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Review

of the doctoral dissertation by MSc. Eng. Sima Shabani
entitled: "Analysis of the blade geometries for a highly efficient wet steam turbine stage"

1. Characteristics of dissertation

The subject of the doctoral dissertation by MSc. Eng. Sima Shabani is the analysis of the blade geometry of the last stage of a low-pressure steam turbine in relation to changes in its operating parameters. The work combines experimental research with advanced numerical modelling, focusing on improving the performance of a steam turbine stage operating under condensation conditions, in which the formation of wet steam leads to significant efficiency losses. The motivation for undertaking this research was the need to refine numerical tools for predicting condensation phenomena and optimizing blade configurations in order to minimize energy losses and the risk of mechanical erosion. The main research objective was to verify numerical models used for simulating flows with steam condensation. Understanding these phenomena has important practical significance, providing engineers with knowledge and tools necessary for the design and optimization of machines in which condensation processes occur. Therefore, the undertaking of this research by the doctoral candidate must be considered fully justified.

In the introduction and literature review (Chapter 1), the author presents the fundamentals of wet steam flow in axial turbines and summarizes the state of research on condensation modelling, thermodynamic losses, and blade optimization. Special emphasis is placed on computational fluid dynamics (CFD) models and equations of state, as well as on their limitations in industrial applications. This analysis defines the aim of the doctoral dissertation: to identify accurate modelling approaches and to propose optimized blade geometries for steam turbines operating under condensation conditions. Chapter 2 presents the experimental investigations carried out in a dedicated steam tunnel at the Silesian University of

Technology. Various measurement techniques are described, including the Light Extinction Method (LEM) for determining mean droplet diameter and wetness fraction, as well as Schlieren flow visualization. The author provides detailed descriptions of calibration procedures and validation tests, ensuring high accuracy of droplet size and distribution measurements. The chapter also presents results for test cases such as a convergent-divergent nozzle and a blade cascade, forming the basis for comparison with numerical models. In Chapter 3, the author evaluates different CFD approaches, comparing built-in commercial codes with in-house models. The accuracy of several droplet growth models, as well as equations of state, is assessed against experimental data, highlighting their strengths and limitations. This systematic analysis leads to recommendations for selecting the most reliable numerical models for practical engineering use.

Chapter 4 presents three-dimensional CFD simulations of wet steam flow through the last stage of a steam turbine. The analysis includes velocity triangles, thermodynamic parameters, grid independence tests, and comparisons between diabatic and adiabatic flow conditions. The results provide valuable insight into loss mechanisms in real turbine geometries. The most significant part of the dissertation is Chapter 5, devoted to assessing the influence of stator blade geometry modifications on stage efficiency. A detailed analysis made it possible to identify the optimal blade geometry, achieving the greatest reduction in energy losses and improvement in turbine stage performance.

Finally, Chapter 6 summarizes the research and presents the key conclusions, emphasizing the most accurate CFD models for simulating condensation flows, a better understanding of loss mechanisms in wet steam, and practical recommendations for blade optimization. The dissertation constitutes both a scientific contribution and a set of engineering guidelines for the design of more efficient steam turbines.

2. General evaluation of dissertation

The title of the doctoral dissertation, "Analysis of the blade geometries for a highly efficient wet steam turbine stage," accurately reflects the scope and content of the research, although it could also specify the broader context in which the analysis was conducted. The dissertation has a logical structure and includes all essential components of a scientific work: a literature review, clearly formulated objectives, a description of research methodology, a detailed analysis of results, and a summary with conclusions. In this respect, the dissertation can be considered complete and well-composed.

The experimental investigations, conducted in a steam tunnel, are carefully planned and provide reliable data on wet steam flow. The author successfully employed advanced measurement techniques such as the Light Extinction Method and Schlieren flow visualization, ensuring high quality of the experimental results. The range of tested cases, including measurements in a convergent-divergent nozzle and a turbine blade cascade, is sufficient for validating the numerical models. The numerical studies are extensive and have been carried out systematically. The doctoral candidate compared and evaluated several commercial and in-house CFD models against the experimental data. The dissertation contains a detailed analysis of droplet growth models (such as those by Gyarmathy, Fuchs–Sutugin, and Young) as well as the equations of state used to describe the thermodynamic properties of wet steam. Although the scope of the simulations could have been further expanded, the presented range is appropriate and allows the author to draw meaningful conclusions.

