HEAT TRANSFER INTENSIFICATION IN A SYSTEM OF SEVERAL RIBS ORIENTED AT DIFFERENT ANGLES TO THE MAIN FLOW

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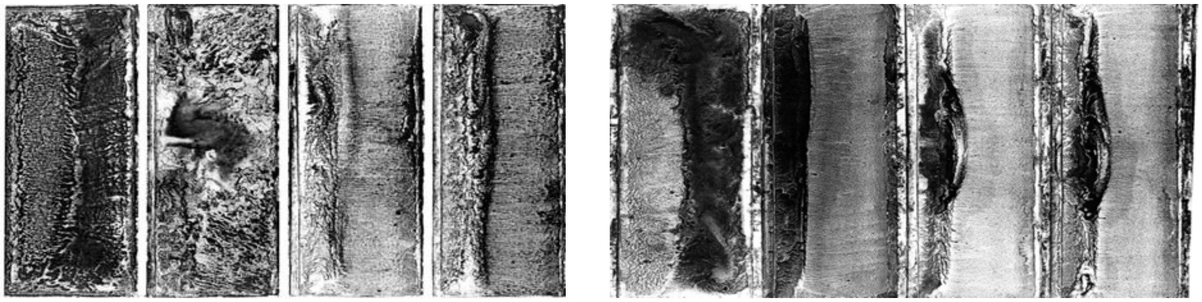
To intensify inner cooling of the turbine blades, the ribbed surfaces with ribs located at an attack angle to the flow are used. There are many experimental studies in this field both for laminar and turbulent flows. However, they dealt mainly with the averaged values. The mechanism of heat transfer intensification becomes clearer, if we study the flow around a single rib. Investigation of a detached flow behind a single obstacle gave an opportunity to determine the physical processes of transfer in separated shear layers and recirculation areas together with the control mechanisms. Vortex formation and heat transfer behind a rib, oriented variously to the turbulent flow, were studied in detail in previous studies of the authors [1-3]. It was shown that the rib height, orientation angle and outer turbulence can efficiently control the detached flow and heat transfer intensification. It seems to be reasonable to continue this research for the system of several ribs. Unfortunately, the studies on the flow structure and heat transfer at the initial regions of the surface with several ribs are insufficient. The effect of the outer conditions on the detached flow is maximal just at the initial regions; and this can influence the following features of the flow around the whole surface. From the point of flow evolution it is also important to determine the moment, when the flow on the ribbed surface becomes self-similar.

Experimental results on development of the turbulent detached flow and heat transfer at streamlining of a system of several ribs (not more than five), transversal and oriented at some angle to the flow, are presented in the current report. Attack angle φ was 45, 60, 75 and 90°. Experiments were carried out at the Institute of Thermophysics SB RAS in the subsonic flow of the wind tunnel with rectangular working channel of 200x200 mm and 1000-mm length. The ribs with the height of 3 – 60 mm were located across the whole width of the channel. The conditions of low and high turbulence degree of the incident flow were considered: $Tu_0=\sqrt{\overline{u'^2}}\,/U_0$ = 1.5% and 15%. High turbulence was supported by a flag turbulence generator, mounted at the distance of 330 mm in front of the first rib. The polyethylene flags with the length of 10 mm were attached to a perforated grate with the hole diameter of 20 mm, which blocked the whole cross-section of the channel.

Data on visualization, pressure and heat transfer coefficients are presented; results obtained for two levels of turbulence are compared. Formation of significantly unstable flow in the second interrib cell was determined for the systems of three to five transversal ribs in a low-turbulent flow. At a high level of outer turbulence flow instability is observed in the first interrib cell (Fig.1), what is proved by a change in pressure distributions (Fig.2). It is shown that every additional rib reduces the detached area behind the last rib, the area of pressure restoration, and the coordinate of maximal heat transfer.

It was found out that heat transfer increases drastically in the second interrib cell. The maximal local heat transfer coefficient at five rib streamlining in the low-turbulent flow is achieved in the third cell at the distance of 3 rib height; in the high-turbulent flow it is achieved in the second cell at the distance of 2 rib heights; whereas, behind a single rib this distance is 15 rib heights. High turbulence intensifies heat transfer. In the second cell intensification of the heat transfer coefficient, average over the cavity surface, is 30% (Fig.3).



a) b)

Fig.1. Vortex-formation pattern at the bottom surface in the system of five ribs
a) Tu_0 = 1.5 %; b) Tu_0 = 15 %.

