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Abstract

Heat transfer enhancement and aerodynamic losses reduction in internal cooling passage of gas turbine blade

The cooling system of turbine stages is an essential part of operation of the modern aero-engine. The first turbine stage located at the outlet of the combustor chamber operates in extremely heavy condition. The temperature of hot gases exceeds a melting point of the turbine blade's material by about 700-900 K. It shows a great importance of advanced and efficient cooling system for turbine stages. The heterogeneous heat flux distribution on the surface of turbine blade enforce the application of variety type of cooling techniques. The leading edge on its internal surface is cooled usually by means of impinging jets. On the opposite side, in trailing edge region, short and wide cooling channels are used, in order to meet with geometrical limitation, in the mid-chord region, radial, serpentine passages are used. Cooling channels are most often equipped with flow turbulators in form of riblets placed on two opposite walls located near the suction and pressure sides of the blade. As a result, vortex structures appear in the channel, which intensify the heat exchange between the cooler air in the channel and the hot wall.

This thesis focuses on analysis of ribbed channels equipped with ribs located at two opposite walls and set in 45° angle to the main flow. The results were obtained in experimental measurements and numerical calculations. During the investigations rectangular channels with the same width and three different aspect ratios of AR=1:2, AR=1:4 and AR=1:6 were tested. Moreover, the tests were performed for two Reynolds numbers, 63 000 and 120 000. As part of the experimental tests, a number of aerodynamic and heat transfer measurements were performed, i.e: measurement of stagnation parameters at the channel inlet; static pressure measurements along the tested channel; measurements of static and stagnation pressures, velocity at the outlet and measurements of heat transfer by means of TLC method using thermochromatic liquid crystals. It is notable that channel's ribs geometry is identical to solution used in real aero-engine's turbine blade. What is also important, the measurement campaign was conducted on the channels with aspect ratio 1:6, which could be

used in high loaded blades with thickened cross section. Such type of cooling channels are not well represented in the publications.

One of the characteristic feature of flow through the inner blade channel are main longitudinal vortices formed by ribs placed on two opposite walls and local rib vortex structures which flows form rib area toward channel centre along sidewall. The ribs pattern (parallel or crossed) has influence on the sense of rotation of main vortices which can be corotating or counterrotating. Sense of rotation in some cases can influence on the flow losses and heat transfer enhancement.

The results of measurement campaign show that the width of the channel determines main longitudinal vortices dimensions. As the height of the channel increase and the Reynolds number is constant and the main flow velocity decreases as well as the vorticity. In the channel with AR=1:4 one can observe gradually developing of vortices along the channel, where at the outlet plane the main vortices filled almost whole cross section of the channel. One can observe similar structures in AR=1:6 channel. Main vortices have identical height as in AR=1:4 channel and filled almost 2/3 of channel cross section at the outlet. Between vortices one can observe undisturbed longitudinal flow. This channel provides the lowest flow losses and also the heat exchange. The flow pattern slightly differs in the channel with aspect ratio of AR=1:2. One can observe two counterrotating main longitudinal vortices in parallel rib configuration, although their dimension are limited compare to higher channels. In the cross ribs setting, due to the interaction of the corotating main vortices, they finally form one vortex, which fill the whole cross section of the channel. It results in lower flow losses, as well as a slight reduction in heat exchange relative to the parallel setting of the ribs.

Literature survey has shown lack of papers with detailed description and systematic analysis of relation between flow losses, flow structure with heat exchange especially in channels with aspect ratio AR<1:4. Moreover most of the papers have focused on analysis of simplified channel and ribs geometries, but in these investigations ribs geometry is identical to solution used in real aero-engine’s turbine blade.

This work focuses on improving of the part of cooling system of gas turbine blade by means of decreasing flow losses and maintaining similar heat exchange. The main goal was achieved in case of channel AR=1:2, where decreasing of flow losses was obtained in case of crossed ribs pattern. It provided to modify flow structure from two corotating vortices into single vortex. In case of channels with aspect ratio AR=1:4 and AR=1:6 flow structure, flow losses and heat exchange were less influenced by the rib pattern regarding to channel AR=1:2. According to principle of energy conservation, difference in enthalpy in the flow between inlet and outlet should correspond to heat flux and dissipation process (including friction). Therefore without significant changes in flow structure it is difficult to decreases flow losses and improve heat exchange. This work presents new results which develops state of knowledge in the subject of heat exchange and flow losses in internal cooling channels of gas turbine blades.