§21. Dynamic Simulation of a Large Cryogenic Plant

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The real-time simulator for the large-scale cryogenic system has been developed since 1993. In 2004, as a result of extensive collaboration with Taiyo Nippon Sanso Co., National Institute for Fusion Science (NIFS) successfully demonstrated the capability of C-PREST, simulating the LHD helium refrigerator/liquefier. As for the next step of the development program, LHD cryogenic system was selected to be the target plant. LHD has been operated since 1998, conducting eight-year of operating campaign. Since then, the cryogenic plant has been demonstrating its reliability. Still, it is mandatory to pursue its safety and reliability, and efficient operation procedures as well. As increasing the operating period, the hardware and/or software required to be updated and/or replaced. This is primarily caused by the termination of products, especially for the control system hardware. Since the processing speed of the hardware unit has been greatly improved, it is inevitable to replace the old one. The driver or the system software has to be modified as replacing the hardware unit; otherwise this would induce the software crush and/or malfunction of other hardware. To secure the reliability of a new system, it is required to test the system before installing to the plant. To do so, the most reliable way should be the testing a new system, utilizing the identical control system and the plant. In addition to these, it is essential to study the plant process to increase its efficiency which will lead to a reduction of running cost,

A simulation model has been implemented to demonstrate the cooldown process of LHD. In this study, the modeling of LHD components was limited to the following; a pair of helical coils, three sets of poloidal coils and supporting structures. To save the CPU time, a simulation of thermal radiation shields was substituted by the heat input to the refrigerator. A cooldown process of LHD has been designed to maintain the temperature difference within the system for less than 50 K, it is obvious to assign the massflow rate to each component with its cold mass. Since some components were eliminated for this simulation study, the total massflow ratio is less than one. The Process and Instrument Diagram (P&ID) for the simulation model has been developed. The priority for the simulation was set to achieve a real-time computation and to understand a dynamic behavior of the total cryogenic system, even though the model accuracy is considered to be more important. So, the model was executed to sustain the fast computational speed and was simplified to eliminate any additional CPU load to the process calculation. The lumped-capacitance model, neglecting any spatial temperature variations, was employed to implement the components as:

$$M_i C_i \frac{dT_i}{dt} = mC_p\left(T_{in} - T_{out}\right) \qquad (1)$$

where M_i is a mass and C_i is a specific heat of component i; m is a massflow rate of helium gas and C_p is its specific heat. T_{in} and T_{out} are the inlet and the outlet of helium gas temperature, respectively.

Equation 1 has been solved with imposing the efficiency of temperature, η, between the helium gas and the component i:

$$\eta = \frac{T_{out} - T_{in}}{T_i - T_{in}} \qquad (2)$$

Cooldown operation was conducted and compared with the cooldown process during the 7th experimental campaign in August, 2003. There are numbers of temperature sensors in LHD system, while the simulation, as mentioned before, was done based on one temperature for each component. The simulated data were considered as an averaged temperature of the component, which agrees well with the actual operation.