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Automated operation modes for the ESS cryogenic moderator system

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The European Spallation Source (ESS) will provide long-pulsed cold and thermal neutron fluxes at exceptionally high brightness. Spallation neutrons generated at a rotating tungsten target are transformed into lower-energy cold and thermal neutrons through a thermal water pre-moderator and two liquid hydrogen moderators, which was designed to optimize the brightness of the cold neutron beams for scientific experiments, meeting the requirement of a parahydrogen fraction exceeding 99.5%. Upon injection of the proton beam, a rapid liquid hydrogen temperature rise occurs due to nuclear heating, which is estimated to be 6.7 kW for the proton beam power of 5 MW. The temperature rise propagates downstream of the moderator and induces pressure fluctuations. The cryogenic moderator system (CMS) was designed to supply subcooled liquid hydrogen at 17 K and a parahydrogen concentration of over 99.5% at a flow rate of 0.5 kg/s, to satisfy the moderator requirements. An ortho-para hydrogen catalyst vessel is placed into the loop and an in-situ ortho-to-parahydrogen fraction measurement system have been integrated. Pressure fluctuations caused by abrupt nuclear heating are mitigated by a pressure control buffer with a volume of 65 liters, while the CMS pressure is adjusted by recondensing vapor in the buffer tank through another small heat exchanger. The heat load is removed through a plate fin heat exchanger by a large-scale 20 K helium refrigerator with a cooling capacity of 30.2 kW at 15 K, referred to as the Target Moderator Cryoplant (TMCP).
An automated operation control system for the CMS has been developed, featuring seven operational modes: cooldown mode, steady-state mode, energy-save mode, beam injection mode, warm-up mode, quick warm-up mode and ortho-to-parahydrogen measurement mode. The CMS cooldown process was divided into three phases (vapor state, condensation state, and liquid state). The operational procedures and parameters were optimized based on CMS cooldown simulations and TMCP commissioning results. The cool down operation mode is expected to be completed within 27 hours before transitioning to the steady-state or energy-save mode.
During proton beam operation, the beam injection mode mitigates the pressure fluctuations resulting from beam injection or trip while providing thermal compensation for the nuclear heating using a TMCP valve box and a heater in the CMS. The warm-up mode is also divided into three modes, similar to the cooldown mode. CMS temperature is increased to 40 K by adjusting the feed helium temperature of the TMCP, while one of the two cold turbines is in operation. Moreover, the quick warm-up mode aiming to release liquid hydrogen within 10 minutes is integrated. The CMS installation was completed in February 2024. Preliminary CMS commissioning, excluding the moderators, is currently underway using nitrogen and helium. Hydrogen operation for the CMS is scheduled to start Q3 2024. The automated operational control system will have been completed by the beam-on-target.

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