The Design of Cryogenic He line for In-cryostat Components of the KSTAR

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1. Introduction

The cold components of the KSTAR tokamak are superconducting (SC) magnet system with its supporting structure, thermal shields (TS), current feeder system and in-vessel cryopumps. Three different cooling schemes are required to cool the cold components of the KSTAR; forced flow of supercritical helium (SHe) for the SC coils, coil structures and SC bus-line, pool boiling liquid helium (LHe) for the current lead system and in-vessel cryopumps, gaseous helium (GHe) for the thermal shields(TS). The cold components of in-cryostat have 16 TF coils, 8 CS coils, 6 PF coils, 16 TF structures, a CS structure, 26 in-cryostat bus-line(ICB), 16 cryostat thermal shields(CTS) and 16 vacuum vessel thermal shield(VVTS) [1]. All coils, structures and ICBs cool down with the 4.5K supercritical helium, and all TS cool down with the 55K gaseous helium. The fundamental notion of pipe design is to minimize thermal loss. So all components are cooled and acted well.

2. In-cryostat He line routing

2.1. Cooling conditions

The KSTAR SC coils are cooled with forced-flow supercritical helium (SHe). The required mass flow rate of the SHe to cool the SC coils is about 600 g/s during the normal operation. The cooling lines of the TF magnet structures are embedded inside the walls of the structures and the cooling lines of the TF-PF intercoil structure are attached on the outer surfaces of the structures. The cooling lines of the CS structure are serially connected to the return helium lines of the CS3/4 coils and attached on the surface of the structure [2]. Table 1. shows the He supply conditions of each components.

Table 1. The He supply condition of each components.

Components	Inlet Temp. (K)	Inlet Pressure (bar)	Mass Flow Rate (g/s)
TF coils	4.5	5.1	300
CS coils	4.5	5.1	150
PF coils	4.5	5.1	150
TF structures	4.5	3.3	300
CS structures	4.5	3.3	50
ICBs	4.5	3.05	80
Thermal shields	55	16	80

2.2. Size of pipes

The size of SHe line manifold defined by calculating as following equation. [3]

$$\dot{m}=\rho A_{He}\bar{v} \quad (1)$$

$$\mathrm{Re}=\frac{e\bar{v}D_h}{\mu} \quad (2)$$

$$f=\frac{1.635}{[\ln[0.135(e/D)+(6.5/\mathrm{Re})]]^2} \quad (3)$$

$$\Delta P=\frac{f\rho\bar{v}^2}{2D_h} \quad (4)$$

This is the method choosing the lowest pressures drop of using the standard pipe size. Table 2. shows the size of He manifold related to cold components

Table 2. The pipe size of each component.

Components	Lengt (m)	Number of pipe (ea)	Press. Drop (mbar)	Pipe size
TF coil in	10	4	2.23	32A
TF coil out	10	1	1	65A
CS coil in 1	1	4	1.14	32A
CS coil in 2	10	8	3.34	20A
CS coil out	10	2	8.75	32A
PF coil in 1	1	3	1.18	32A
PF coil in 2	5~10	6	3.46	20A
PF coil out	10	1	2.29	65A
TF structure in	10	4	2.34	32A
TF structure out	10	1	1.03	65A
CS structure in	10	1	1.04	32A
CS structure out	10	1	1.26	32A
ICB	4~10	8	3.94	15A
TS in	10	1	0.67	65A
TS out	10	8	2.27	32A

2.3. Cooling flow diagrams

The 16 TF magnets cool down in quadrant base which supply He with one manifold for four TF magnets. The TF structure is identical to cooling scheme of TF magnet. TF coil and TF structure have the 4 inlet and one outlet manifolds respectively.

Each of the CS coil and the PF coil is cooled helium with one manifold. For example, inlet manifold of PF5U and PF5L coil is one. CS coil system has 4 inlet manifolds and PF coil system has 3 inlet manifolds. All of CS and PF magnet He channel connected in one manifold. So, CS and PF magnet system have one outlet, including CS structure have one inlet and outlet manifold. ICB is supplied helium with eight manifolds of similar in heat load among 26 ICBs. ICB have 8 inlet manifolds, one outlet manifold. CTS and VVTS have one inlet manifold and 4 outlet manifolds respectively. Table 2. describes the number of manifold of each component. Fig 1. shows the 2D drawing of KSTAR in-cryostat He line routing. Fig 2. shows the 3D drawing the KSTAR In-cryostat He line routing. And fig 3. shows the 3D drawing manifolds and channels of the CS magnet system.

