Reliable longtime operation of the SC Feeder System for the LHD

Shuichi Yamada, Sadatomo Moriuchi, Shinji Hamaguchi, Toshiyuki Mito, and the LHD group

National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu, 509-5292, Japan

National Institute for Fusion Science

Abstract

A superconducting (SC) current feeder system is used as the current transmission lines for the experimental fusion device, LHD. It consists of nine SC bus-lines with total length of 497 m, and nine pairs of gas-cooled current leads. The first campaign for the plasma confinement study on LHD started in 1998. Cryostable condition of the SC coils has been kept for more than four months in every year. The cooling process is automatically switched from forced-flow of two-phase helium to pool boiling, when the faults happen. The total time of the coil excitations exceeds 9,000 hours. Total number of the plasma production exceeds 120,000 shots.

History of LHD

The main objective of the LHD is to demonstrate the high potentiality of the helical-type device producing current-less steady-state plasma. The body of the LHD consists of a pair of helical SC coils, three sets of poloidal SC coils and their supporting structure with a total cold mass of 820 tons. Each helical coil is divided into three block coils that can be excited independently. The construction of the LHD, including the SC current-feeder system, finished in February of 1998, and the experiments for the plasma confinements started on 31 March. History of the LHD experiment is summarized in Table 1.

Table 1 Operation history of the LHD.

Operating Cycle / FY	No. of coil Excitations	Coil excitation (hh:mm)	Plasma Exp. (hh:mm)	No. of plasma Shots
1 / 1997-8	132	582:24	132:27	1,888
2 / 1998	121	508:53	345:07	5,244
3 / 1999	143	718:52	568:16	10,179
4 / 2000	106	625:00	484:46	8,896
5 / 2001	106	628:33	501:14	9,024
6 / 2002	88	460:16	341:42	6,081
7 / 2003	111	578:50	426:19	7,510
8 / 2004	87	574:31	461:15	7,398
9 / 2005	94	673:00	556:21	9,833
10 / 2006	99	669:42	554:28	9,598
11 / 2007	84	635:38	532:10	9,217
12 / 2008	80	485:54	392:12	6,933
13 / 2009	76	417:37	331:46	6,229
14 / 2010	70	463:52	373:17	6,793
15 / 2011	66	482:06	402:08	7,284
16 / 2012	40	342:28	289:57	5,135
17 / 2013	69	512:41	435:53	7,384
Total	1,572	9360:17	7129:18	124,626

Conclusions

The overall operational characteristics of the SC current-feeder system for the LHD were reported. The results are concluded as follows:

(1) The SC current feeder system of the LHD have been operated for 16 years without serious trouble. It contribute for the plasma experiments.

(2) Both liquid helium levels in the sub-cooler and current leads will automatically equalize by a siphon method without the mass-flow adjustment in the leads. This leads to full automatic operation of the SC feeders.

(3) We have demonstrated successfully that the SC current-feeder system with high-current capacities was reliable and safe, and was useful for the SC experimental fusion device.

SC Current Feeder System for LHD

Figure 1 gives an SC coil system of the LHD. The application of the SC bus lines leads to a decrease of the electrical power consumption for the power supplies and reduction for the installation work on site. Space for the heating device and diagnostics apparatus around the LHD enable to expand, by locating the current leads apart from it. Main parameters of the current-feeder system are listed in Table 1.

The cross-sectional view of the SC bus-line is shown in Fig. 2. An aluminum-stabilized, SC-compacted stranded cable that is the same size and same structure of the full-scale model was applied to the SC bus lines for the LHD. Electrical insulation was inserted between a pair of +/-cables. The vacuum-insulated transfer line consists of five corrugated stainless steel tubes assembled coaxially.

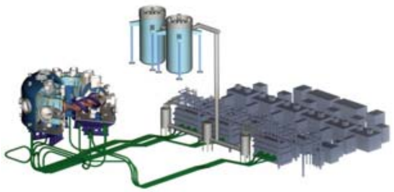

Fig. 1. LHD and SC current feeder system.

Table 2 Main parameters of the SC bus-line.

Items	Specifications
Number of SC bus-lines	nine
Total length of nine SC bus lines	497 m
Rated current	32 kA
Rated withstand voltage	dc 5 kV @ 77 K G-He
Minimum bending radius	1.5 m
Cryogenic transfer-line	five corrugated SUS tubes
Mass flow rates	12 g/s
Type of current-lead	Vapor gas cooled type

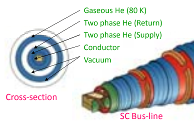

Fig. 2. Structure of an SC bus-line..

