§4. Performance of Cooling System of the Helical Coils for LHD

Imagawa, S., Mito, T., Watanabe, K.

The helical sub-system of the LHD cryogenic system covers the helical coils, the shell-arms, the supporting structures, the cryogenic supporting posts, and 80 K thermal shields. The total inventory of coolant reaches almost 15 m^3 as shown in Table 1. Coolant from the helium refrigerator is distributed by the Helical-coil-valve-box (HC.VB) that equips 49 valves. The helical coils are pool-cooled, and the conductors are packed into thick cases to endure large electromagnetic forces. The coolant is supplied from ten bottoms of the coil cases through two inlet headers. The gas generated in the coils is vented to an outlet header tank from ten tops of the coils. There are 20 parallel passes in the coils. The inlet headers and the header tank are connected to a large buffer tank in HC.VB. The coolant for the other objects flows in cooling pipes attached on them by cleats mechanically and epoxy resin of STYCAST 2580FT thermally. Because of huge area of the structures, the total length of cooling pipes exceeds 7.5 km, and the pipes also form a large number of parallel passes. The number for the supporting structures is 80 in pre-cooling process from the room temperature to 10 K. It is reduced to 20 in steady cooling. In spite of the large number, the temperature difference among the outlet pipes was well controlled within 30 K, as shown in Fig. 1. The difference among ten periodic points of the Outer 80 K shield was less than 5 K. Besides, the pressure drops are in good agreements with the design values based on circular pipes and bends in turbulent flow. These are evidence of justness of design and construction.

Since the coil case is a bath of helium, all the joints are welded, and there are no electric breaks. The supporting structures were also assembled by welding in order to attain high reliability for strength and rigidity. Then, large amounts of AC losses are induced by various discharges. The estimated values are listed in Table 2 for the normal discharge of 30 minute and resistor dumps in emergencies from 3 T. AC losses of the conductors was derived from the measured overall time constant of eddy current of the conductor.[1] AC losses of the other objects were estimated by being approximated to equivalent current circuits for the coil. The AC losses and steady heat load of the coils and the coil cases were measured by the decrease of liquid helium level during the 1M dump from 1.5 T, as shown in Fig. 2. These AC losses are in good agreements with the design values. The steady heat load is slightly larger than the design value of 60 W. The reason is not clear yet.

In the 1Q dump from high field, the helical unit was released from the refrigerator, and the pressure in the coil case increases rapidly. When the pressure exceeds 1.6 ata, controlled release-valves act, and the helium in the outlet header tank is exhausted to atmosphere. In the actual 1Q dump from 2.75 T, the liquid helium in the coil cases was almost vaporized in several minutes. The system worked precisely, and the refrigerator could start recovering the helium at early time after the dump. As the results, the amount of lost helium was saved to be 900 Nm^3.

Table 1 Helium inventory of helical sub-system

Parts	Inventory [LHe] (m3)
Helical coils and inlet headers	2.57 [2.57]
HC leads	0.36 [0.36]
HC outlet header tank and connecting pipe	2.57 [1.20]
Connecting pipe to safety valve	0.45 [0.0]
Shell-arm cooling pipes and headers	0.27 [0.27]
Supporting shell cooling pipes and headers	1.14 [1.14]
Outer 80 K shield cooling pipes and headers	0.35 [0.0]
Inner 80 K shield cooling pipes and headers	0.52 [0.0]
Cryogenic post 80 K cooling pipes	0.01 [0.0]
Buffer tank	4.34 [1.0]
Inner pipes in HC.VB and R.T. return pipe	2.22 [0.28]
Sum	14.80 [6.82]

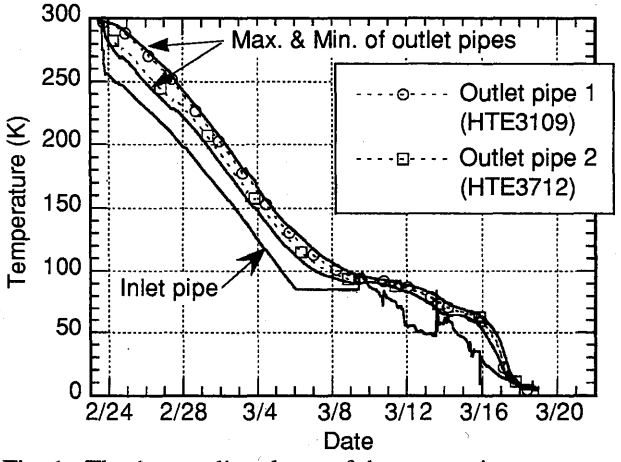

Fig. 1. The 1 st cooling down of the supporting structures.

Table 2 Estimated AC losses by discharge from 3 T [MJ]

	1Q (20 s)	1M (300 s)	Normal
Conductors	4.51	0.353	0.119
Coil case	6.49	0.433	0.144
Shell-arms	2.61	0.174	0.058
Supporting structures	10.83	0.722	0.241

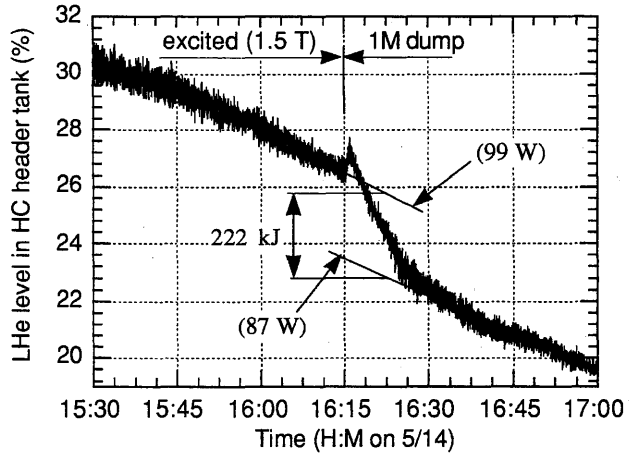

Fig. 2. LHe level in the HC header tank during 1M dump from 1.5 T. LHe supply was stopped from 60 min before the dump.

Reference
1) N. Yanagi, et al., Cryogenics 37 (1997) 783.