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Development and test of a dynamic Modelica model of the He refrigerator for superconducting magnet systems

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The magnetic confinement of the plasma in existing and future nuclear fusion reactors is often provided by superconducting magnets. To show their superconducting properties, they must be kept sufficiently colder than the current sharing temperature during the pulsed reactor operation; therefore, they are usually cooled by supercritical He obtained by a refrigeration process. The technological complexity and cost of the He refrigerator are a significant fraction of those of the entire machine. For these reasons, a suitable dimensioning and safe operation is required and needs to be supported by adequate and reliable models. The latter, however, are currently limited to static or simplified dynamic models used for the industrial dimensioning of the refrigerators.

A new, dynamic and fast-running model of such a refrigerator is presented here, based on the object-oriented Modelica programming language. The (5 kW @ 4.5 K) He refrigerator of the ITER Central Solenoid Model Coil (CSMC), installed at the National Institutes for Quantum and Radiological Science and Technology, Naka (Japan), is chosen as reference for the model development, being its thermodynamic cycle fully representative of the refrigerators operating in many existing superconducting magnet facilities as well as in different existing and future tokamaks. The Collins cycle operated by the CSMC refrigerator features three cooling stages: the first one, assisted by liquid nitrogen precooling, from 300 K to 80 K, the second, based on two isentropic expansions in turbines, and the third, relying on isenthalpic J-T valves down to 4.5 K.

The model of each component, developed based on the CSMC design and operation data, is independently tested and then added to the "CryoModelica" library, which is also used by the 4C code for the analysis of thermal-hydraulic transients in SC magnets.

The new refrigerator model is tested both in steady-state conditions, when a constant heat source is applied to the system, and in transient mode, connecting a time varying heat source to the client. The results are shown to be coherent with what expected from the operation of the real plant in both operation-modes.

The model presented here is ready for the implementation of all the necessary controls and for its coupling to the detailed 4C magnet model. This will allow the integrated simulation of the cryoplant and the magnet for validation purposes, and, in perspective, the prediction of the refrigerator operation in support of the design and optimization of its automatic control strategies.

Keywords

Nuclear fusion, superconducting magnets, He refrigerator, thermal-hydraulic modelling, dynamic model

Category

Tools to support commissioning and operation phases of superconducting magnet systems

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