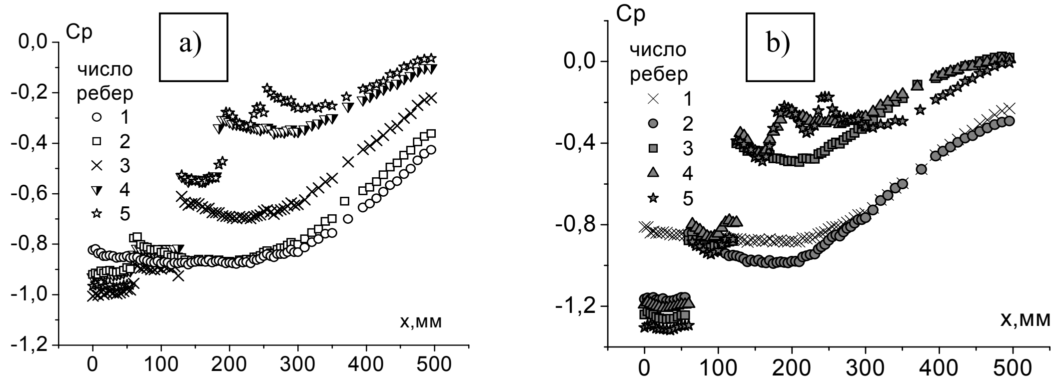


Fig.2. Distribution of pressure coefficient in inter-rib cells in systems
with different number of ribs. a) - Tu_0 = 1.5 %; b) - Tu_0 = 15 %.

According to thermographic visualization in the system of ribs located at some angle to the flow, there is significant temperature field nonuniformity across the interrib cells: a drastic decrease in temperature from the ends of ribs downward the flow and an increase from the ends of ribs upward the flow. This nonuniformity complicates the experiment and requires detailed measurements across the channel width. The total temperature pattern on the surface was obtained with the help of a thermal imager.

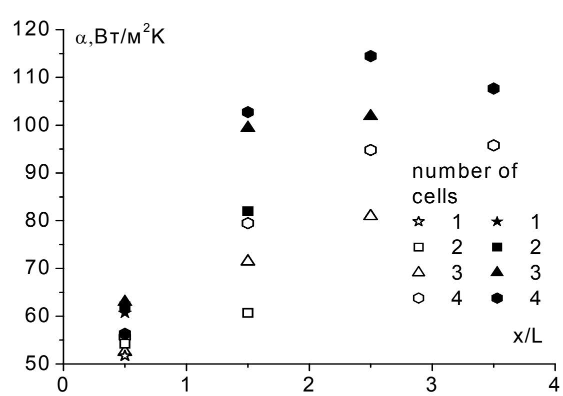


Fig.3. Distribution of cell surface-average heat transfer coefficient α in the
systems of two to five ribs (open symbols - Tu_0 = 1.5%, full symbols - Tu_0 = 15 %).

According to Fig. 4, the heat transfer coefficients, average over the heat-releasing surface, demonstrate weak dependence on orientation angle φ, if there are five ribs of the 6-mm height. Coefficient α in Fig. 4 is normalized to the heat transfer coefficient average over the heat-releasing surface without ribs. Maximal α corresponds to angle φ=60°. Intensification of heat transfer at high outer turbulence is approximately 30% for all angles φ (Fig.5).

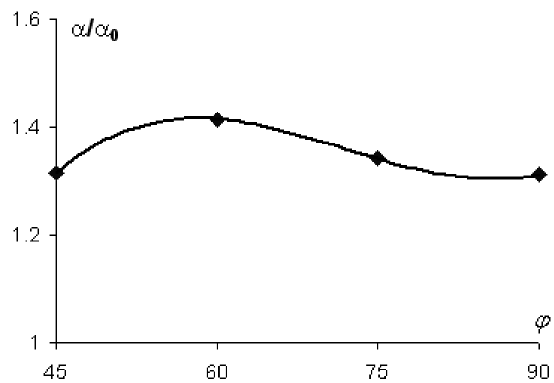


Fig.4. All heated surface-average heat transfer coefficient normalized to the same coefficient on a flat plate for four angular configurations of the system of five ribs.

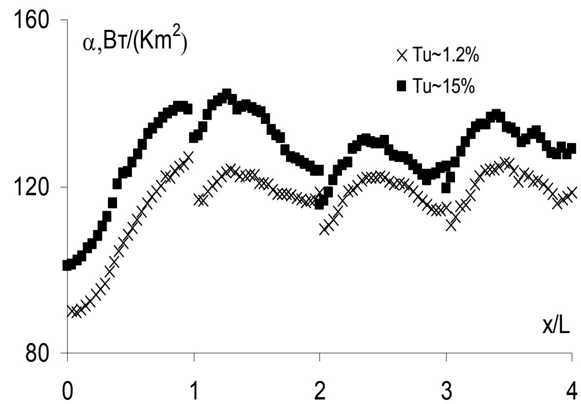


Fig.5. Distribution of local heat transfer coefficient in the system of 45° angled ribs at two turbulence

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