Improving the performance of the air-cooling unit in the cooling system of a radar

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Abstract. The article discusses the issues of reducing the size of the cooling unit of the antenna of a radar station by improving the gas-dynamic processes occurring in the air-cooling unit. The results of the experimental studies of the gas flow in a plate-fin heat exchanger, being blown by one axial fan are presented. The feasibility of changing the number of axial fans for organizing a more uniform flow around the heat-exchange surfaces has been determined by calculation and theoretical methods. The calculation results are confirmed by experimental studies of the air flow in the segment of the heat exchanger, which is provided by a smaller fan.

1. Introduction

It is known that the active phased antenna array, in contrast to the increased reliability, generates a significant amount of heat during operation and, accordingly, needs cooling.

Scientists from the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS), together with specialists from PJSC “Almaz”, developed an experimental stand of a cooling unit based on a two-circuit scheme [1]. One of the key requirements in the development of such a system is to reduce the weight and size of the cooling unit. Since in any operating mode the heat received from the radar antenna and the elements that make up the cooling unit are ultimately rejected into the environment, the weight and dimensions of the unit directly depend on the size of the air-cooling unit (ACU).

Therefore, the purpose of this work is to improve the performance of the ACU, by reducing the unevenness of the gas velocities in the cross section of the heat exchanger, which will lead to a reduction in its mass and dimensions.

2. Experimental studies of the gas flow in the ACU of initial configuration

As a result of a preliminary thermodynamic calculations, the required dimensions (heat exchange surface area) of the plate-fin heat exchanger, which transfers heat from the cooling unit to the environment, and the parameters of the air flow inducers (axial fans) were determined. FC 100-6DQ.8S.A5 were chosen as fans, providing a pressure drop of 240 Pa at a flow of 32,000 m³/h.

To determine the uniformity of the distribution of air flow rates in the cross section of the heat exchanger, measurements were made in accordance with the diagram shown in Figure 1 (measurements were made in the center of each rectangular segment). The speed was determined using the air speed probe with a heated wire D12 0635 1535 as part of the Testo 435-4, which measures the speed in the
range from 0 to 20 m/s with an error of 0.01 m/s. The measurement at each point was carried out for 30 seconds, after which the average value of the air velocity through the segment was recorded.

**Figure 1.** Layout of the points for measuring air flow rates in front of the heat exchanger.

As a result of experimental studies, the field of air velocities at the inlet of the plate-fin heat exchanger was determined, and is shown in Figure 2.

**Figure 2.** Velocity field in front of the heat exchanger.

It is clearly seen that closer to the left and right boundaries of the investigated section, the air velocity significantly exceeds the average value (6.2 m/s). At the same time, there is a region of low velocities near the upper boundary (about 5 m/s). Such unevenness of the speed distribution will significantly worsen the heat transfer processes in the plate-fin radiator.

3. **Computational and theoretical studies of the gas flow in ACU with four fans**

To reduce the degree of unevenness of the air velocity blowing through the plate-fin heat exchanger, it was proposed to increase the number of fans. As the new fans, axial machines were selected, providing a capacity of 8000 m$^3$/h at a pressure drop of 240 Pa.
To simulate the air flow inside the ACU flow cavity using numerical methods [2–4], we constructed a computational domain (Figure 3), consisting of a radiator flow cavity (1), a fan (2) and a casing with a motor located inside (3). To reduce the time for modeling gas-dynamic processes, the calculated area of the radiator was replaced by a porous body with constant coefficients of hydraulic resistance, which correspond to the coefficients determined experimentally. In addition, the flow cavity of the fan was considered as a single segment. The entire calculation was carried out for a quarter of the heat exchanger under the assumption that the gas flow through 1 fan has not effect on the neighboring regions.

The mathematical model of the gas flow through the ACU was described by the system of Navier-Stokes and continuity equations, supplemented by the SST (Menter) turbulence model. The properties of air at a temperature of 25°C were set as the properties of the working medium. The boundary conditions were the value of the total pressure at the inlet of the computational domain and the mass flow rate at its exit, as well as the velocity at the boundaries with solid surfaces taken to be equal to 0.

![Figure 3. Computational area of the ACU segment.](image)

As a result of the calculation, the distribution of the air flow velocity in the inlet section of the heat exchanger has been developed and is shown in Figure 4.

![Figure 4. Air flow velocity distribution at the inlet to the ACU segment.](image)
The results obtained allow us to conclude that the unevenness of the velocity field in the cross section of the radiator is insignificantly reduced. To obtain a greater effect, it is necessary to install a guide vane between the radiator and the fans, however, this measure will lead to an increase in the dimensions of the ACU.

4. Experimental studies of the gas flow in an ACU with four fans
To confirm the calculated results, experimental studies of the air flow through a segment (1/4 part) of the original radiator, provided by an axial fan VO 16-308-6 / 17-5.6, were carried out. To determine the uniformity of the distribution of air flow rates in the cross section of the heat exchanger, measurements were made in accordance with the diagram shown in Figure 5 (similar to those described earlier).

![Figure 5. Layout of the points for measuring air flow rates in front of the heat exchanger.](image)

As a result of the experimental studies, the field of air velocities at the inlet of the segment of the plate-fin heat exchanger has been determined and is shown in Figure 6.

![Figure 6. Velocity field in front of the segment of the heat exchanger](image)

The obtained distribution highly matches the results of theoretical calculations.

Conclusions
As a result of the work, the distributions of air velocities at the inlet section of the plate-fin heat exchanger have been determined using one and four axial fans. The increase in the number of fans allowed slightly reducing the unevenness of velocity distribution. In addition, such a replacement served to reduce the axial dimension of the ACU from 670 mm to 430 mm, which decreases the unit size by
10%. In this case, the total power consumption for both options may be considered the same. It can also be concluded that a further increase in the number of axial fans will not lead to a significant reduction in the axial size of the ACU (due to the size of the electric motor).

The increase in the efficiency of the cooling unit with the modernized ACU has been confirmed in the tests.

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