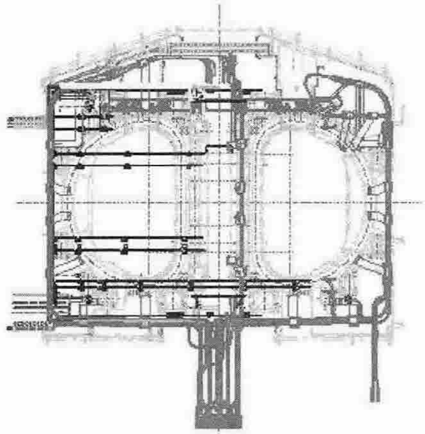

Fig 1. 2D drawing of He line routing in-cryostat.

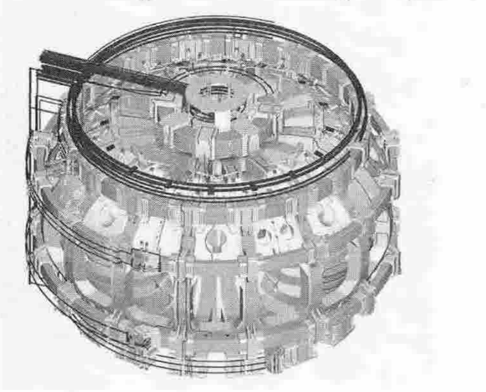

Fig 2. 3D drawing of He line routing in-cryostat.

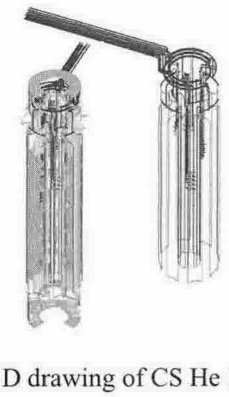

Fig 3. 3D drawing of CS He line routing.

2.4. Heat load of pipes

All pipe of in-cryostat except TS are wrapped with MLI(multi layer insulation) for minimizing heat loss. Table 4. shows the effect of heat load on pipe with MLI and TSs from the following equations [3].

$$Q=\sigma F_e A_c (T_h^4 - T_c^4) \quad (5)$$

$$\sigma=5.669\times 10^{-8} W/m^2 K^4 \quad (6)$$

$$F_e = \frac{1}{\frac{1}{e_c} + \frac{A_c}{A_h}[\frac{1}{e_h} - 1]} \quad \text{without MLI} \quad (7)$$

$$\frac{1}{F_e} = (\frac{1}{e_c} + \frac{1}{e_s} - 1) + (N-1)(\frac{2}{e_s} - 1) + (\frac{1}{e_h} + \frac{1}{e_s} - 1) \quad \text{with N MLI} \quad (8)$$

Table 4. Heat load of He line in-cryostat.

Compo-nents	F_e	A_c	Q	ΔT at 4.5K
TF coils	8.74×10^{-3}	1.34	1.6×10^{-2}	0.0036
CS coils	8.74×10^{-3}	0.65	0.78×10^{-2}	0.0017
PF coils	8.74×10^{-3}	1.07	1.3×10^{-2}	0.0028
TF structures	8.74×10^{-3}	2.15	2.57×10^{-2}	0.0057
CS structures	8.74×10^{-3}	1.12	1.34×10^{-2}	0.0030
ICBs	8.74×10^{-3}	0	7.21×10^{-6}	0
Thermal shields	8.74×10^{-3}	4.67	3.46×10^{-2}	0.0077

It follows that all pipe supply the helium with smaller than about 0.01K temperature change

3. Conclusion

KSTAR in-cryostat He line routing consist of 40 manifolds and about four hundreds channels. The result of pipe size with cooling condition, we will use a kind of standard pipe. If we use the MLI on pipe, the heat load of pipe is small and the temperature increasing of pipe is smaller than 0.01K.

REFERENCES

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