Suitability of light scattering technique for measurements of water droplets in turbine wet steam flows

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Introduction

Measurements in wet steam conditions such as in the last stages of low pressure turbines always have been a challenging task. At the Institute for Power Plant Technology, Steam and Gas Turbines (IKDG), RWTH Aachen University, wetness determination is performed by means of droplet measurements with an optical light scattering probe. With knowledge of the wetness fraction thermodynamic conditions in between the turbine stages are estimable thus enabling the determination of the low pressure turbine efficiency. Measurements of single droplets and their respective dimensions and distribution across span enhance the blade design process. The knowledge of the areas where high wetness throughput occurs gives a deeper insight into condensation mechanisms in rotating machinery.

The transition from single to two-phase flow during fluid expansion in low pressure steam turbines evokes condensation of droplets. Those are of small initial size, typically a few nanometers in diameter, and follow the flow without slip and wall interaction, growing steadily until they are too sluggish for flow redirection inside blade rows. These droplets strike and wet downstream blades causing liquid films on their surface. Subsequently ligaments form and droplets break-off at the blade trailing edges. These so called secondary droplets are much bigger than the condensation generated primary droplets. With diameters of up to several 100 µm their momentum at impact on blades causes erosion and hence affects mechanical stability and flow efficiency. Therefore efficient blade design processes have to take two phase flow into account.

Other than the evaluation of the overall turbine efficiency that only needs an integral wetness value, blade designers desire determination of local droplet quantities, size distributions and wetness fractions. Light scattering technology is supposed to meet those requirements without influencing the flow and its two-phase composition.

This paper states the applicability for droplet measurements with scattered light techniques and highlights its necessity if a deep understanding of condensation phenomena inside the machine is desired.

1. Methods

The suitability of light scattering technique for measurements of water droplets in turbine wet steam flow depends on a variety of parameters. To a great extent suitability of this method therefore also depends on assumptions and simplifications that are or are not permissible within the environment the measurement is performed. The present paper examines all relevant aspects for the measurement of droplets inside a low pressure steam turbine. On basis of Mie’s light scattering theory, influence of these aspects for the distinct measurement of droplets is investigated. This includes external conditions such as the fluid properties of water and steam, the droplet velocity, size, shape and density per volume and predefined conditions of the measuring device such as laser
wavelengths and intensities, the scattering and observation angle and the illumination of the measuring volume.

After clarification of these factors a brief discussion on measurement errors is given. This discussion comprises errors that lie within the physics of light scattering theory as well as those caused by the measurement configuration. Namely, these are extinction and beam expansion due to droplets in between the measuring volume and the imaging optics, coincidence due to a large measurement volume or high droplet current densities, side errors due to a Gaussian distributed laser beam intensity and errors due to an unevenly illuminated measurement volume. Possible avoidance by selection of proper measurement equipment and an elaborate design and setup of the probe is described. This section closes with an estimation on each errors significance on the measurement results.

Light scattering measurement is then evaluated on its applicability for low pressure steam turbines and contrasted to other measurement approaches for droplet and wetness measurements in this environment like shadowgraphy, holography, diffractometry, interferometry or extinction measurements. It is argued in favor of the light scattering method that only measurements of single droplets provide insight into the very fundamentals of droplet condensation and their growth during expansion.

Conclusively the requirements for droplet measurements with a light scattering probe in low pressure steam turbines regarding the design and composition of the measuring system are pointed out. Finally, taking into account all previous discussed conditions, a probe design is introduced which has been successfully applied by IKDG in the past well as an outlook on present and future developments.
References


