Active control of the leakage flow by air injection into the rotational shroud or the fixed carter of an axial fan composed of hollow blades

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Abstract :

In axial fan, the static pressure difference between the suction and the pressure side of the impeller produces a leakage flow through the blade and the casing. This secondary flow occurs in the opposite direction of the working flow and has a negative impact on the overall performances. It tends to reduce the pressure coefficient, the efficiency and the fan operating range while increasing the noise level. That is why many studies dealt with ways to reduce this leakage flow. In this paper, the study focusses on the control of the secondary flow by air injection. Two ways to control this flow are compared. In a first case, the air is ejected from the fixed casing and in a second case the air exit from the rotating shrouds. In both configurations, the ejected air has a direction to counter the leakage flow. To realize the second configuration, a new method to build fan with hollow blades was developed. This new kind of fan allows having internal flows which could exit by any area of the fan. The results obtained by the active controls on the fan characteristic and the efficiency are presented in this article.

Keywords : active control ; air injection ; leakage flow ; axial fan ; hollow blades.

1 Introduction

In recent years, more and more investigations on turbomachinery deal with the control by tip injection. In fact, this type control could improve different aspects of the device which could not be enhanced by the geometry. By using injection upstream of the rotor, Weigl et al. [1] succeeded to stabilize rotating stall and surge in a transonic compressor which provided an enlargement of the operating range. Rhee et al. [2] increased the lift of a hydrofoil by injection control. Eberlinc et al. [3, 4, 5] experimentally rose of approximatively 6% the pressure of an axial fan composed of hollow blades. This gain was due to a free jet at the trailing edge of the blades. In fact, the free jet increased the velocity and consequently reduced the adverse pressure gradient in the boundary layer. Wang and Zhao [6] experimentally and numerically investigated a transonic turbine cascade with different trailing edge ejection. As Eberlinc et al., the authors successfully reduced the vortex at the trailing edge of the blades.
This paper focuses on the injection used to reduce the phenomenon of leakage flow occurring at the blade

tip. This flow driven by the pressure difference between the pressure side and suction side is responsible for important energy dissipations.That is why many authors have sought to reduce this phenomenon. Neuhaus and Neise [7] attempted to reduce the leakage flow of an axial fan by applying active flow control in the tip region of the impeller. They injected air in the opposite direction of the flow by slit nozzles flush mounted in the inner casing wall. By this process, the authors succeeded to shift the stall point towards lower flow rates and to enlarge by 62% the usable range of the fan characteristic. They also increased the pressure of 28% and the efficiency by about 10%. Hamik and Willinger [8] analytically and numerically investigated the concept patented by Auxier [9] in 1995. The idea is to connect the blade leading edge to the blade tip by an internal channel. Due to the pressure difference, a jet is injected to the tip gap and blocks the leakage flow. With an injection mass flow rate of 0.5% of the mass flow, they predicted a performance improvement which is independent of the tip gap width. Hu et al. [10] applied the concept proposed by Auxier to an axial fan and experimentally investigated the interaction between the tip leakage flow and the tip injection flow by a 2D-PIV. As expected, the authors observed a reduction of the leakage flow. However, the tip injection generated a flow phenomenon similar to Karman vortex street in the wake which exacerbate the complexity and non-stationarity of the flow.
In this study, active control by air injection in the tip clearance gap of an axial fan is experimentally investigated. A new methodology was developed to build hollow fan in which an internal flow could occur. The internal flow, generated by the compressed air system of the laboratory, exited the fan at the tip clearance in purpose to reduce the leakage flow. The results of this control by air injection are presented in this paper.

2 Experimental setup

The fan (figure 1a) used in this study was developed for automotive engine cooling system application [11]. The fan has six blades with a hub-to-tip radius ratio ($R_{\text{int}}/R_{\text{max}}$) equal to 0.337 and a the tip radius (R_{max}) equal to 179 mm. It has the particularity to be built in polyethylene by a rotomolding process in order to make it hollow. This characteristic allows a fluid circulation into the fan. With internal flows into the fan different applications could be developed. The authors thought to use a heat-transfer fluid into the fan so that the fan could also operate as a heat exchanger. The authors also planned to study the impact of air ejected from the trailing edges. According to Eberlinc et al. [3], ejected air from the trailing edges increases locally the velocity flow and tends to reduce the boundary layer stalls. In addition to flow ejection, the authors have also planned to experiment suction flows for fan control. In this study, air is injected into the fan and exits at the shroud of the fan. The shroud is composed 8 holes of 4mm regularly spaced on the circumference. The holes are oriented in the direction $(r, \theta, z) = (1, -1, 1)$ in order to counter the leakage flow. The directions have a component in θ to compensate the fan rotation.

The leakage flow control is also realized by ejecting air from the fixed casing (figure 1b). To compare the better method to control this phenomenon between air injection into the rotational shroud and the fixed casing, the injection holes was realized in the same configuration as for the shroud : 8 holes of 4mm regularly spaced. Yet as the casing does not rotate, the holes have all the direction $(r, \theta, z) = (-1, 0, 1)$. To not damage the fan, the casing was made of rigid foam.

