Abstract of PhD Dissertation

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Title of the PhD dissertation:

THERMO- HYDRAULIC-MECHANICAL OPTIMIZATION OF THE DESIGN OF CRYOGENIC TRANSFER LINES

Supervisor: **Prof. Maciej Chorowski, PhD. Eng.**

This work describes the methods for transporting cryogens through single- or multichannel pipelines. It also presents examples of the use of cryogenic lines and of their designs, referring in detail to typical structural nodes found in cryogenic transfer lines.

The second principle of dynamics and the Gouy-Stodola theorem are discussed from the perspective of their application in optimizing and evaluating heat and mass transfer devices. Literature studies allow presenting a number of examples of using methods based on Newton's second law to optimize thermal processes as well as to design and to evaluate a variety of heat and mass transfer devices. Based on the provided examples, a thesis was advanced that a possibility exists to use a method based on the minimization of entropy production to perform complex optimization of cryogenic lines.

Further, the dissertation presents sources of the losses which occur during the flow of cryogen through cryogenic transfer lines, and discusses the methods for determining entropy fluxes generated on the mentioned irreversibilities. It also details all of the sources of entropy which exist in single-channel cryogenic lines. Later in this work, the design of a single-channel cryogenic transfer line is optimized by using the method of minimizing entropy production. a method is presented, which enables the determination of an optimal diameter for the flow channel, allowing for the irreversibilities related to pressure drops and heat inleaks to the flowing cryogen. The introduction of entropy indicator N_S allows a comparison between the qualities of systems which have different parameters (different cryogens, different mass flow rates and different operating temperatures). The indicator shows to what an extent a given system deviates from the optimal condition in which the increases of entropy are possibly lowest.

In the next part, the internal structure of multi-channel cryogenic transfer lines is discussed. Each type of supports in multichannel lines is presented in detail, for both the radiation shield and the process pipes. This part describes the function of radiation shields in cryogenic devices and – by employing the method based on minimizing entropy production – it offers an exemplary calculation of optimum values for shield temperature, having the lowest sum of the increase of entropy due to heat inleaks to the transported cryogen.

The dissertation also includes an analysis of the impact of increased design pressure on the efficiency of a multichannel pipeline. The analysis was performed by the author in order to define an optimal design for a planned cryogenic line supplying helium to the FCC accelerator (*Future Circular Collider*). To this end, a method based on the second principle of dynamics was also used, thus allowing a conclusion that the best solution – from the perspective of minimizing entropy production and lowering the failure rate – is an innovative design employing process pipes made of Invar®.

In the next stage, the XATL1 multichannel cryogenic line was used to verify the theses and assumptions included in the dissertation. The line was designed by a research team from Wroclaw University of Science and Technology with a significant contribution of the author. Currently, the line is operated in DESY – a research center in Hamburg – to supply cryogen to the test stands of the XFEL laser (*European X-ray Free Electron Laser*). The XATL1 line was used in this work as an equivalent of an experimental set-up. The second principle of dynamics and the Gouy-Stodola theorem allowed performing acceptance evaluations of the line. The data obtained during the start-up and the operation of the XATL1 line enabled the author to evaluate the consistence of the line's parameters with the specifications, and also to determine and compare power output loss in the constructed transfer line against the operating parameters required in the technical specification. In the next stage, an entropy analysis was performed for all of the supports in the XATL1 transfer line, which allowed conclusions that might be used as guidelines in the design of future cryogenic lines. The analysis also allowed the author to verify the design of some supports in the XATL1 transfer line and to suggest more optimal design solutions.

The optimization and comparative evaluation of single- and multi-channel cryogenic transfer lines offered confirmation to the thesis and assumptions presented in this dissertation. The use of the XATL1 line model resulted in developing guidelines and recommendations for designing cryogenic transfer lines.