Aerospace Science and Technology 60 (2017) 68–83

Contents lists available at ScienceDirect

Aerospace Science and Technology

www.elsevier.com/locate/aescte

On the aero acoustic and internal flows structure in a centrifugal compressor with hub side cavity operating at off design condition

Ibrahim Shahin [a,*], Mohamed Alqaradawi [b], Mohamed Gadala [c], Osama Badr [d]

[a] Mechanical Engineering Department, Shoubra Faculty of Engineering, Benha University, Egypt
[b] Mechanical and Industrial Engineering Department, Collage of Engineering, Qatar University, Doha (2713), Qatar
[c] Mechanical Engineering Department, UBC-University of British Columbia, Vancouver, BC, Canada
[d] Mechanical Engineering Department, the French University in Egypt, Al-Shorouk City, New Cairo, Egypt

ARTICLE INFO

Article history:
Received 11 May 2016
Received in revised form 9 October 2016
Accepted 28 October 2016
Available online 11 November 2016

Keywords:
Aero-acoustic
LES
Centrifugal compressor
Hub side cavity and surge

ABSTRACT

This paper covers the characterization of the acoustic noise and the unsteady flow field of a high speed centrifugal compressor NASA CC3. In order to accurately predict the noise, all analyses are carried out through the use of Large Eddy Simulation and Ffowcs Williams–Hawkings model for noise prediction. The relative effect of hub cavity on flow characteristics and sound levels is investigated, for a compressor stage with a total pressure ratio equal to 4, working from surge to near choke condition. In comparison with the experimental results from literature, the predicted compressor performance and flow field are predicted well, some trends seen in experiments are captured. The hub cavity flow effect on the compressor aero acoustic generated noise is shown in the paper. The unsteady static pressure and sound pressure levels are compared not only at different location but also for design and off design operating points. The internal flow results inside the hub cavity are presented at surge, design and near choke points. The conclusion is that the cavity effect of the centrifugal compressor cannot be ignored in the numerical prediction of aerodynamic generated noise. The impeller back plate of the rotor experiences a strong pressure fluctuation, which is maxima at the impeller outer radius for all operating point, but higher pressure values at the surge point.

© 2016 Elsevier Masson SAS. All rights reserved.

1. Introduction

The aero-acoustic analysis of turbo machines has become urgent not only due to demands requirements for environment-friendly products [1] but also to prevent compressors from mechanical failure [2]. If acoustics resonances occur within centrifugal compressor, the pressure fluctuations may reach high values which results in high cyclic fatigue. Even though compressor parts are designed for high cycle fatigue; this would jeopardize the safe operation of the compressor and the facility. Due to the progress in aero-acoustic computational methods, however, the aerodynamic/acoustic optimum design of the centrifugal compressor parts has become available. Rotating stall is an unsteady flow phenomenon in which one or more “stall cells” travel around the compressor annulus in the direction of rotation of the compressor, with a rotational speed which may reach 50% of the compressor rotational speed. Rotating stall results in a noticed vibratory stresses in the compressor rotating parts, which is unfavorable for structural issues, although the compressor may continue to give suitable performance [3]. Surge consists of large-amplitude oscillations of the flow through the entire compressor which also produces large oscillations in compressor delivery pressure [4].

The unsteady flow in centrifugal compressor has been studied by many researchers, and the unsteady flow phenomena such as stall and surge are also investigated. Mckain and Holbrook introduced the detailed design for a single stage centrifugal compressor with pressure ratio equal to 4 [5]. The data published by Skoch et al. [6] included experimental results for the internal flow velocities measured by Laser-Doppler Anemometer in the impeller of a centrifugal compressor. The results indicated that the tip clearance flow is the main source of through-flow velocity deficit in the impeller region. Wernet et al. [7] presented experimental measurements with pressure transducer, to indicate the unsteady behavior of the pressure inside centrifugal compressor just the inception of rotating stall. To capture the instantaneous velocity and pressure data during surge event, The Digital Particle Image Velocimetry was used in the vanned diffuser area. The measurements helped in understanding the stall and surge initiation in centrifugal compressor. Also, it has been used for optimizing active surge control

* Corresponding author.
E-mail addresses: Ibrahim.shahin@feng.bu.edu.eg (I. Shahin), myq@qu.edu.qa (M. Alqaradawi), gadala@mail.ubc.ca (M. Gadala), Osamaabadr@outlook.com (O. Badr).

http://dx.doi.org/10.1016/j.ast.2016.10.031
1270-9638/© 2016 Elsevier Masson SAS. All rights reserved.

