International Journal of Heat and Fluid Flow 77 (2019) 157–170

Contents lists available at ScienceDirect

International Journal of Heat and Fluid Flow

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

Effect of a casing fence on the tip-leakage flow of an axial flow fan

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ARTICLE INFO

Keywords:
Axial flow fan
Casing fence
Tip-leakage flow
Tip-leakage vortex
Large eddy simulation

ABSTRACT

The effect of a casing fence on the tip-leakage flow of an axial flow fan is investigated using large eddy simulation. A fence is attached on the shroud near the trailing edge of an axial flow fan used in an outdoor unit of air conditioner. The Reynolds number is 547,000 based on the blade tip radius and tip velocity. At the design condition, the fan efficiency is increased by the casing fence. The roles of the fence are to block backward leakage flows near the shroud and to weaken the movement of the tip-leakage vortex (TLV) in the azimuthal direction. Also, the fence reduces the double-leakage tip-clearance flow generated at the aft part of the blade tip due to the TLV-blade interaction, reducing the strength of the tip-separation vortex. Consequently, the tip leakage and total pressure losses are reduced, and the efficiency is increased. The pressure fluctuations on the aft part of the blade tip of the pressure surface caused by the TLV-blade interaction are also significantly reduced by the fence, indicating reduction of the noise source. According to the interaction between the fence and backward leakage flow induced by the TLV, the fence significantly and slightly increases the aerodynamic performances at the design and peak efficiency conditions, respectively, but reduces them at an overflow condition.

1. Introduction

An axial flow fan that produces small pressure rise and large flow rate in the axial direction is one of the most widely used axial turbomachines for cooling and ventilation in various engineering applications. Because of the environmental regulation of fan efficiency and noise, the analysis and control of the flow across the fan become more and more important. In axial turbomachines including the fan, the tip-leakage flow (TLF) is inevitable due to the tip clearance for its operation. It is driven by the pressure difference between the pressure and suction sides of the blade tip. The leakage flow collides with the incoming main flow and turns radially inward to form a tip-leakage vortex (TLV). Also, when the blade loading is high (Sirakov and Tan, 2003) or the tip clearance is large (Berdanier and Key, 2016; Hah, 2017), a double-leakage tip clearance flow (Khalid et al., 1999), a leakage flow migrated from the previous blade penetrating into the tip clearance of the next blade, is generated. In addition, the separated flow from the tip clearance near the trailing edge generates small-scale vortices corresponding to tip-separation vortices (TSVs) (You et al., 2007a, 2007b; Zhu and Carolus, 2018). This and associated flow phenomena in the blade tip region cause several detrimental effects on the machine performance: blockage to the through flow of the passage (Khalid et al., 1999), efficiency loss (Denton, 1993), mixing loss (Li and Cumpsty, 1991a, 1991b; Hah, 2017), onset of the stall (Tan et al., 2010), and noise emission (Kamier and Neise, 1997; Jang et al., 2003; Fukano and Jang, 2004; Pardowitz et al., 2013; Boudet et al., 2015; Pogorelov et al., 2015; Moreau and Sanjosé, 2016; Zhu et al., 2018).

Therefore, to improve the machine performance, it is necessary to control the leakage flow and related vortical structures in the blade tip region. Blade-tip modification and casing treatment applied to the blade tip and shroud of the axial turbomachines, respectively, have been proposed. For the blade-tip modification, a winglet, which is also called as an end plate, has been commonly used and employed on the pressure (Corsini et al., 2007; Aktürk and Camci, 2010), suction (Yen and Lin, 2005), or both (Wadia, 1983) sides. However, since the effectiveness of the winglet depends on the type and operating condition of the machine, its application is not so straightforward. The casing treatment (Moore et al., 1971; Osborn et al., 1971; Corsini et al., 2014) is an application of circumferentially continuous grooves, discrete slots and stabilization rings on the shroud. The grooves, slots and rings typically manipulate the TLF near the tip and weaken the TLV, resulting in stall margin improvements with efficiency penalties.

In the axial flow fan used for cooling and ventilation, the geometry of the shroud surrounding the fan blade has been also modified. Longhouse (1978) reduced the tip clearance noise by attaching a rotating shroud to the blade tip. Shimada et al. (2003) applied a labyrinth

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https://doi.org/10.1016/j.ijheatfluidflow.2019.04.005
Received 20 June 2018; Received in revised form 17 March 2019; Accepted 3 April 2019
Available online 09 April 2019