Functional Analysis of the Distribution Box of the KSTAR Helium Refrigerator

H.-S. Chang, Y. S. Kim, J. S. Bak
Korea Basic Science Institute, Yusung-Gu, Daejeon, 305-333, Korea, chsik@kbsi.re.kr

1. Introduction

KSTAR (Korea Superconducting Tokamak Advanced Research) is a tokamak device with 30 superconducting (SC) magnet coils. The main duty of the KSTAR helium refrigerator is to keep all cold components of KSTAR (SC magnet coils, magnet structures, SC bus-lines, current lead system, and thermal shields) at suitable temperatures in order to operate the SC magnet coils consistent with the operation scenario of KSTAR. A distribution box (D/B) which is equipped with helium-property-measuring sensors, cryogenic valves (CV's), cryogenic circulators, and heat exchangers (HX's) submerged in a huge liquid helium (LHe) bath (thermal damper), intervenes the cryogenic helium via cryogenic transfer lines (TL's) between the refrigerator cold box (C/B) and the KSTAR cold components. The major functions of the D/B can be classified as listed below [1]:

i) Supplying the proper cryogen to the respective cold components of KSTAR during various operation modes (including the idle mode).
ii) Cool/re-cool down of the KSTAR cold components from any temperature down to their operating cryogenic temperature within the constraints of time and temperature difference between the components.
iii) Protection of the KSTAR cold components and refrigerator from damaging in case of probable abnormal events.
iv) Simulation of the temporal variation of the thermal load and pressure drops occurring in the KSTAR cold components to pre-commission the refrigerator and test the cryogenic circulators.
v) SC coil/bus-line cable-in-conduit conductor (CICC) cleaning.

Since the helium flow in the thermal shields (TS's) is rather routine and the current lead (CL) system has its own helium distribution system, in this proceeding mainly the supercritical helium (SHe) circuits of the SC magnets and bus-lines will be discussed.

2. Helium Flow Description

The normal operation of KSTAR consists of idle (no coil is charged), toroidal-field (TF) ramp/de-ramp, stand-by (only TF coils are charged), and poloidal-field (PF) shot mode (all coils charged). During the idle mode the refrigerator switches to a partial liquefaction state and LHe is stored in the storage tank. This LHe is consumed during the other modes by transferring the LHe from the storage tank to the thermal damper (TD) via valve D83 and vaporizing it through the cold compressor (CP), as illustrated in Figure 1. The CP is necessary to keep the temperature of the TD at 4.3 K and to pressurize the GHe supplied to the suction side of the compressor station. [From now on "capital letter+figure(s)" is a CV of Figure 1, unless otherwise stated]. The TS's [CL's] are supplied with 18 bar, 55 K, ~140 g/s GHe [4.5 K, 1.3 bar, ~13 g/s LHe] via D61 [D81].

2.1 Helium Flow During Normal Operation

A constant SHe mass flow rate of 300 g/s (~5.5 bar) is forced by the cryogenic circulator CC1 [CC2] to the TF [PF] coils. Before entering the coils, the SHe is cooled in HX1 [HX4] down to 4.4 K and distributed via the TL's to each particular coil by manipulating the inlet CV's of the TF [PF] coils. The return SHe from the TF [PF3/4] coils deposits the thermal load of the coils via HX2 [HX5]. The 4.4 K SHe is then supplied to the TF [CS=PF1~4] magnet structure and the return SHe from the TF magnet structure [CS magnet structure and PF1/2/5/6/7 coils] is cooled down to 4.4 K (~3 bar) in HX3 [HX6] before entering the suction side of CC1 [CC2].

During the idle mode when the coils are not charged, the thermal load of the magnets is much less than that during the other modes. Therefore, instead of operating CC1 [CC2], which heat loss is about 0.9 kW during nominal operation, D08 [D28] and D09 [D29] are closed and about 60 [30] g/s of SHe (~3.5 bar) is directly issued from the C/B through D04 [D24] to the TF [PF] magnets and finally expanded thorough D05 [D25] into the TD [2, 3]. This idle-mode cooling scheme saves about 1.8 kW of the cooling power for 14 hours a day.

SHe (~5K, ~3.5 bar) coming from the C/B and cooled down to 4.4 K in HX7 is distributed via the TL's to each particular bus-line group by manipulating the CV's. The return SHe is expanded into the TD by D44. The value of the SHe mass flow rate depends on the specific operation mode [1].

2.2 Helium Flow During Cool Down, Re-cool Down and CICC Cleaning

One constraint imposed on the TF magnet cool/re-cool down procedure is that the temperature of the magnet structures always has to be lower than that of the coils [1]. To achieve this, V1~4 are closed; B1 is opened; helium is fed from the C/B into the coils and structures via D01 and D02, respectively; and released through D03. To cool/re-cool down the PF coils [SC bus-lines], V5~8 [V11~13] are closed; B2 is opened;

