TIP AND HUB CLEARANCE VORTEX DEVELOPMENT DUE TO ROTOR-STATOR-INTERACTIONS IN AXIAL COMPRESSORS

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EXTENDED ABSTRACT

The real flow in axial compressors of multistage stationary gas turbines and jet engines is three-dimensional, viscous and unsteady. As a result of aerodynamic interactions of the rotor and stator blade rows, the flow field is highly periodically unsteady and very complex, even for stable operating conditions.

Although this fact has received increasing attention within recent years, blade row interaction effects are not yet typically addressed in current design systems of turbomachinery. It is therefore one of the challenges of the engine design to include beneficial unsteady effects to improve the performance. This requires a detailed physical understanding of the unsteady flow field and the resulting effects on the engine parameters.

The secondary flow phenomenon, dominating the flow field in the tip region of cantilevered blades, is the tip clearance vortex (TCV). The TCV is of crucial importance for the compressor design and operation because of its detrimental impact on the efficiency and the pressure rise due to the blockage effect in the endwall region. Furthermore the tip leakage flow plays an important role on the flow stability and the rotating stall inception process. The objective of the present paper is to contribute to an improved physical understanding of the periodical unsteadiness of the TCV of cantilevered stator vanes and rotor blades in axial compressors, which is triggered by aerodynamic blade row interactions.

Detailed experimental investigations were performed in the four-stage low-speed axial compressor (LSRC) of the Dresden University of Technology. The vertically aligned compressor consists of four identical stages, which are preceded by an inlet guide vane row, fig. 1. The blading was developed on the basis of the profiles of a middle stage of a high-pressure compressor of a jet engine. The results discussed in this paper are for the reference blading of this compressor with cantilevered stator blades ("build 2"), see refs. [1],[2]. Different measurement techniques are used to investigate the steady and unsteady flow features.

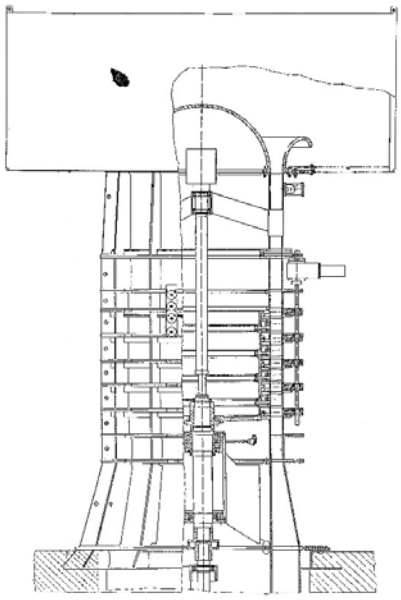

Fig 1: Sectional drawing of Dresden LSRC

The time-averaged flow was investigated with pneumatic five-hole probes. For capturing the time-resolved flow parameters hot-wire measurements were performed within the axial gap downstream of the cantilevered stator vanes at multiple clearance levels. Based on these measurements technique the effect of the rotor wakes on the stator hub clearance vortex is quantified. Additionally, the velocity distribution within the rotor blade row was determined with a 2D Laser Doppler Anemometry System. Focus of these measurements is to investigate the periodical unsteadiness of the TCV during its development within the rotor passage.

It was found that the rotor tip clearance vortices are strongly affected by the passing of the stator wakes. This is exemplarily shown for vorticity and the perturbation velocity vectors near rotor blade tip (fig. 2). Due to the stator wake impact, the position of the maximum tip clearance mass flow, the vortex intensity and consequently the orientation and extension of the tip clearance vortices strongly

change in time. Therefore the tip clearance vortices periodically pulsate (fig. 3). Vice versa the stator hub clearance vortex is dependent on the passing of the rotor wakes. Thus comparable effects can be observed.

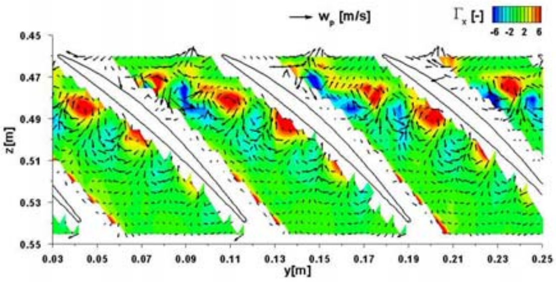

Fig 2: Periodical unsteady flow field inside the blade passages of rotor 3 (fixed point of time): vorticity contours and perturbation velocity vectors, near rotor blade tip, design point

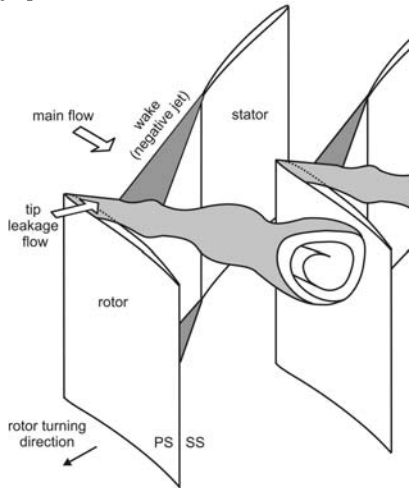

Fig 3: Schematic of rotor tip clearance vortex influenced by the passing stator wakes, 3D-view (fixed point of time)

To account for these unsteady phenomena in the design of new compressors requires adequate modelling of these effects. The commercial CFD-Solver EURANUS of *Numeca* was used to predict the flow. For the unsteady simulation two options are available. The full unsteady computation requires an identical pitch for the section of rotor and stator blades to be simulated. This can be achieved by an adjustment of the blade count to give a common multiple for rotor and stator blades. In the current case it is therefore necessary to model three rotor blades and four stator vanes per row using the domain scaling approach, leading to an increased numerical effort. Additionally the non-linear harmonic method gives the opportunity to estimate the unsteady flow field with less computation time [3], [4]. The method is based on the assumption that the flow field can be described by a time averaged mean value and time-dependent sinusoidal oscillation components. These periodically perturbations, which in this case are due to the wakes of the previous row, are transformed into the frequency domain by a Fourier transformation. The flow field is then solved by a steady solution and additional equations for the real and imaginary part of the members of the Fourier series. Following the computation the flow field can be reconstructed for the different time steps, which are equivalent to the relative rotor – stator positions. This method enables a fast estimate of the unsteady flow field within the design phase. Its accuracy is basically dependent on the number of frequencies and perturbations per blade row considered within the computation.

Both methods have been used to calculate the flow field of the Low Speed Research Compressor for the different test cases. The data over the third rotor tip clearance is compared with the detailed experimental data. The numerical and experimental data are discussed in comparison. Special focus lies on the validation of the non-linear harmonic method in comparison to the domain scaling approach. Further the simulations are used to analyze the flow field near the hub clearance of the stators in detail, where less experimental data is available.

Summarizing, the presented work will help to increase the understanding of hub and tip clearance vortex unsteadiness and contribute to the adequate modelling of these effects.

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