To supply air to the fan and the casing, the compressed air system of the laboratory is used. A flowmeter and a valve are installed upstream the fan and the casing in order to control the injection. A specific drive system showed on figure 2 was built to connect the compressed air system to the hollow fan. The drive

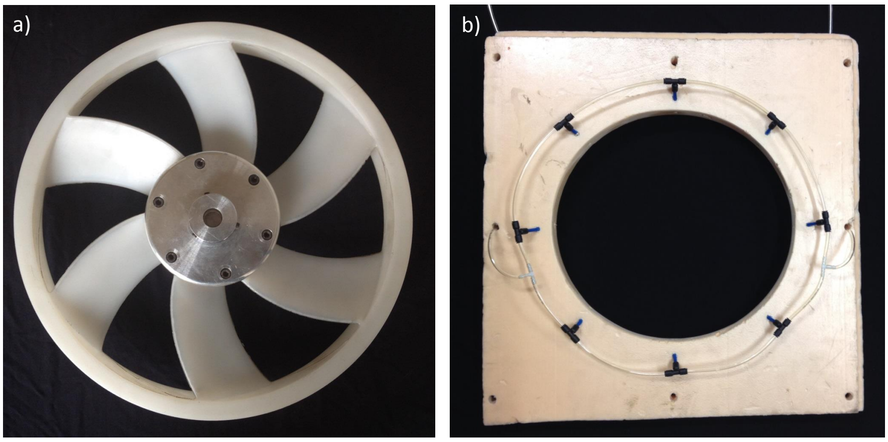

FIGURE 1 – The hollow fan (a) and the casing (b)

system has two functions. It transmits the rotation from the motor to the fan and allows the injection from the compressed air system into the fan. To fulfill its functions, the drive system is composed of two shafts connected through a pulley and belt system. The first shaft connects a 4kW motor to the pulley and belt system. On this shaft a HBM strain gauge transducer is installed. It measures the torque with an uncertainty corresponding to 0.1% of the full scale. In this case the full scale is equal to 1N.m. The second shaft connects the pulley and belt system to the fan. It also connects the compressed air system to the fan. This connection is possible because the shaft has the particularity to be hollow. The fan angular velocity is measured with a tachymeter of relative precision $\pm 0.2\%$. The power absorbed on the fan shaft is then estimated through the product $C\omega$. To determine the global performances of the fan, an air suction test bench was used. This experimental facility was designed and built at the laboratory according to the ISO 5801 standard [10]. The air flow rate is set and measured according to the ISO-5167 norm [11] by setting the hydraulic impedance of the bench through diaphragms of various sizes. The elevation pressures are measured with an absolute precision of ± 0.1 Pa.

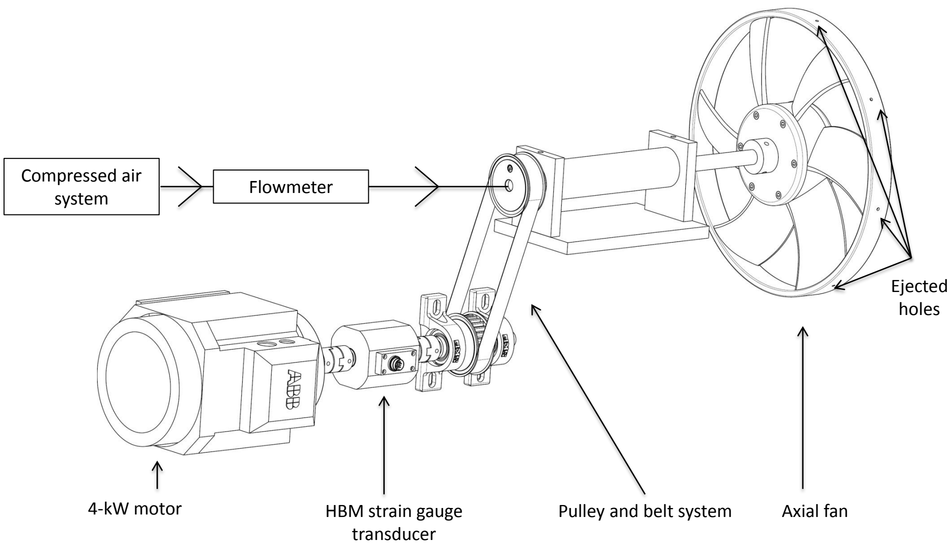

FIGURE 2 – The fan drive system

3 Results

Only the aerodynamic characteristic is represented in this extended abstract. The figure 3 shows the results obtained at three rotation speeds 1020, 1560, 2000 rpm for two configurations with and without air injection into the fan. The injection control was realized with an internal flow equal to 13.3% of the external volume flow. Each curve is the result of five measurement points. The air injection induced an increase in pressure difference regardless of the rotation speed. As the injection was realized in the purpose of controlling the leakage flow, the pressure increase is assumed to be a consequence of the secondary flow reduction. For $\phi = 0.065$, the increase varies from 18% to 25% depending of the rotation speed, whereas at higher flow rate of about 0.1, it varies from 41% to 98%. These results could be explained by a better control of the leakage flow at $\phi = 0.065$ than at 0.1 as this phenomenon intensifies at higher flow rate [7].

