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C3Or2B-01: Development and verification of a steady-state operating methodology for wide-range operation of 2K cold compressor system

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Superconducting radio frequency (SRF) cavities used in modern particle accelerators require operation at 2 K with sub-atmospheric (saturation) pressure. For large-scale systems, the most practical approach is to use multi-stage cryogenic centrifugal compressors (cold compressors or CCs) to compress the sub-atmospheric helium returning from the load to positive pressure. This compressor train is typically controlled with a lead compressor while the remaining compressors are coupled to the lead compressor through electronic speed ratios. Historically, the steady-state system parameters (e.g. speed ratios) for a specific operating point were obtained empirically from extensive testing. Hence, the operating regime for these systems remained limited to the design point regardless of the actual 2 K load requirement. However, stable operation of the cold compressor system over a wide range of (mass flow) capacities is a major factor in terms of operational cost savings. Each gram per second of reduction in CC mass flow can result in a 15 –20 kW reduction of input power at the main compressor. The overall cryogenic system operational cost savings from turning down the CC flow (perceived as a partial liquefaction load by the 4.5 K cryo-plant) can significantly outweigh the inefficiencies due to operation of the cold compressor system outside its peak efficiency regime. A steady-state operating algorithm has been developed to improve 2 K system reliability and stability over a wide range of steady-state operational conditions. An in-house 1D mean line centrifugal compressor characterization model is used in conjunction with the developed algorithm to estimate the selection of electronic speed ratios for optimal stability under a given load (flow). Functionality and validity of the developed steady-state methodology is tested using the FRIB cold compressor system up to 2:1 turn-down capacity range. An excellent agreement between the model predictions and the FRIB cold compressor system response is observed as presented.

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