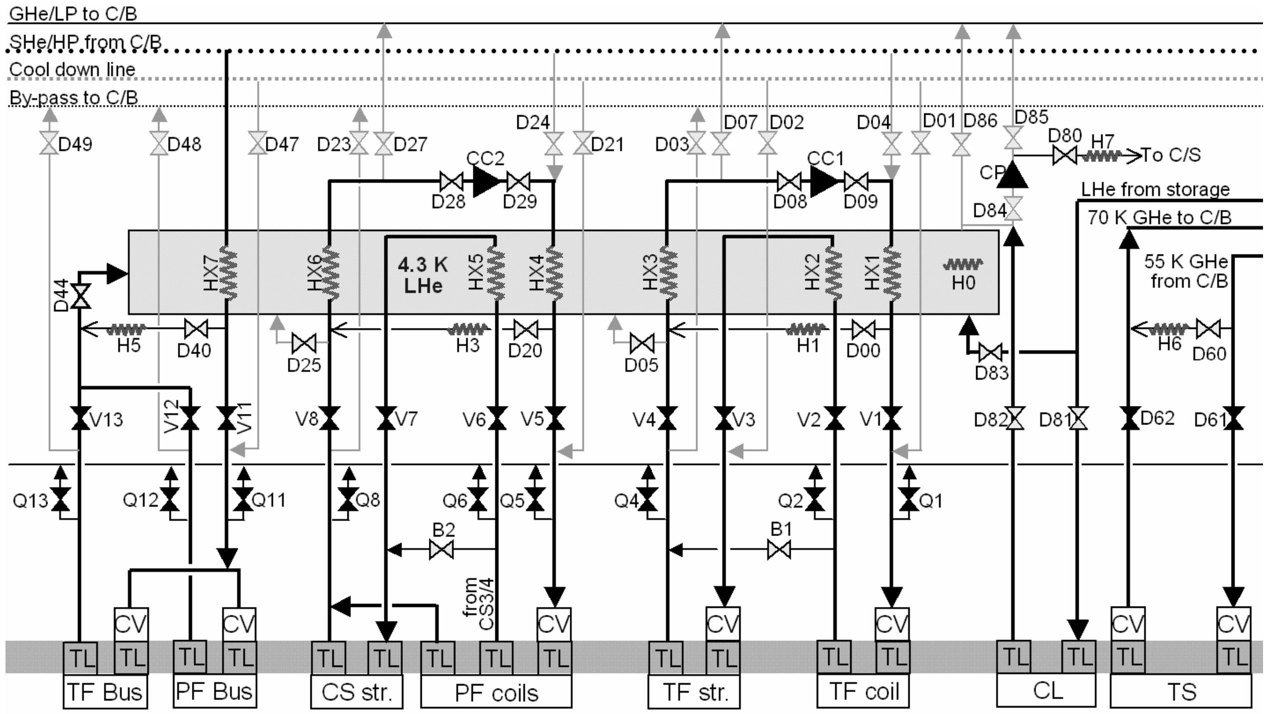

Figure 1: A schematic illustration of the magnet and bus-line helium circuits in the D/B. All valves are of cryogenic type and all HX's (HX1~7) are of brazed aluminum plate fin type. Imbedded sensors and filters are not shown.

helium is issued from the C/B through D21 [D47] and returned via D23 (D49). B1 [B2] serves as a by-pass to HX2 [HX5] in order to protect the LHe inside the TD and satisfy the TF magnet cool/re-cool down constraints.

To clean the CICC of the TF coils [PF coils; SC bus-lines], V1~4, and B1 [V5~8 (B2 is opened); V11~13] are closed and pressurized GHe is issued from the refrigerator external purifier upstream Q1 [Q5; Q11] to the TF coils [PF coils; SC bus-lines]. The returned GHe is gathered downstream Q2 [Q8; Q12 and Q13], its impurity analyzed, and finally sent to the refrigerator recovery compressor.

2.3 Helium Flow During Abnormal Events

When the refrigerator process control system receives a emergency signal of the TF coils [PF coils; TF SC bus-lines; PF SC bus-lines] from the KSTAR main control system, V1~4, B1, and the TF structure CV's [V5~8 and B2; V12 and the TF bus-line CV's; V13 and the PF bus-line CV's] are quickly closed and helium is actively evacuated via Q1~4 [Q5~8; Q12; Q13] into the quench collector.

2.5 Helium Flow During Thermal Load Simulation (Pre-commissioning of Refrigerator)

To simulate the time variation of the thermal load and pressure drop occurring in the TF magnets [PF magnets; SC bus-lines, TS's; CL's], V1~4 [V5~8; V11~13; D61/62, D81/82] have to be closed first. While CC1 [CC2; ; ;] is operating, the heater H1 [H3; H5; H6; H0 and H7] and D00 [D20; D40; D60; D80] simulate the thermal load and the pressure drop of the TF magnets [PF magnets; SC bus-lines, TS's; CL's], respectively. It must be noted that HX2 [HX5] is not tested in real conditions and HX3 [HX6] is overloaded.

The heater H0 is also used (no other heaters used) to simulate the time evolution of the total thermal load of the KSTAR cold components, including the heat loss of the refrigerator itself. In this way, it is possible to do a simple test of the cooling power of the refrigerator C/B.

3. Conclusion

By installing proper CV's, heaters, and by-pass lines in the helium circuit of the D/B, it is possible to perform the required tasks of the D/B of the KSTAR helium refrigerator.

This work was supported by the Korea Ministry of Science and Technology under the KSTAR Project Contract.

REFERENCES

[1] Y. S. Kim *et al.*, Technical Requirement for the KSTAR Helium Refrigeration System, 2004.

[2] P. Briend *et al.*, KSTAR Helium Refrigeration System PROCESS JUSTIFICATION FILE, 2004.

[3] H.-S. Chang *et al.*, Design Issues of the Distribution Valve Box of the KSTAR Helium Refrigerator, ICEC20 Beijing 2004.