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C2Po1A-06: Basic design of a 17 kW orifice type heater for the ESS cryogenic moderator system

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At the European Spallation Source (ESS), a cryogenic moderator system (CMS) has been designed to circulate subcooled liquid hydrogen at 17 K with a parahydrogen fraction exceeding 99.5% and a flow rate of 0.25 kg/s for each hydrogen moderator. The nuclear heating for the 5-MW proton beam power is estimated to be 6.7 kW and is projected to increase to 17.2 kW for the four moderators in the future. The static and dynamic heat load is effectively dissipated through a plate-fin exchanger by a large-scale 20 K helium refrigeration system, known as the Target Moderator Cryoplant (TMCP) with a cooling capacity of 30.3 kW at 15 K. When the proton beams are injected, a stepwise heat load applied to the hydrogen moderators results in a 1.76 K temperature rise. This temperature fluctuation propagates toward the heat exchanger at a rate corresponding to the circulation flow rate. To compensate for the transient heat load, ESS employs two approaches: a valve box integrated with the TMCP, and an electrical heater installed within the CMS loop. This valve box adjacent to the CMS cold box regulates a cooling power by adjusting the feed helium flow rate to the CMS, without altering the operational conditions of the TMCP turbines. As proton beam powers increase, a fast-response and high-power heater is required to improve the stability of the CMS and TMCP, while maintaining a stable hydrogen supply temperature at 17 K within ±0.1 K during the proton beam injection or trip. The heater compensates for rapid nuclear heating without causing thermal disturbance, ensuring that heat loads transferred from the CMS to the TMCP remains constant. The heater was designed based on an orifice-type heater with a 5-kW capacity, originally developed at J-PARC by the author. Its geometry was optimized through CFD simulations using ANSYS FLUENT, ensuring that the heated surface temperature does not exceed 27 K, which is 4.26 K lower than its saturated temperature at an operational pressure of 1.0 MPa. The results confirmed that the designed heater met the required performance specifications. Furthermore, a straightforward method for determining the parameters of the orifice type heater using a conventional heat transfer correlation was also established.

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