Contribution to the Numerical Simulation of Rotating Flow Pattern in an Annular Compressor Cascade Test Rig

Dipl.-Ing. Matthias Teich, Department of Thermal Power Engineering, Section of Turbomachinery, University of Kassel, Germany

Univ.-Prof. Dr.-Ing. Martin Lawerenz, Department of Thermal Power Engineering, Section of Turbomachinery, University of Kassel, Germany

Long Abstract

Introduction

The basic objectives of developing modern turbo compressors are high efficiency, low costs and a stable and safe operating range. These requirements are connected with highly mechanically and aerodynamically stressed blades. Thereby the flow is dominated by complex three-dimensional, unsteady processes, which among other things are mainly caused by relative motion and boundary layer interaction between blade and side-wall. These so called secondary flows have a significant impact on the stability limit and the operating range. A deeper understanding is the objective of many experimental and theoretical investigations. For instance, these secondary flows cause blade vibrations [1], which can damage single components or, even worse, lead to a fatal failure of the whole machine. Inlet disturbance, acceleration or fouling may lead to a shift of the operating point towards the surge line. For this reason a safety margin is required.

Well known flow phenomena which are associated with approaching or crossing the surge line are rotating stall or surge. In addition to these effects, there is a rotating flow pattern at stable operating condition previous to rotating stall, which is called rotating instability (RI) [2, 3, 4]. The rotating instability can be described as a self-induced rotating flow phenomenon at high incidence, which rotates in circumferential direction and has a characteristic signature in the frequency spectrum. It is suggested that the rotating instability is linked with the spike initiated rotating stall [5] and could be used as a preliminary indicator.

Taking into consideration this background a deeper understanding of flow instabilities, already at a stable operating point and the transition to rotating stall, is the focus of the present paper. With the help of specific knowledge of the mechanisms and causal interactions it is possible to predict the appearance and to initiate counteractions, which contribute to a reduction of surge or stall risk and to a safer operation of compressors.

1. Methods

In order to enhance the knowledge about the origin and the development of such phenomena, three-dimensional unsteady computations of a stator cascade are preformed. This stationary cascade is the main component of the annular cascade test rig at the Section of Turbomachinery in the University of Kassel and offers the opportunity to investigate unsteady effects without interaction with other rotating structures.

The focus of the numerical investigation and analysis is the pattern of the rotating flow linked to the rotating instability (RI). Earlier experimental studies have shown strong indications for the existence of the rotating instability at specific conditions [6, 7].

At a first step URANS simulation with Fine^{TM}/Turbo [8] are conducted, in order to answer the question if this approach is capable to show the characteristics of rotating instability, which were observed in the experiment. Therefore time resolved pressure signals at the hub as well as PIV measurements from previous experimental investigation are compared with numerical results.

Another point of the study deals with the question regarding boundary layer prediction. It is assumed that the rotating instability (RI) is mainly caused by boundary layer flow instabilities upstream of the leading edge. Therefore a parametric study of the different RANS turbulence models is carried out to identify the capabilities of the numerical models in order to simulate this unsteady effect.

References

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