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Tip leakage aerodynamics over stepped squealer tips in a turbine cascade

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ABSTRACT

Tip gap flow physics and aerodynamic loss generations for two stepped squealer tips of a "Higher Pressure-side rim and Lower Suction-side rim" (HPLS) tip and a "Lower Pressure-side rim and Higher Suction-side rim" (LPHS) tip have been investigated in a turbine cascade. For a fixed tip gap height-to-chord ratio of $h/c = 2.0\%$, oil film flow visualizations are performed on the casing wall as well as on the cavity floor, and three-dimensional flow fields downstream of the cascade are measured with a five-hole probe. For the HPLS tip, the leakage inflow over the pressure-side rim cannot reach the suction-side rim in the upstream region due to the presence of an inlet flow intrusion, and there exists a strong near-wall flow heading toward the trailing edge all over the cavity floor. On the other hand, the LPHS tip has a mid-chord leakage flow penetration into the blade flow passage, and also provides a downstream leakage flow penetration deeper than that for the HPLS tip. Its cavity floor can be divided into a backward flow region and a wide separation bubble. Aerodynamic loss for the HPLS tip, which is nearly identical to that for the cavity squealer tip, is lower than those for the LPHS and plane tips in a considerable degree.

1. Introduction

In a turbine rotor passage, there exists a clearance gap between the stationary casing wall and the tip surface of a rotating turbine blade. Due to the presence of the pressure difference between the pressure and suction sides of the blade, a tip leakage flow from the pressure side to the suction side is inevitably existent through the tip gap. This leakage flow develops into a tip leakage vortex near the blade suction surface, due to the interaction with the blade passage flow, and results not only in an aerodynamic loss generation but also in an additional thermal loading to the near-tip surfaces.

Tip leakage aerodynamics and/or heat transfer over a plane tip have been investigated by many researchers [1–9]. Recently, Lee et al. [10] identified a pair of tip gap vortices in the leading edge region and converging flows toward the mid-chord within the separation bubble over the plane tip surface of a turbine blade. Based on tip surface flow visualizations and heat/mass transfer rate data, they proposed realistic tip gap flow models for tip gap height-to-chord ratios of $h/c = 1.0\%$ and 4.0%.

A cavity squealer tip has a recessed cavity which is surrounded by a full-length squealer. Aerodynamics and/or heat transfer characteristics over the cavity squealer tip are investigated by Ameri et al. [11], Azad et al. [12], Key and Arts [13], Mischo et al. [14], and Lee and Chae [15]. Recent studies by Lee and Kim [16] and Lee and Choi [17] concluded that in comparison with plane tip results, the cavity squealer tip decreases the leakage flow discharge out of the tip gap exit in the region from the mid-chord to the trailing edge, which leads to an aerodynamic loss reduction in the tip leakage vortex region, and it also decreases the leakage flow discharge upstream of the mid-chord, which results in an aerodynamic loss reduction in the adjacent passage vortex region.

Partial squealer tips have a squealer or squealers of different length, coverage, and shape on the tip surface other than the full-length squealer of the cavity squealer tip. There are a lot of studies on aerodynamic and/or thermal performances of turbine blades equipped with various kinds of partial squealers. Heyes et al. [18] studied the effects of using plain tips, suction-side and pressure-side squealer tips, and showed that the squealers are capable of changing leakage flow loss in comparison with the plane tip result. Ameri [19] carried out a numerical study on the heat transfer and flow on the blade tip equipped with a mean camber-line squealer, and showed that the sharp-edge camber-line squealer works better than the radiused-edge tip in reducing tip leakage flow and tip heat transfer. Kwak et al. [20] measured heat transfer coefficients on the squealer tip and near-tip regions of a gas turbine blade with single or double squealer for $h/s = 1.0\%$, 1.5%, and 2.5%. The squealer rims were located at one or two places along the camber line, the pressure side, or the suction side. They found that the suction-side squealer tip provides the lowest heat transfer coefficient compared to the other squealer geometries. Nasir et al. [21] investigated the effects of tip gap and squealer geometry on heat transfer over a high-pressure turbine rotor blade tip in the cases of $h/s = 1.0\%$ and 2.6%. They employed full squealer and four

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