Features of the operation of the heat exchanger-condenser of modern passenger aircraft

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Abstract. This paper presents a description of the design problems of the heat exchanger-condenser of modern aviation air conditioning systems (ACS) of passenger aircraft. The purpose of the work is to study known design methods and explore an alternative option. The paper presents a description of the problems of operating an ACS heat exchanger-condenser: freezing of the heat transfer surface along the cold and hot paths, as well as known methods of anti-icing systems (AIS) for it. The features of the calculation and design of the design variant under study are described. The results of computer simulation of heat transfer processes for various configuration options of the heat exchanger-condenser are presented. The most effective ways to prevent surface freezing are shown. The work is based on original copyright materials obtained at the Department of Technical Thermophysics of NSTU.

1 Introduction

Currently, compact plate-fin heat exchangers (CPHE) are widely used in the air conditioning systems of Tu-214, Superjet 100, MC-21 and foreign Boeing and Airbus aircraft [1], due to the simplicity of design and maintenance, and also high operational reliability. However, some of them have specific operational problems. These include the problem of freezing of the condenser heat exchanger when operating in humid air with negative operating temperatures [1].

Design using known methods [2-6] does not take into account these operational features, so at present there is a need to develop more advanced methods for calculating and designing the CPHE, allowing for innovative ways to solve these technical problems. A separate task is the problem of import substitution of domestic equipment [1] due to the refusal to supply foreign versions of ACS units to Russia.

The key problem in the operation of a capacitor is the need to provide anti-icing measures [1]. This is complicated by the problems of heat and mass transfer processes in the cold path, since a supercooled aerosol is formed in the air after passing through the turbine, and snow and ice particles also appear. In addition, ice formation and melting processes begin to occur on part of the heat exchange surface. In part of the surface in the hot path, due to the processes of condensation of water vapor, freezing of condensed moisture additionally occurs. This results in a reduction in the volume of air flowing through the turbine, making it critical in

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condenser design to implement systems to prevent ice from forming in the hot end and snow from accumulating on the leading edges of the heat exchanger in the cold end.

2 Methods

2.1 Objective

The main problem of modern ACS is the heat exchanger-condenser, designed to condense water vapor on the high-pressure line of the ACS when the air temperature reaches +5 °C. Since it is cooled by cold air from the turbine of a turbo-refrigeration unit with a temperature of -30 °C, the problem of freezing of the heat transfer surface along the cold and hot paths of the heat exchanger has arisen. Engineering solutions from Boeing and Airbus are described in [9-10]. In particular, three options for implementing the AIS are proposed: introducing into the design of the heat exchanger-condenser special tubes for heating the inlet edges in the coldest part of the surface ("thermal knife"), creating a bypass channel along the cold path to reduce the effect of clogging the path and fluctuations in air flow, creating a line mixing hot air into the condenser inlet to quickly thaw frozen snow. The work [1] proposed alternative solutions from the Department of Technical Thermophysics of NSTU in the fight against freezing of the heat transfer surface: the use of variable fins along the length of the hot and cold path. The work analyzed and selected the optimal heat exchanger from three options: changing the pitch of the hot fins, changing the pitch of the cold fins, and changing the pitch of both fins.

2.2 Methods

The most effective method turned out to be variable fins along the heat transfer surface. In particular, the zone consists of dividing the initial grid for calculating the heat exchanger-condenser into four equal sectors I ... IV along the length of the hot and cold path (Figure 1). As a result, the heat transfer surface is divided into 16 elementary "heat exchangers", each of which has its own geometric parameters of the fins [1].

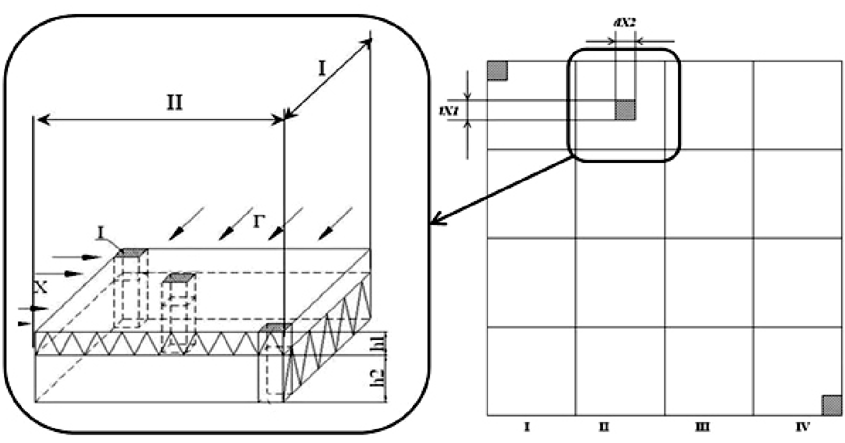

Fig. 1. Sectional division of the surface into paths: Γ (indices 1, I) – hot fins; X (indices 2, II) – cold fins; I…IV – sectors with different fin parameters, h – fin height, ΔX – calculation cell.

