Journal of Sound and Vibration 433 (2018) 99–123

Contents lists available at ScienceDirect

Journal of Sound and Vibration

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

Effect of rotor deformation and blade loading on the leakage noise in low-speed axial fans

Edward Canepa [a], Andrea Cattanei [a], Francesco Jafelice [a], Fabio Mazzocut Zecchin [a, *], Davide Parodi [b]

[a] DIME-Università di Genova, via Montallegro, 1, I-16145 Genova, Italy
[b] Johnson Electric Asti srl, Corso Alessandria, 395, I-14100 Asti, Italy

A R T I C L E I N F O

Article history:
Received 23 December 2017
Received in revised form 20 June 2018
Accepted 4 July 2018

Handling Editor: L. Huang

Keywords:
Axial-flow fan
Rotating shroud
Leakage flow noise
Turbulence reingestion
POD
PIV

A B S T R A C T

The noise generated by the leakage flow in rotors provided with rotating shroud has been experimentally studied by means of acoustic measurements in an anechoic chamber and the basic features of the noise generating mechanism have been identified by means of LDV and PIV aerodynamic measurements.
The acoustic tests, performed at constant rotational speed and during speed ramps, have shown a combined dependence of the received SPL spectra on the rotor axial position, on the rotational speed, and on the operating point. It has been shown that the confinement of the recirculating flow may result in a stronger noise, that the acoustic similarity is often not respected by the leakage noise, and that, in a number of situation, the pattern of the SPL spectrum has a sudden change as the rotational speed or the pressure coefficient exceed a certain value.
The aerodynamic measurements have confirmed that the flow structures spouted from the gap have a non-periodic component and that, basically, two flow patterns exist which correspond to the two kinds of SPL spectra: a recirculation bubble anchored to the rotor shroud or a large recirculation zone. The former corresponds to a higher SPL than the latter, and the reason for this is that if the recirculation bubble is attached, a weaker mixing of the recirculating flow takes place. The suddenness in the SPL spectra transition is likely caused by an analogous flow pattern modification.
Rotational speed and pressure rise may act on both the momentum of the recirculating flow and the change in shape of the gap geometry due to the rotor deformation. Possibly, the rotational speed acts on the Reynolds number of the gap flow, but it has not been possible to identify such an effect.

1. Introduction

The axial fans employed in automotive cooling systems are commonly provided with a rotating shroud, i.e. a ring connecting the blade tips which improves the volumetric efficiency and also strengthens the whole assembly. This also eases the adoption of strongly swept blades, which constitute a quite effective solution when noise reduction is pursued. Beyond the

* Corresponding author.
E-mail address: Fabio.MazzocutZecchin@unige.it (F. Mazzocut Zecchin).

https://doi.org/10.1016/j.jsv.2018.07.005

Nomenclature

a_0	speed of sound
f	frequency
$F(St,\psi)$	source spectral distribution function
G(f)	propagation function
g_{ax}, g_{rad}	axial and radial gaps
k	kinetic energy
N_{rec}	number of data records employed in the PSD computation
OASPL	overall SPL, ref. 20 μPa
p	acoustic pressure
p_{ref}	reference acoustic pressure, 20 μPa
Q	volume flow rate
r	radial coordinate
R_{tip}	rotor tip radius
Re_g	Reynolds number based on gap size
S_{pp}	one-sided auto power spectral density of p
SPL	sound pressure level spectrum, ref. 20 μPa
St	Strouhal number based on the rotational frequency, $= 60f/\Omega$
Tu	turbulence intensity based on u_{tip}
Tu_{bulk}	turbulence intensity based on v_{bulk}
u_{tip}	peripheral speed at the blade speed
v_{bulk}	reference velocity based on Q
v_x, v_r, v_ϑ	components of the absolute velocity
$\mathbf{v}_{mer}$	$_{mer}$velocity vector projected on the meridional plane
x	position of the rotor ring, axial coordinate (referred to the mounting panel)
x_0	reference position of the rotor ring
z_R	rotor blade number
α	Mach number scaling exponent
Δf	Bandwidth
Δp	static pressure rise
Δx	axial displacement of the rotor
ϑ	tangential (azimuthal) coordinate
$\lambda^{(l)}$	eigenvalue associated to the l-th POD mode
$\varphi_{v'}^{(l)}(x,r)$	l-th POD mode of v'
$\varphi_k^{(l)}(x,r)$	l-th POD mode of k
φ	flow coefficient
$\chi^{(l)}$	eigenvector associated to the l-th POD mode
ψ	pressure coefficient
ω_ϑ	instantaneous ϑ-component of the vorticity vector
Ω	rotational speed (expressed in rev/min)

Superscripts

$\sim$	related to ensemble average
$-$	related to time average
$'$	related to non-periodic instantaneous fluctuation

Subscripts

assigned	employed in the spectral decomposition
filt	related to the filtered SPL, Eq. (4)
hub	related to the rotor hub
scaled	related to the scaled SPL, Eq. (5)
step	related to the step in the SPL spectra

Acronyms

BPF	$= z_R\Omega/60$, blade passing frequency
DP	related to design point conditions
FD	related to free-discharge conditions