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First Cycle Operation of SC Current Feeder System for the LHD

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A superconducting (SC) current feeder system with total length of 497 m had been kept in cryostable condition during two months. Mass flow rates, pressures and liquid helium levels of the system were controlled automatically in the steady state operation. The stable operation for current-leads were investigated by using a siphon method. The SC current feeder system had been successfully performed with no trouble during the first experimental period.

1. INTRODUCTION

The Large Helical Device, LHD, is an experimental fusion device of the Heliotron type [1,2]. It consists of a pair of helical SC coils and three sets of poloidal SC coils. Each helical coil is divided into three block coils that can be excited independently. Nine SC bus-lines were prepared. The rated current and withstand voltage of the SC bus-lines are 32 kA and dc 5 kV, respectively. The average distance between the SC coils and their power supplies is 55 m.

A full scale model of a 20 m long SC bus-line was fabricated in 1994, and the experiments were conducted to study its characteristics. The SC cables for the bus-line were cryostable at a rated current of 30 kA, and charged up to 40 kA without quenching [3,4]. Using the full scale model, Inner Vertical (IV) coil for the LHD was excited up to the rated current of 20.8 kA [5]. The design and construction of the SC current feeder system was started in 1995 [6].

This paper describes the cool-down and current carrying properties of the SC current feeder system for LHD. Stable operation method for eighteen parallel current-leads is also investigated.

2. SC CURRENT FEEDER SYSTEM

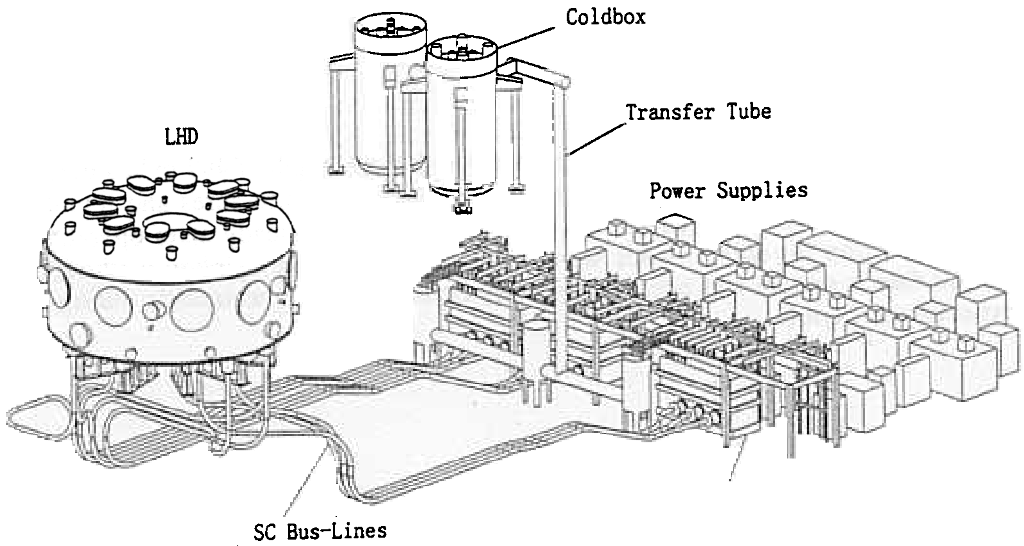
Figure 1 gives a Bird's-eye view of the experimental layout for LHD, showing the SC current feeder system. The application of the flexible SC bus-line leads to an electrical power consumption for the power supplies and reduction for installation works on site. Space for the diagnostics and/or heating device around the LHD enable to expand, by locating the current-leads apart from it. The SC current-feeder system requires high reliability and safety. An aluminum-stabilized, SC-compacted stranded cable was developed to satisfy the high stability requirements of an SC bus-line [3,4]. Vacuum-insulated, five-corrugated stainless steel tubes with a thermal shielding channel were used for the cryogenic transfer-tube. The specifications of the SC current feeder system are listed in Table 1.

Figure 2 shows the helium flow circuit of the SC current feeder system. In a steady state, two-phase helium from the cold box is sub-cooled in the sub-cooler tank, and is supplied to the SC bus-line. Returned two phase-helium from the SC bus-line flows into the sub-cooler tanks, and separates into liquid and gas phase. A part of liquid helium is used for the current-leads cooling. Most parts of liquid helium evaporates by the heater and returns to the coldbox.

