Experimental Thermal and Fluid Science 35 (2011) 1214–1222

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Experimental and numerical investigations of tip injection on tip clearance flow in an axial turbine cascade

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ARTICLE INFO

Article history:
Received 8 August 2010
Received in revised form 16 February 2011
Accepted 18 April 2011
Available online 23 April 2011

Keywords:
Tip injection
Tip clearance flow
Secondary flow
Axial turbine cascade

ABSTRACT

This investigation presents detailed experimental measurements of an active tip-clearance control method based on tip injection in a high-turning axial turbine cascade. Besides that, numerical investigations are also conducted to study phenomena which are not easily measured in the experiments. It aims to study the influence of tip injection on tip clearance flow, with emphasis on the effects of injection locations. Detailed flow field measurements were made downstream of the cascade using a three-hole probe. Static pressure distributions were also measured on the blade surface at 50% and 97.5% span, respectively. The results suggest that tip injection can weaken tip clearance flow, reducing the tip clearance mass flow and its associated losses. Meanwhile, the heat transfer condition on the blade tip surface can be also improved significantly. It also can be found that injection chordwise location plays an important role in the redistribution of secondary flow within the cascade passage. When the same number of injection holes and injection mass flow are applied, holes located in the aft part of blade can perform much better than that in the front part.

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1. Introduction

In axial turbines, a finite clearance is necessary to allow the relative motion between rotor tips and the casing wall. The pressure difference between the pressure surface and the suction surface drives some passage flow to pass through this gap, leading to the development of the tip clearance flow. Many investigations were conducted on the tip clearance flow, which is thought to be detrimental to turbine performance. The work output of the rotor decreases because the leakage flow passes through the tip clearance without being properly turned and expanded. Moreover, tip clearance flow emerges from the tip gap at an incidence to the passage flow, acting as an obstruction and leading to loss generation within the rotor passage. Schaub et al. [1] stated that the tip clearance flow should account for about 45% of the losses in the rotor and 30% of the total losses in the stage in a typical high pressure turbine. Moreover, flow separation and reattachment on the blade tip surface cause higher heat load to the tip region. Metzger and Rued [2] observed that tip clearance flow generated increases of about 200% in the heat transfer near the tip clearance.

Thus, there is a strong motivation to look for other means to minimize the influence of tip clearance flow. The most main method is to modify the blade tip geometry, including winglet [3,4], squealer rims [5,6], tip surface chamfering [7], blade bowing [8,9] and casing treatment [10,11]. By applying these methods, turbine performance and the heat transfer condition around the tip regions can be improved significantly. However, Rao [10] stated that only the double squealer tip could find actual applications in service.

Another potential approach of increasing aerodynamic performance and reducing the heat transfer level around the blade tip regions is to inject cooling air from the blade tip surface. Pouagare et al. [12] experimentally investigated the influence of tip injection, and demonstrated the potential effects of tip injection on reducing losses associated with tip clearance flow. Hohlfeld et al. [13], Couch et al. [14] conducted experimental and computational works on cooling from dirt purge holes. They stated that the obstruction effect by tip injection performed quite well for a small tip clearance, but was not effective for a larger tip gap. Christophel et al. [15] found that for a smaller tip clearance case, significant cooling benefits could be obtained from cooling injection from dirt purge holes. Hamik and Willinger [16] connected the blade leading edge and the blade tip surface using an internal channel, therefore a small part of passage flow was injected from the blade tip surface forced by the pressure difference. He found that tip injection could reduce flow over-under-turning near the casing wall and the losses due to the tip clearance vortex. Li [17] carried out a numerical simulation of the effects of tip injection. He concluded that the reduction of the tip clearance loss could be attributed to three factors: the blockage effects; weaker mixing process between the tip

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0894-1777/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.expthermflusci.2011.04.009