Flow Diagram & Control Scheme

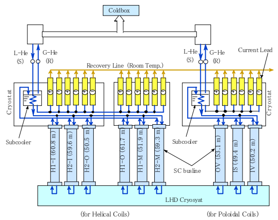

Fig. 3. Flow diagram of the helium flow in the SC current-feeder system.

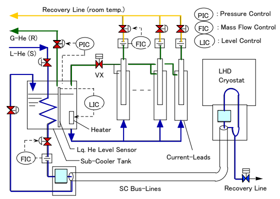

Fig. 4. Control scheme of the helium flow in the SC current-feeder system.

In a steady-state, two-phase helium from the cold-box is cooled to 4.4 K by the heat exchanger in the sub-cooler tank, and is supplied to the SC bus lines. Returned two-phase helium from the SC bus line flows into the sub-cooler, and separates into liquid and gas phase. A part of the liquid helium cools the current leads. Most of the liquid helium evaporates by the heaters, and returns to the cold-box.

The PID compensators for the cryogenic valves and the heaters adjust automatically for the manipulated values of the pressures in the sub-coolers, and mass flow rates of the SC bus lines and current leads, and the liquid helium levels in the sub-coolers.

Steady-State Operation

Fig. 5 and 6 give a typical example of the steady-state operation. The SC coils of the LHD are continuously charged up for ten hours in a daytime. Total mass flow rate of two phase helium of nine SC bus-lines had been kept in constant value of 90 g/s. The mass flow rates of the current leads have also been kept in constant value, even if the coil current changes from zero to the nominal value of 3 T operations. Both liquid helium levels in the sub-cooler and current leads will automatically equalize by a siphon method without the mass-flow adjustment in the leads, when the valve VX shown in Fig. 4 was open. Even if the mass-flow rates of the current leads were less than that of the self-cooling condition, a part of the evaporated helium gas from the current leads flowed into the sub-cooler through the valve VX, and returned to the cold-box. In steady-state, the heaters automatically adjust the overall heat balance between the SC current-feeder system and the refrigerator/liquefier system.

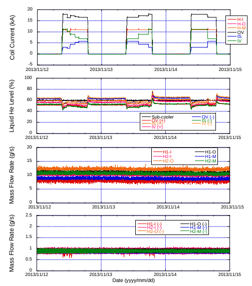

Fig. 5. Typical example of the steady-state operation: (a) coil current, (b) liquid helium in the leads, (c) flow rate of SC bus-lines, and (d) flow rate of current-leads.

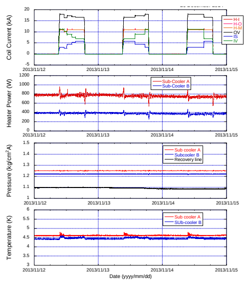

Fig. 6. Typical example of the steady-state operation: (a) coil current, (b) heater power of sub-cooler, (c) pressure in sub-cooler and recovery line, and (d) temperature of helium gas returned to the coldbox.

Fault Protection Properties

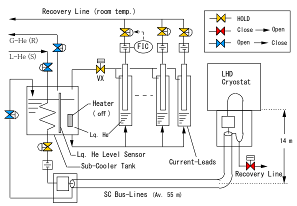

Fig. 7. Protection mode of SC current feeders.

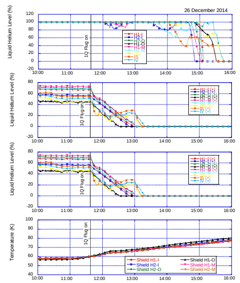

Fig. 8. Typical waveforms of the fault protection: Liquid helium level of coil-side terminal (a), Liquid helium level of plus CLs (b) and minus CLs (C), and He temp. of thermal shield channel of bus-lines (d).

The SC current-feeder system has a sufficient safety margin exceeding that of the SC coils of the LHD. The system is designed to maintain its rated current carrying capacities for 30 minutes, even if the coolants supplied to the SC current-feeder system are accidentally stopped. Function of this fault protection control scheme as shown in Fig. 7 was confirmed. The property of liquid helium levels of the coil-side terminals (CST) and current leads (CL) are monitored. The results are shown in Fig. 8.

Decay of the liquid helium in CST and CL was about 1 hour and 3hours, respectively. Liquid helium consumption of the innermost tube of the SC bus-line is negligible, because the liquid helium in the second inner channel absorbed the heat load of about 0. 3 - 0.4 W/m.

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