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Investigation of Vortex Shedding and Wake-Wake Interaction in a Transonic Turbine Stage Using Laser-Doppler-Velocimetry and Particle-Image-Velocimetry

The current paper presents a time-resolved experimental flow investigation in a highly loaded transonic gas turbine stage operating continuously under engine representative conditions. The measurement was performed with a two-component laser-doppler-velocimeter (LDV) and a three-component stereoscopic particle-image-velocimeter (3C-PIV). Unsteady velocity data were obtained in axis perpendicular planes (LDV) and tangential planes (3C-PIV) between stator and rotor as well as downstream of the rotor. The results of the time-resolved investigation at several radii show the vortex shedding process from the trailing edges of nozzle guide vanes and rotor blades. This vortex shedding was found to be phase locked to higher harmonics of the blade passing frequency. Pressure waves evoked by reflection of the trailing edge shocks of the vanes on the passing rotor blades interact with the boundary layers on the rear suction side of the vanes and on the rotor blade surfaces while running upstream and downstream the flow. They are responsible for this phase-locking phenomenon of the shedding vortices. At midspan, the vortices shedding from stator and rotor blades were also observed by PIV. The in-plane vorticity distribution was used to discuss the wake-wake interaction indicating that wake segments from the nozzle guide vanes were chopped by the rotor blades. These chopped segments are still visible in the distributions as a pair of counter rotating vortices. The nozzle wake segments are transported through the rotor passages by the flow, influencing the vortex street of the rotor blades as they pass by with the higher velocity of the main flow. A comparison with a numerical simulation is also given.
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Introduction

The unsteady flow in turbomachines is characterized by the interaction between stationary and rotating blade rows and their wakes. The wake flow moves downstream and influences pressure distribution, heat transfer, and boundary layer transition on succeeding blades. One source of loss is generated by wake mixing.

Much research work has been performed to investigate these wakes including the vortex shedding process and loss generation in nonrotating cascades, e.g., [1,2]. Recent research deals with the wake flow in rotating machines. The retroaction of rotor blades on the vortex shedding frequencies of the upstream vanes has been investigated by [3,4] with phase locking of the vortex shedding to higher harmonics of the blade passing frequency observed by the authors.

Less literature is available dealing with wake-wake interaction, e.g., [5]. The vortex streets of the nozzle guide vanes are chopped by the rotor blades into individual segments which subsequently pass through the rotor passages independent from each other. They interact with the vortices shed from the rotor blades as they pass by with the higher velocity of the main flow. A modulation and destabilization of the rotor vortex streets was shown in [6].

The current paper focuses on the vortex shedding and the wake-wake interaction of a highly loaded transonic gas turbine stage which operates under engine representative conditions in the continuously running cold-flow test facility of the institute.

The flow investigation was performed with nonintrusive optical measurement techniques like laser-doppler-velocimetry (LDV) and particle-image-velocimetry (PIV). The LDV data were recorded under the same conditions already published in [7]. This set of time-resolved flow data for single positions in the fluid flow together with the stage geometry is available for download at the institute's home page. Additionally, PIV measurements were performed in tangential planes at midspan between stator and rotor as well as downstream the rotor to get instantaneous velocity measurements of the whole flow field, thus enabling the determination of the vortex streets and their interaction mechanisms.

Experimental Facility and Instrumentation

Test Facility. The transonic test turbine of the Institute for Thermal Turbomachinery and Machine Dynamics (Styria, Austria) is a continuously operating cold-flow open-circuit facility which allows the testing of turbine stages with a diameter up to 800 mm in full flow similarity (corrected speed and pressure ratio) due to its modular design. Pressurized air is delivered by a separate 3 MW compressor station. The shaft power of the test stage drives a three stage radial brake compressor. This brake compressor delivers additional air mixed to the flow from the compressor station and increases the overall mass flow. The air temperature in the mixing chamber (turbine stage inlet) can be adjusted by coolers between 40°C to 185°C. The maximum shaft speed of the test rig is limited to 11 550 rpm. Depending on the stage characteristic a maximum coupling power of 2.8 MW at a total mass flow of

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