Particularly valuable are the analyses of blade geometry modifications, conducted in both two- and three-dimensional configurations. These studies clearly demonstrate that even small changes in stator blade design can significantly influence the stage efficiency. The detailed analysis enables the formulation of practical recommendations for optimal configurations, representing an original and valuable contribution to the advancement of turbomachinery engineering.

In summary, the dissertation is well-prepared. From a scientific standpoint, it may leave some room for further exploration, yet it presents original and noteworthy results that emphasize the significant influence of steam condensation on turbine flow leading to changes in flow parameters, increased losses, and reduced efficiency. Therefore, my overall evaluation of this doctoral dissertation is positive.

3. Discussion and specific comments

Although the dissertation is well written and presents important results of original research, several aspects deserve further discussion.

In the description of the 3D numerical studies, the author provides information about mesh independence tests and the criteria for selecting turbulence models. However, in Chapter 3, where suitable numerical models are investigated, such an analysis is missing. For a complete picture of the computational setup, it would have been appropriate to include the y+ values for individual walls, the boundary conditions for the turbulence models, and the criteria used to select those particular settings.

In Section 3.4, the author compares the computational results obtained with different droplet growth models against experimental data and concludes that some models predict the location of the condensation shock well, while others capture its intensity more accurately. I would, however, urge some caution in drawing such conclusions, because in the experimental investigations condensation shock oscillations are likely to occur, which would lead to a smearing of the measured pressure distribution. In contrast, in steady-state numerical simulations, such oscillatory behaviour does not usually appear.

The evaluation of condensation and droplet growth models is presented in detail, yet the comparative analysis sometimes remains qualitative. In the discussion of results, a more extensive scientific commentary on the limitations and simplifications of the individual models would have been valuable - for instance, why some models yield better pressure distributions, while others better predict the mean droplet diameter. Nonetheless, the author does provide discussion of droplet growth models in the introduction and Chapter 3; however, the dissertation would have benefited from bringing this discussion back when interpreting the results.

The numerical simulations of the last turbine stage, although extensive, were carried out for a limited range of operating conditions. In practice, 200 MW turbines operate throughout the day under varying load levels. Do the computational parameters in the dissertation correspond to nominal operating conditions? And would a reduced mass flow rate improve or worsen the condensation phenomena in the last turbine stage?

Furthermore, from the description of the computational domain and Figure 4.4, one may infer that the last stage is, in fact, also modelled as a Baumann stage with the same dimensions, only without the partial admission from the preceding stage. What is the purpose of this approach? This point is not sufficiently explained in the dissertation. In typical 200 MW turbine modernizations, such as those by Alstom, the Baumann stage has been replaced with a fully reactive stage; the entire steam flow passes through the last rotor, and the last-stage blades are elongated, increasing the stage diameter.

The dissertation contains many figures and tables; however, at times the material seems overly detailed or repetitive. A more concise selection and clearer integration of graphical materials would improve readability and better highlight the key research results. In several instances, one gets the impression that the author was somewhat in a hurry. For example:

- on page 36, the Sauter mean droplet diameter is introduced without definition;
- on page 49, the author presents computational test cases for droplet growth models, but the table summarizing these cases appears six pages later, on page 55;

- on page 107, one finds conclusions such as: "the presence of condensation increases the intensity of the shock waves" and "the occurrence of condensation significantly lowers the Mach number." Since an increase in shock intensity is associated with a higher upstream Mach number, how should this statement be reconciled with the reported decrease in Mach number?

4. Final conclusion

In summary, the dissertation submitted for review represents an independent solution to a complex scientific problem, and the results obtained constitute an original contribution by the author to the advancement of knowledge in the field of steam turbine stage computations and blade geometry optimization. The results have both cognitive and practical value, and the analysis clearly demonstrates that the objectives of the doctoral research have been successfully achieved.

The conducted studies confirm the doctoral candidate's comprehensive expertise in both numerical modelling and experimental research. The candidate carried out demanding experimental investigations in a specialized steam tunnel, employing advanced measurement techniques, and demonstrated a solid understanding of the modelling of wet steam flows in complex three-dimensional turbine geometries. The results were correctly interpreted, and the conclusions are scientifically justified and significant for the further development of turbomachinery engineering. The comments presented in this review do not diminish the scientific merit of the dissertation and do not affect my overall positive assessment of the work.

Considering the above, I state that the doctoral dissertation of MSc. Eng. Sima Shabani meets the requirements of the Act on Higher Education and Science (Journal of Laws of 2018, item 1668, as amended) regarding doctoral dissertations, and I hereby recommend that it be admitted to public defence in the discipline of Environmental Engineering, Mining, and Energy.

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