The potential of interstage injection for axial compressors

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Long Abstract

Introduction

WetCompression is a widely used approach to maximize the power rate of stationary gas turbines. It is practically realized by injection of liquid water into the air main flow via a nozzle rack at the air inlet duct of the compressor. Only minor parts of the injected water evaporate on the way to the compressor inlet. In fact, a multi-phase flow of humid air and water droplets enters the compressor. To protect the blades from erosion by the entering water droplets the blades have to be coated. In most cases the coating is used for all compressor blades and vanes. The continued water evaporation in the compressor causes further cooling during the compression process. The benefit of WetCompression is demonstrated by numerous authors, see e.g. [1, 2] and [3].

Water injection between the compressor stages is called interstage injection. This is rarely investigated yet. Bagnoli et al. [4] and Roumeliotis et al. [5] calculated the benefit of the interstage injection process for some operation conditions. Ingistov [6] described a first nozzle test of an interstage injection system for online compressor washing. An advantage of interstage injection compared to WetCompression is the optimized injection of water at specific positions inside the compressor. The amount of injected water can be adapted to operating conditions for the individual injection positions to improve compressor cooling by representing a more isothermal compression process. Additionally, the risk of blade icing at the first compressor stages can be avoided by interstage injection.

1. Methods

Implementing water injection between the stages is technically challenging. Nozzles producing a homogeneous water spray consisting of tiny droplets with a diameter of less than 10 µm are required; see Schnitzler et al. [8]. Tiny droplets follow the main flow which reduces the blade erosion due to an impact of the droplets on the blades.

Residence time of the water droplets inside the compressor is in the range of microseconds and therefore high evaporation rates are needed. The evaporation rates significantly increase by decreasing the droplet diameter. The evaporation process of tiny droplets might even be too slow for the short residence time of the droplets inside a compressor.

An increase of the temperature of the injected water has two positive effects. The first effect is that waste heat from other processes e.g. the steam turbine can be used to energize the water and reduce the required heat transfer to accelerate the droplet evaporation. The second effect is the reduction of the water surface tension. This reduction leads to a higher Weber-number. Spray generation at higher Weber-numbers results in reduced droplet diameter for the same nozzles hardware.

In this paper, a parametric study of the benefit of the increase of water temperature with regard to the evaporation process and the spray properties is demonstrated. The evaporation process is simulated with the droplet vaporization model of Abrazom and Sirignano [7]. Physical limits and technical consequences referring to evaporation process and internal compressor cooling are discussed. A thermodynamic analysis of interstage injection is presented with the focus on the amount of water required for optimized cooling.

References

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