[Extended Abstract]

Influence of pressure on droplet splashing behaviour inside gas turbine compressors during wet compression

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Introduction

With increasing shares of electric power converted from renewable energy sources, their fluctuating supply impacts net frequency and poses a possible threat to overall grid stability. A possibility for compensating unsteady supply of electric energy is, putting emphasis on the ability of conventional power plants to perform fast load changes and increase overall flexibility in power output. For gas turbines, this can be achieved by injecting droplets as a spray inside intake duct. The vaporisation of the injected water decreases the turbine inlet temperature and increases mass flow. Wet compression considers droplets entering the gas turbine compressor and reducing temperature rise during compression process and thereby reducing compression work.

Since droplets above a specific size cannot follow the flow of air, they are likely to collide with compressor blades and disintegrate. This splitting leads to deposition of water on the blades and formation of secondary droplets, whose characteristics influence the subsequent vaporisation. To apprehend these splashing phenomena in compressors as well as in general and to predict the outcome of these disintegrations, e.g. the distribution of the secondary droplets’ diameter, impact of single droplets was studied elaborately.

In addition to the influence of fluid and surface properties, it was discovered that the pressure of the surrounding gas is also of importance to the outcome of a droplet impact. In the knowledge of the authors, only the influence of 100 kPa and pressures below has been examined until now. To investigate the droplet surface interaction at pressures above ambient pressure, a test rig (Figure 1) was developed at the Laboratory of Turbomachinery which allows to study droplet impacts inside a compressor at pressures up to 500 kPa.

1. Methods

The drop impact was analysed using high speed shadowgraphy recordings taken with a Phantom v2512 camera. These recordings were then processed by LaVision’s software DaVis which yields quantity, diameter and velocity of all detected droplets. The primary drops were produced by pumping liquid to a cannula, where fluid tears off and forms drops of consistent diameter. The droplets fall freely about 0.65 m and impact on the substrate. After each droplet impact, the surface was dried. This process was carried out at pressures between 100 and 500 kPa. To compensate the greater form drag due to increased gas density at higher pressures, a flow was generated by a fan to eventually accelerate falling drops. Since the drop’s shape has a strong influence on the outcome of the splash, the evaluation was restricted to nearly spherical drops.

2. Results

Figure 2, taken from a preceding study where drop shape wasn’t restricted and the form drag has not been compensated [4], shows images of water droplets 0.195 ms after impacting the substrate with a surface roughness of $R_z = 2,009 \mu m$, at pressures from 100 to 500 kPa. For the conducted examinations Weber and Ohnesorge number range were chosen within typical range for wet compression inside gas turbine compressors resulting in every drop disintegrating in a prompt splash with increasing intensity at higher pressures, although the impact velocity decreases. As the gas pressure increases, the number of ejected secondary droplets grows significantly, especially with the first pressure increment. At 100 kPa secondary droplets are difficult to perceive and could not be recognised by the used particle detection algorithm, whereas 960 droplets were collectively detected from 10 impacts at 200 kPa. The number of detected secondary droplets increases to 4688 at 300 kPa and 8909 at 400 kPa before it then drops to 4762 at 500 kPa due to high percentage of prolate primary drops, which eject only a small number of secondary droplets when splashing.

In addition to this, the distribution of secondary droplet diameters, shown in Figure 3, changes so that greater diameters are more frequent at higher pressures.

3. Prospect

The Paper will provide the results of more sophisticated investigations of spherical drop impacts on a horizontal dry surface for pressures up to 500 kPa within Weber and Ohnesorge number ranges typical for wet compression applications.

References

[1] Christoph Günther and Franz Joos. “Fluid Properties at Gas Turbine Inlet Due to Fogging Considering Evaporation and Condensation Phenomena as Well as Icing Risk”. In: Journal of

Figure 2. Images of water droplets impacting a dry surface with a roughness of $R_z = 2,009 \mu m$ at different gas pressures and impact velocities from 3.45 at 100 kPa to 2.92 m/s at 500 kPa. All images are taken at 0.195 ms after the first contact.

Figure 3. Measured number probability density functions of secondary droplet diameter for various pressures