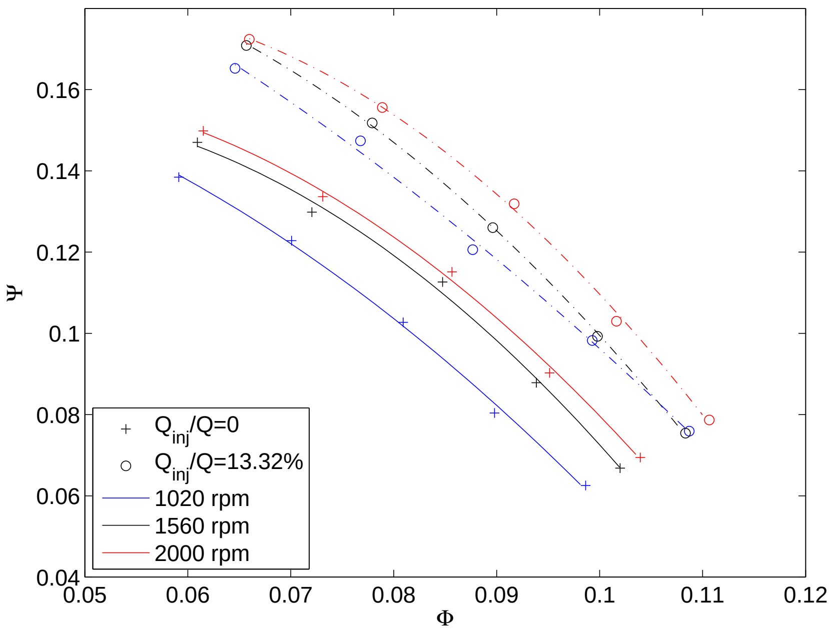

FIGURE 3 – Comparison of aerodynamic characteristic of the axial fan for the case with and without internal flow and for 3 rotation speeds : 1020, 1560 and 2000 rpm

Références

[1] H. J. Weigl, J. Paduano, L. Frechette, A. Epstein, E. Greitzer, M. Bright, and A. Strazisar, "Active stabilization of rotating stall and surge in a transonic single stage axial compressor," in *ASME 1997 International Gas Turbine and Aeroengine Congress and Exhibition*, pp. 1–15, American Society of Mechanical Engineers, 1997.

[2] S. Rhee, S.-E. Kim, H. Ahn, J. Oh, and H. Kim, "Analysis of a jet-controlled high-lift hydrofoil with a flap," *Ocean engineering*, vol. 30, no. 16, pp. 2117–2136, 2003.

[3] M. Eberlinc, B. Širok, and M. Hočevar, "Experimental investigation of the interaction of two flows on the axial fan hollow blades by flow visualization and hot-wire anemometry," *Experimental thermal and fluid science*, vol. 33, no. 5, pp. 929–937, 2009.

[4] M. Eberlinc, B. Širok, M. Dular, and M. Hočevar, "Modification of axial fan flow by trailing edge self-induced blowing," *Journal of Fluids Engineering*, vol. 131, no. 11, p. 111104, 2009.

[5] M. Eberlinc, B. Širok, M. Hočevar, and M. Dular, "Numerical and experimental investigation of axial fan with trailing edge self-induced blowing," *Forschung im Ingenieurwesen*, vol. 73, no. 3, pp. 129–138, 2009.

[6] Y. Wang and L. Zhao, "Investigation on the effect of trailing edge ejection on a turbine cascade," *Applied Mathematical Modelling*, vol. 37, no. 9, pp. 6254–6265, 2013.

[7] L. Neuhaus and W. Neise, "Active control to improve the aerodynamic performance and reduce the tip clearance noise of axial turbomachines with steady air injection into the tip clearance gap," in *Active Flow Control*, pp. 293–306, Springer, 2007.

[8] M. Hamik and R. Willinger, "An innovative passive tip-leakage control method for axial turbines : Basic concept and performance potential," *Journal of Thermal Science*, vol. 16, no. 3, pp. 215–222, 2007.

[9] T. Auxier, "Aerodynamic tip sealing for rotor blades," 1995, No. 5.403.158.

[10] J. Hu, X. Kong, Z. Li, Y. Zhang, and J. Xu, "Experimental investigation of aerodynamic interaction between tip leakage flow and spontaneous tip injection flow using 2d-piv," *Experimental Thermal and Fluid Science*, vol. 54, pp. 127–135, 2014.

[11] C. Sarraf, H. Nouri, F. Ravelet, and F. Bakir, "Experimental study of blade thickness effects on the overall and local performances of a controlled vortex designed axial-flow fan," *Experimental Thermal and Fluid Science*, vol. 35, no. 4, pp. 684–693, 2011.