Design of a low pressure turbine stage with control stage characteristics for investigations of partial admission effects

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Long Abstract

Introduction

Partial admission results from a asymmetric flow field at the inlet of a turbine stage, for example in small scale industrial turbines with part load control when one or more nozzles are closed. In this case a highly transient flow field with specific partial admission effects occurs. Especially the control stage of the turbine is high loaded in case of partial admission and furthmore, additional losses result in the flow field. Those effects are insufficient investigated, especially experimental data are rare. Several measurement campaigns e.g.[1] includes field traverses in different planes of a stage. More extensive experimental investigations, especially the measuring of rotor blade forces are carried out by Fridh et al [2]. Numerical investigations are presented by Hushmandi [3] and Kalkkuhl [4].
In this paper the reconstruction of an existing low pressure test facility in a control stage will be presented at first. According to the new stage design three dimensional CFD calculations are carried out with focus of estimation of unsteady fluctuations and field of influence due to partial admission. Also the positions, where the important effects are noticeable are determined. After the design process and the numerical investigation to partial admission the test facility was modificated and the measurement positions in the test facility are established. The experimental setup in this project includes field traverse, measurement at the endwalls as well as the pressure distribution on the rotor blades. All measuring campaigns includes time averaged and time resolved measurement techniques.

1. Methods

The aim of the design process is the determination of a stage geometry with control stage characteristics. To achieve comparable stage characteristics (stage loading Ψ_h, degree of reaction $\rho_{y,s}$ and pressure coefficient c_p) in the test turbine compared to a high pressure control stage of a industrial turbine a suitable operating point and geometry transformation are necessary. Therefore, steady state CFD simulations with different blade geometries and numbers are evaluated for a series of operating points. The stator and rotor blade geometry for the test facility results from a scale up of a high pressure control stage blade geometry. In addition, the blade number ratio z_{Rot}/z_{Stat} is similar to a high pressure turbine blade ratio. To compare the flow field in the test facility with the flow field in the high pressure control stage it is useful to consider the dimensionless velocity triangles in the relative frame. For similar dimensionless velocity triangles also the stage loading and the reaction of degree are compared. After designing the stage, according to the customized geometry of the test facility a numerical setup for the reference case (admission degree $\epsilon = 100\%$) and a partial admission case ($\epsilon = 88.6\%$) was created. The detailed setup as well as the results for steady state and transient simulations are presented below.

2. Test Facility and numerical setup

The CFD based design process results in a single stage air low pressure test turbine. The reaction of degree at the operating point ($\rho_{y,s} < 0.1$) as well as the reaction of degree in the high pressure stage is low. The stage loading is $\Psi_h \approx -2.92$ and the stage includes 44 stators and 75 rotors. To achieve these characteristics at the operating point the massflow is set to $\dot{m} = 7\frac{kg}{s}$ and the number of revolutions is set to $n_T = 500\frac{rev}{min}$. Due to constructive limitations of the traversing a circumferential blockage of 40.9° is chosen. In addition to the CFD simulations a structural analysis of the rotor is carried out. The calculated eigenfrequencies are considered for different engine orders because of e.g. constructional components.

After that, a numerical setup of the modificated test facility was created. Due to the single blockage of 40.9° a circumferential periodicity for the CFD simulations can not be used. Thus, a 360°-CFD model is simulated. The grids of stator and rotor passages are generated with the inhouse meshing tool AxTurboMesh [5]. A total pressure boundary condition is specified at the inlet whereas an average static pressure is chosen for the outlet. These conditions are used for the reference and partial admission case. The same total to static pressure ratio results, under ideal gas conditions, in a constant enthalpy drop as well as constant stage loading. The blockage walls are assumed as infinity thin with no slip wall conditions. The SST-tubulence model is used and steady state and transient simulations are carried out. Steady state simulations are performed with the so called frozen rotor interface in order to connect rotating and non rotating parts.

3. Results and Conclusion

A modification of an existing test facility based on comparison of the dimensionsless numbers and dimensionsless velocity triangles was possible so a stage with control stage characteristics was designed. Based on further numerical investigations with the new design the expected transient fluctuations of the static pressure and velocity field are determined and according to these results the specifications of the measurement technique is chosen. Further, the field of influence and interest due the partial admission is specified to define the measurement positions. In doing so, the capability to resolve the transient fluctuations is ensured and the required spatial resolution of the flow field is determined. In addition, the expected force fluctuation and amplitudes are recognizble (see figure 1 and figure 2).

