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Estimation of the Aerodynamic Force Induced by Vaneless Diffuser Rotating Stall in Centrifugal Compressor Stages

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Abstract

Rotating stall in centrifugal compressors not only adversely affects the performance before surge, but also can generate high subsynchronous vibrations, marking the minimum flow limit of a machine. Recent works presented an experimental approach to estimate the stall force induced by the unbalanced pressure field in a vaneless diffuser using dynamic pressure measurements. In this study, the results of a 3D-unsteady simulation of a radial stage model were used to estimate the stall force and to compare it with the approximation obtained with an "experimental-like" approach. Results showed that: *a)* the experimental approach, using an ensemble average approach for transposing data between time and space domains provides sufficiently accurate results; *b)* the momentum contribution, neglected in experiments, gives negligible contribution to the final intensity of the stall force.

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Keywords: centrifugal compressor; CFD; rotating stall; experimental analysis; stall force

1. Introduction

Centrifugal compressors play a fundamental role in the present world energy scenario, particularly for oil & gas industries [1]. Due to the huge amount of power associated to their industrial applications, even small efficiency

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and/or rangeability increases would in fact provide significant energy and money savings. In view of an extension of the minimum flow limit, in particular, manufacturers pay much interest to an inner comprehension of the aerodynamic phenomena which precede the surge, with particular focus on rotating stall (e.g. [2-9]). Recent studies in fact showed that a proper estimation of the aerodynamic forces generated during rotating stall conditions [10], and a consequent revised design of the stages [11], could provide notable increases of expected rangeability.

Nomenclature

b	diffuser width	[m]
f	mass forces	[N]
F	force	[N]
n	versor normal to surface	
p	pressure	[Pa]
S	surface of the control volume	
t	time	[s]
T	revolution period	[s]
u	flow velocity	[m/s]
V	control volume	
y^+	dimensionless wall distance	[-]
Greek letters		
θ	azimuthal angle	[deg]
ρ	air density	[kg/Nm^3]
τ	work coefficient	[-]
τ_w	viscous stresses	[N]
ϕ	flow coefficient	[-]
ω	pulsation	[rad/s]
Superscripts		
*	dimensionless value	
Subscripts		
e	external	
m	momentum	
p	pressure	
r	radial	
stall	value at stall	

1.1. Experimental approach to stall force estimation

The evaluation of the destabilizing force generated by the unbalanced flow field during rotating stall is not easy in real compressors, since the use of laboratory-like measurement system is very often not allowed by mechanical constraints or reliability issues. Some of the authors have assessed in the last few years a systematic approach for determining the stall force in vaneless diffuser rotating stall making use of a limited number of dynamic pressure sensors positioned at the diffuser's inlet [10,12]. The approach is based on at least two sensors inserted at given azimuthal positions within the diffuser, whose signals in time are manipulated with an ensemble average approach clocked at the subsynchronous revolution frequency of the stall. This frequency is identified by the autocorrelation function of one of the signals, while the cross-correlation function is used to define the phase shift between the signals at that frequency and then calculate the number of lobes of the stall pattern, cross-checking the proper selection of the stall frequency [10,12]. The method has been validated against experimental data [10-11], obtaining a satisfactory agreement. As discussed by the authors themselves, however, some important assumptions are needed in applying the methodology. First, the pressure pattern induced by the stall is assumed to be stable during its rotation [13]; by doing so, pressure data acquired can be transposed from the time domain to the space domain.