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[Extended Abstract]

Numerical Simulation of the Rotating Instability in an Annular Compressor Cascade Test Rigs

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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 conditions previous to rotating stall, which is called rotating instability (RI) [2, 3]. The rotating instability can be described as a self-induced rotating flow phenomenon at high incidence, which rotates in circumferential direction and shows a characteristic signature in the frequency spectrum. It is suggested that the rotating instability is linked with the spike initiated rotating stall [4] and could be used as a preliminary indicator.Taking this background into consideration, a deeper understanding of flow instabilities, already at a stable operating point, 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 lead 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 were performed. This cascade is the main component of the annular test rig of the Section of Turbomachinery 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 [5]. Flow simulations of one blade passage have shown that a DES/DDES method is capable to capture the Kolmogorov energy spectrum much better compared to a URANS simulation and that a time-step of at least $\Delta t \approx 5 \cdot 10^{-6}$ s and a grid resolution of $\Delta x \approx 0,7 \cdot$ mm has to be applied, [6]. With the identified combination of method, grid and time-step, unsteady full annulus DES calculations are presented and also compared to experimental results. To investigate the unsteady flow field, up to 28800 virtual sensors have been applied to the numerical model. Based on temporal change of pressure and velocity as well as power spectral density of both variables, one can identify a RI-like pattern within the flow field and compare the characteristics such as direction of rotation, speed and mode order. To achieve a frequency resolution of at least 10 Hz in all full annulus simulations, 10000 unsteady iterations are performed, which resulted in a lot of computation time and storage. Therefore, all presented calculations as well as the evaluation are conducted on the Lichtenberg high-performance computer of the TU Darmstadt.

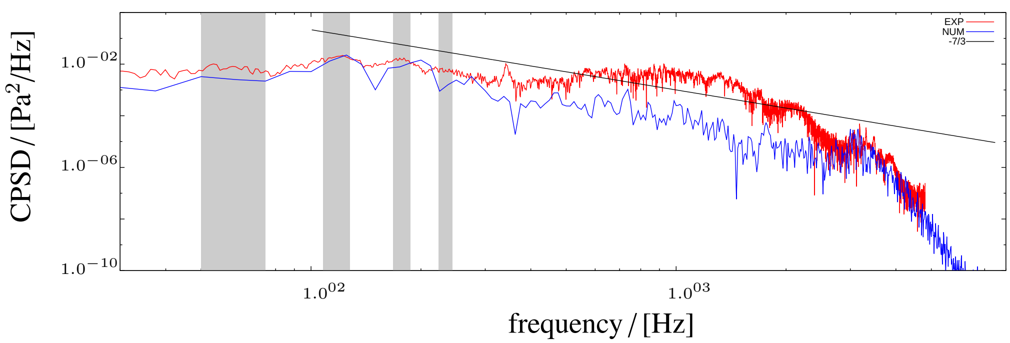

Figure 1. Example of rotating instability (gray rectangles) in the frequency spectra derived from the cross-correlation of two pressure signals with an circumferential distance of 42,4°. Numerical results are an interim result after 4000 iterations.

References

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