Nomenclature

U_2	Impeller tip speed	m/s
r	Radius	mm
R_2	Impeller outer diameter	
ρ	Fluid density	kg/m^3
u	Flow velocity vector	
u_i	Fluid velocity component in the x_i direction	
u_n	Fluid velocity component normal to the surface	
v_i	Surface velocity component in the x_i direction	
v_n	Surface velocity component normal to the surface	
$\delta(f)$	Dirac delta function	
$H(f)$	Heaviside function	
p'	Sound pressure at the far field	
T_{ij}	Lighthill stress tensor	
P_{ij}	Compressive stress tensor	
u_g	Mesh velocity of the moving mesh	
k	The von Karman constant	
L_S	The mixing length for sub grid scales	
$\bar{S}_{ij}$	The rate of strain tensor for the resolved scales	
d	The distance to the closest wall	
C_s	The Smagorinsky constant	
Δ	The local grid scale	
T	Diffusion coefficient	
ϕ	General scalar	
S_ϕ	The source term of ϕ	

Abbreviations

CFD	Computational fluid dynamics
MBPF	Main blade passing frequency
NASA	National Aeronautics and Space Administration
RMS	Root Mean Square
SBPF	Splitter blade passing frequency
SPL	Sound pressure level

techniques. In fact, reviewing existing studies on aero-acoustic interaction indicates that centrifugal compressors have received less care than their axial compressor counterparts and especially in the unsteady aerodynamics flow. Interference generated in axial compressors has received much attention, due to the strict patterns in the aero-engine industry because of its aeronautical use and public demand for aircraft with lower noise [8,9]. Hanson [10] showed that under certain inlet and exit conditions, an acoustic mode could get trapped between blade rows leading to amplification and higher frequency propagation. Mengle [11] analyzed the physical aspects of spinning acoustic modes produced by blade vibration. Besides, the theoretical development is conducted to understand and anticipate the frequency spectra observed in the stationary and rotating reference frames.

Recently Semlitsch and Mihăescu [12] studied numerically the flow inside a ported shroud centrifugal compressor at stable and surge conditions. Unsteady three dimensional flow simulation was conducted with Large eddy simulation. The unsteady flow phenomena has been investigated in details by using the modal decomposition techniques. The flow structure has been analyzed in details during the surge event. Sundström et al. [13] performed a numerical study to predict the internal flow and aero-acoustic noise from a centrifugal compressor operate at stable and unstable flow rates. The noise generation mechanisms are identified in terms of noise directivity maps and sound pressure level spectra.

Raitor and Neise [14] measured aero acoustic performance and investigated the sources and mechanisms of sound generation of the spectral components governing the overall noise level of centrifugal compressors. The aero-acoustic noise sources in a centrifugal compressor are well described at low operating speed. Radial compressor noise is dominated by blade tone noise components, buzz-saw noise components and tip clearance noise (TCN) components. A blade tone noise component is generated from the rotor shaft speed harmonics and it is noticed at the BPF (blade passing frequency) and its harmonics. Buzz-saw tones are also a common noise component that characterizes compressors operating with supersonic fan tip speeds, these components are known to generate a tonal sound spectrum spread over a range of harmonics of the engine shaft rotation frequency. TCN is a narrow-band noise observed at frequencies about half the blade passing frequency (BPF).

A small number of experimental and numerical studies have been conducted on aero acoustic excitation sources in centrifugal compressor stages commonly which are applicable in the gas industry. Recently, Konig et al. [15] studied experimentally a shrouded impeller under high cycle fatigue. Two dimensional impeller with a vanned diffuser and a three dimensional impeller with a vanless diffuser were investigated. The authors described how to make coupling between the impeller vibration mode, a Tyler–Sofrin excitation resulting from RSI, and side cavities acoustic modes. The CFD results show that Tyler–Sofrin type acoustic modes can generate stronger forcing on the impeller external diameter than the vaned diffuser potential field. Turbocharger centrifugal compressor with ported shroud has been studied by Guillou et al. [16]. Flow recirculation has been investigated experimentally to reduce the instability in the flow and increasing the surge margin of centrifugal compressor. Particle image velocimetry (PIV) and dynamic pressure transducers have been used to measure the flow properties at stable and unstable operating point. The results indicated that flow recirculation improve the stability of the compressor, as it removes the reversed floe from the impeller blade tip.

Petry et al. [17,18] conducted experimental study with unsteady pressure instrumentation. Acoustic resonances in the side cavities of the centrifugal compressor stage have been characterized. The results showed that a cavity acoustic mode is excited when the Tyler–Sofrin mode and the cavity Eigen-mode have the same frequency and circumferential harmonics. Richards et al. [19] conducted experimental and unsteady CFD investigation for complex aero-acoustic interaction between the impeller and the upstream and downstream return channel vanes. However, the CFD study of Richards et al. [19] conducted only on blade row interactions and not including the hub and shroud cavities acoustic. Comprehensive descriptions and investigations of the flow between rotating and stationary discs, can be found in the work of Tuliszka-Sznitko [20,21], Gauthier et al. [22], Pellé [23] and Serre [24], but most of these studies neglected the complicated flow out from the impeller region and the unsteady flow during the surge event. Medic et al. [25] performed a numerical study using Large-eddy simulation (LES) with wall-adapting local eddy-viscosity (WALE) sub grid scale model to explain the complex turbulent flow in NACA CC3 centrifugal impeller, but the inlet and diffuser parts were neglected in this study and no validation with experiments has been conducted to ensure the accuracy of numerical solution. Comparison has been conducted between the results obtained with LES, Reynolds Averaged Navier–Stokes (RANS) turbulence models and hybrid RANS/LES approaches.

In this paper, the objectives from the present work are described in section 2. The compressor configuration and tested cases are described in section 3. In Section 4, the mathematical model

Download English Version:

https://daneshyari.com/en/article/5472697

Download Persian Version:

https://daneshyari.com/article/5472697

Daneshyari.com