating (HF) heating [6, 7].

The gas-dynamic stand allows testing to be made as close as possible to real conditions, however, the cost of such tests is very high and their use is not practical at the stage of strength tuning. It is not possible to actually use a gas stand for a control check of the exhausted version of the heat exchanger.

High-frequency induction (HF) heating at a sufficiently high frequency satisfactorily simulates a surface heating in a gas stream [6]. The cost of tests with HF heating is several orders of magnitude lower than the cost of tests on a gas stand. The low cost of the testing allows for comprehensive studies of structures in order to establish the effect on their thermocyclic durability of various structural and technological factors, such as different thicknesses of plate materials, various materials, various assembly methods [6].

For testing, an HF stand was used, including an HF generator with an induction system at a frequency of 400 kHz, a loading device, control systems, measurement systems, and auxiliary devices. After manufacturing the necessary test equipment, the existing equipment was used to study the thermocyclic durability of the heat exchanger elements. In the tests, the blank of the heat exchanger section welded from two plates along the inner rib was used. In order to ensure the rigidity of the element corresponding to the assembled heat exchanger, the profiled metal strips (simulators of the outer rib) of the same thickness and grade as in the main plate were attached to the ribs on both sides by spot welding.

To measure the temperature, the element was prepared with chromel-alumel thermocouples. Fixing the heat exchanger in a predetermined position relative to the inductor is achieved by means of a loading device, providing a force through it through the elastic element. Modified captures were used for element attachment. An inductor was developed to heat the heat exchanger element (Figure 2). With its help, the heating is carried out throughout section element. However, during the research it was found that due to the low stiffness of the element during uneven heating of the long section, its distortion is so strong that the inductor is shorted and the local part of the heat exchanger material burns out. In this regard, the length of the heated zone of the heat exchanger element was reduced to 10-30 mm and the corresponding inductor was developed (Figure 3). The design of the fastening of the inductor to the tires of the HF generator allows you to move it along section element, so that on one element it is possible to conduct consistent studies on the thermocyclic durability of several zones. The warping of the sample was significantly reduced. The heat exchanger element was cooled during
thermal cycling with the help of air supplied after working out the holding mode at the maximum temperature $T_{\text{max}}$ and turning off the heating.

![Figure 2. Inductor for heating heat exchanger section element: 1 – inductor, 2 – plate, 3 – electrical leads, 4 – inner rib, 5 – part of the outer plate (simulator of the outer rib)](image)

The regime for changing the maximum temperature $T_{\text{max}}$ in the thermal cycle is shown in Figure 6. On the Figure 6 the next values are presented: $T_{\text{max}} = 600-650 \, ^\circ\text{C}$, $T_2 = 450-500 \, ^\circ\text{C}$, $T_1 = 300 \, ^\circ\text{C}$. $\tau_1 = 10-20 \, \text{s}$, $(\tau_2 - \tau_1) = 60-300 \, \text{s}$, $(\tau_3 - \tau_2) = 15-30 \, \text{s}$. In the process of thermal cycling, it was found that the largest difference in the heated section of the heat exchanger element reaches $(T_{\text{max}} - T_2) = 150 \, ^\circ\text{C}$ at the end of the $T_{\text{max}}$ mode.

![Figure 3. Inductor for heating of zone (bridge) of the heat exchanger section element: 1 – moving inductor, 2 – plate, 3 – electrical leads, 4 – inner rib, 5 – part of the outer plate (simulator of the outer rib)](image)

In the process of work, the following studies were performed:
- an analysis was made of the working conditions of the heat exchanger elements and the most thermally stressed sections were identified.
- a test procedure has been developed for the section of heat exchanger elements for thermocyclic durability.
- grips for fastening the heat exchanger sections to the installation are designed and manufactured.
- the shape has been tested and the dimensions of the inductor have been established, which ensures heating of the heat exchanger section in accordance with the technical conditions.
- the methods and boundaries of effective control of the temperature gradient (differential) in the elements of the heat exchanger section are determined.
- a preliminary assessment of the thermocyclic durability of the heat exchanger was carried out.
- studies have shown the possibility of using HF heating when testing the heat exchanger section elements for thermocyclic durability.

During the development of the test procedure, the preliminary data were obtained on the thermocyclic life of the heat exchanger (overpressure in the section was not reproduced). When using the inductor
shown in Fig. 2 and heating the jumper along the entire length after 4500 cycles, due to warping, the sections were touched by the inductor. No cracks in the heat exchanger at this point were observed.

![Figure 4. The temperature curves of heat exchanger element ribs: 1 – inner rib, 2 – simulator of the outer rib](image)

The thermal state of the heat exchanger section element was simulated using a modified inductor (Fig. 3) with a length of the heated zone of 25–30 mm during thermal cyclic tests. In this case, crack formation was observed after 14000-16000 heat-changes. The estimated thermocyclic life of the plate heat exchanger section element is 15000 cycles.

3. Conclusion

A method for modeling the thermal state and a method for conducting research on plate heat exchanger elements for an aircraft gas turbine engine using the developed test equipment during thermocyclic tests have been developed. The analysis of the operating conditions of the heat exchanger is carried out and the most thermally stressed sections of the heat exchanger are identified. Optimal inductor designs are selected. The methods and boundaries of effective control of the thermal state in the elements of the heat exchanger are determined. Studies have shown the possibility of using high-frequency induction heating when testing sections of a heat exchanger for thermocyclic durability. The results of testing elements of a plate heat exchanger for a gas turbine engine are presented.

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