References

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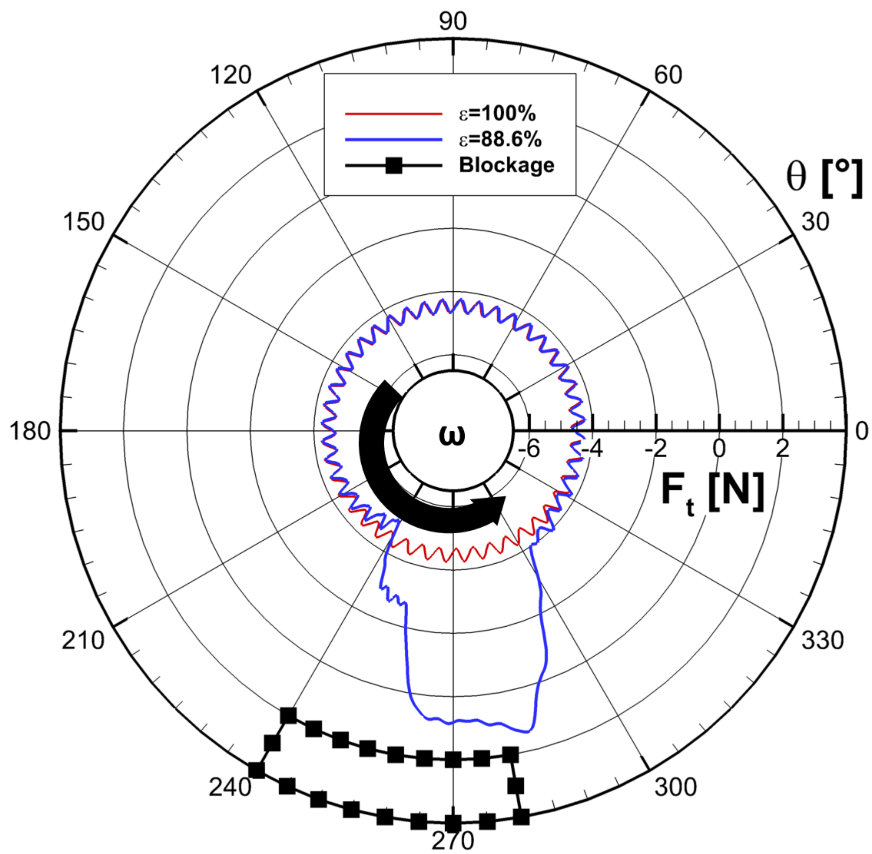

Figure 1. Time signal of tangential force for full and partial admission

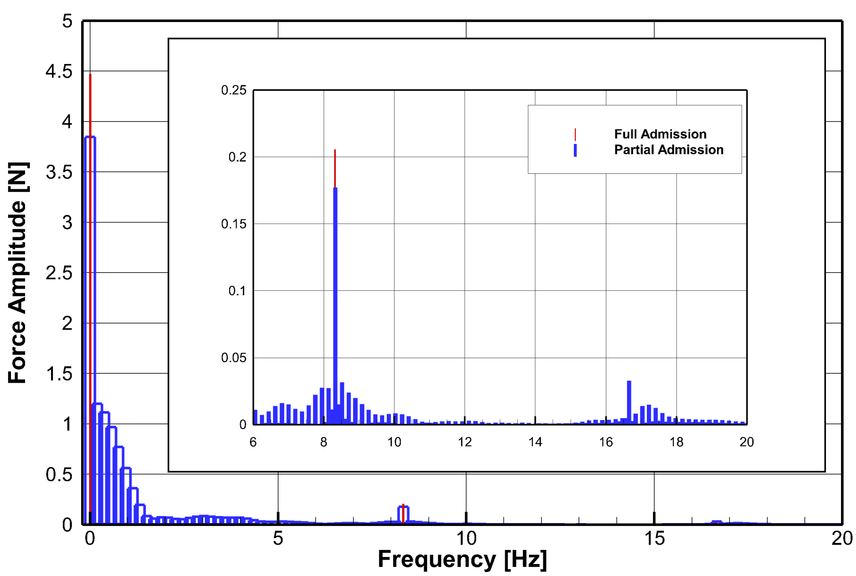

Figure 2. Frequency spectra of tangential force for full and partial admission