The methodology for calculating heat transfer and heat and mass transfer processes in a heat exchanger-condenser is described in detail in [1].

3 Results

3.1 Study of heat exchanger parameters when changing the hot fin pitch

In all figures, the lower surface temperature line corresponds to the standard calculation method (the fin pitch is constant): the temperature varies in the range from -10 to +7.5 °C, 50% of the surface has a negative temperature. As the hot fin pitch decreases (upward lines in Figure 2), an average temperature increases of 5...8 °C is observed. As a result, it was found that this technique made it possible to reduce the proportion of surfaces with negative temperatures to 10...25 %.

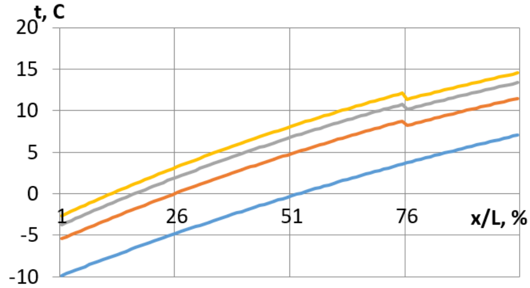

Fig. 2. Effect of hot fin pitch.

3.2 Study of heat exchanger parameters when changing the cold fin pitch

Study of heat exchanger parameters when changing the cold fin pitch. In this series of calculations, we considered a variant of a heat exchanger-condenser with an increase in the cold fin pitch (up lines in Figure 3). As a result, it was found that this technique made it possible to radically change the surface temperature, in particular at the most dangerous inlet edges of the heat exchanger-condenser it becomes above 0 °C, i.e. starts working in the “thermal knife” mode of the anti-icing system.

3.3 Study of heat exchanger parameters when changing the fin wallpaper pitch

With simultaneous joint changes in the pitches of the hot and cold fins (up lines in Figure 4), a significant increase in the temperature of the input edges is observed from 5...7 to 10...15 °C. In this case, the entire surface temperature is at a positive temperature.

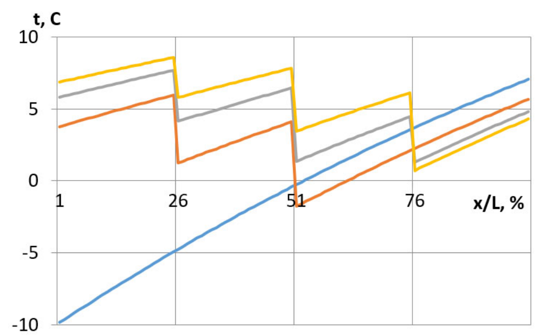

Fig. 3. Effect of cold fin pitch.

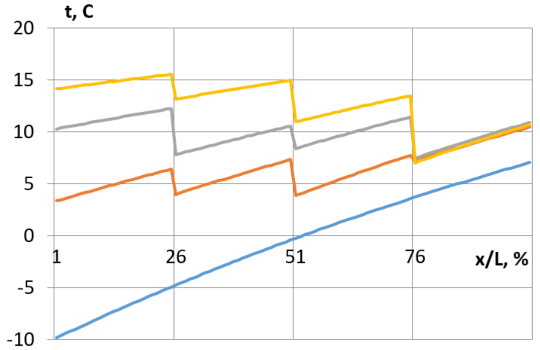

Fig. 4. Effect of changing the pitch of both fins.

4 Discussions

Comparison of the results obtained with known PIC methods [7-8] showed:

- the previously proposed methods offer to combat the consequences of freezing of the heat transfer surface, i.e. solve the problem partially;
- the option under study is aimed at preventing freezing of the most dangerous sections by increasing the surface temperature above zero degrees, i.e. complete solution to the problem.

Analysis of the studied options for changing the fin pitch showed high efficiency in preventing freezing in all three cases: changing hot, cold and both fins simultaneously. The most effective effect was the joint change of fins in the heat exchanger-condenser:

- the surface temperature along the entire length became positive;
- the most dangerous inlet edges of the heat exchanger have a maximum positive temperature and operate in the AIS "thermal knife" mode.

5 Conclusion

The work carried out a set of studies of the temperature distribution of the heat transfer surface when changing the fin pitches. Changing the fin pitch in the hot and cold paths leads to dramatic changes in the temperature distribution in the heat exchanger-condenser. As a result of the research, it was established that the heat exchanger has the best anti-icing characteristics when the steps of both fins are changed together, at which the highest average temperature of the heat exchanger is observed and there is no negative surface temperature, especially at the inlet edges.

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