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C2Or2C-05: Development of a simulation code for analyzing pressure and temperature fluctuations in the J-PARC cryogenic moderator system

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At the Japan Proton Accelerator Research Complex (J-PARC), three hydrogen moderators operate using supercritical hydrogen at 1.5 MPa and 18 K. Nuclear heating induced in the hydrogen moderator during 1-MW proton beam operation is estimated to be 3.8 kW. A cryogenic moderator system (CMS) was designed to circulate the supercritical hydrogen at 162 g/s, effectively removing this transient heat load and limiting the temperature rise to below 3 K. Additionally, a parallel configuration was implemented to ensure consistent delivery of 18 K hydrogen to each moderator. The J-PARC CMS is cooled by a helium refrigerator with a cooling capacity of 6.4 kW at 16 K. An ortho-to-parahydrogen catalyst vessel is also integrated to maintain the parahydrogen fraction above 99%. To mitigate pressure fluctuations caused by transient temperature rises in the moderators due to nuclear heating, a pressure mitigation system was developed. This is system consists of a heater and a helium-filled bellows vessel, ensuring stable operation under varying thermal loads. A simplified simulation model was previously developed to study the cooldown process of the J-PARC CMS and optimize operational parameters. In this model, the parallel distribution lines to the moderators were treated as a single combined line, and the heat load was directly applied without modeling the heat exchanger. However, as the proton beam power increases, adjusting the flow distribution becomes essential to ensure the temperature rise across the moderators remains below 3 K. In this study, we developed a comprehensive simulation code that incorporates the parallel distribution lines and heat exchanger to estimate propagation of temperature fluctuation throughout the entire CMS loop and the resulting temperature fluctuations in the return helium flow to the refrigerator cold box. This code aims to optimize the J-PARC CMS operational conditions for not only the current 1-MW proton beam operation but also to study the future 1.5-MW proton beam operation planned for the upgrade target station. The simulation results demonstrated good agreement with experimental data, validating their ability to predict temperature propagations behavior across the CMS loop.

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