Figure 3 shows a control scheme of a helium flow for the SC current feeder system. Each process

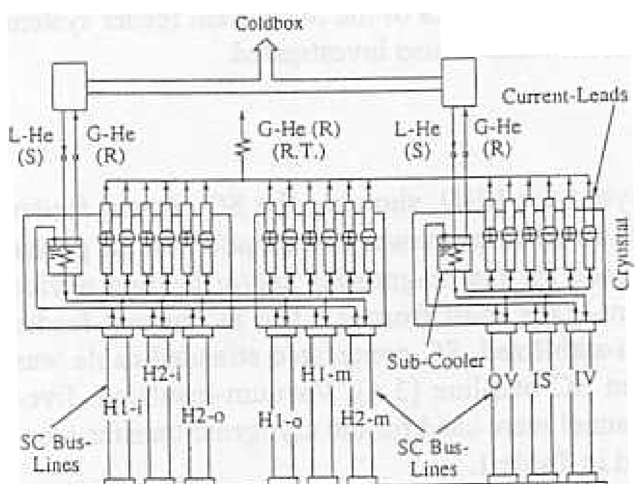
Items	Specifications
Number of SC bus-line	6: for helical coils 3: for poloidal coils
Total length of 9 bus-lines	497 m
Rated current	32 kA
Rated withstand voltage	5 kV (in 77 K gas He)
Minimum bending radius	1.5 m
Cryogenic transfer-line	five corrugated tubes
Cooling	forced flow of 2-phase He
Rated mass flow rate	12 g/s
Current-leads	Vapor gas cooled type

Items	Conditions
SC bus-lines	
Liquid helium level of both terminals	> 50 %
Temperatures on terminals	<5.0 K
Temperature in thermal shield	< 100 K
Mass flow rates	> 5.0 g/s
Current-leads	
Voltages	< 50 mV
Mass flow rate	> 0.5 g/s
Sub-coolers	
Liquid helium levels	> 50 %
Pressures	< 0.185 MPa



Bird-eye's view of an SC current feeder system for the LHD.

of a cooling-down, steady-state operation and warming-up is controlled by the sequential program that is linked together with the program for the refrigerator system. The PID compensators for the cryogenic valves and heater powers adjust automatically for the manupulated values of the mass flow rates of the SC bus-lines and current-leads, a liquid helium level and pressures in the sub-cooler tanks. The allowable conditions for the coil excitation are listed in Table 2.



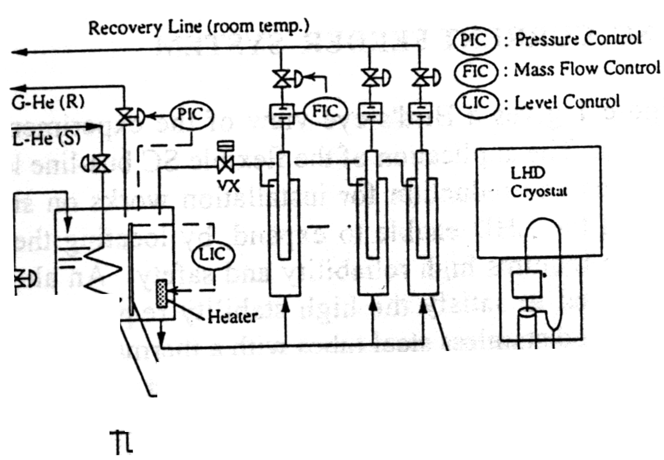


Fig. 3 Control scheme of a helium flow in the SC current feeder system.

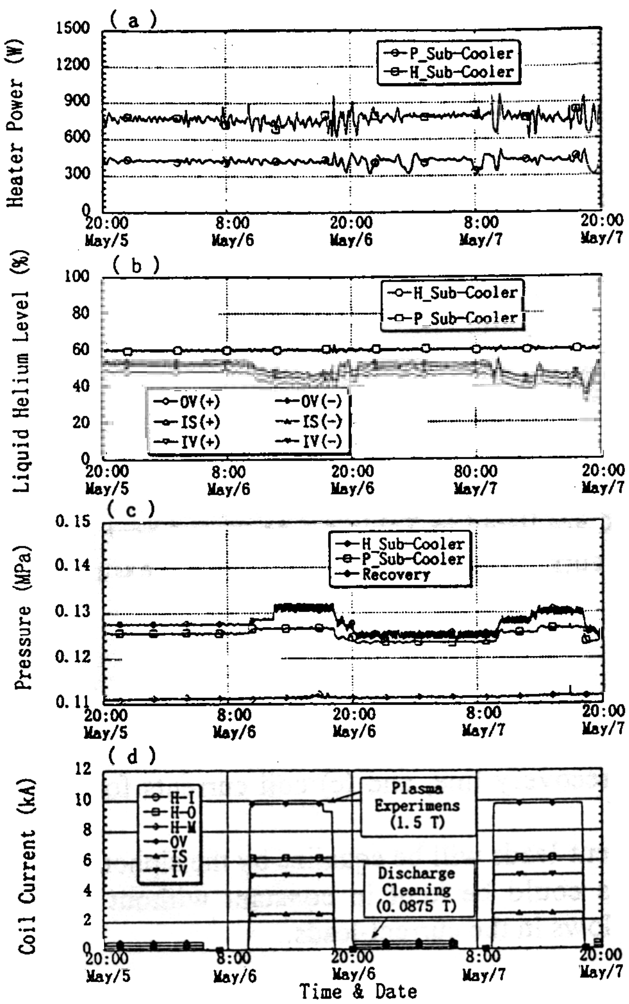


Fig. 4. Typical examples of steady state operation for the plasma experiments.

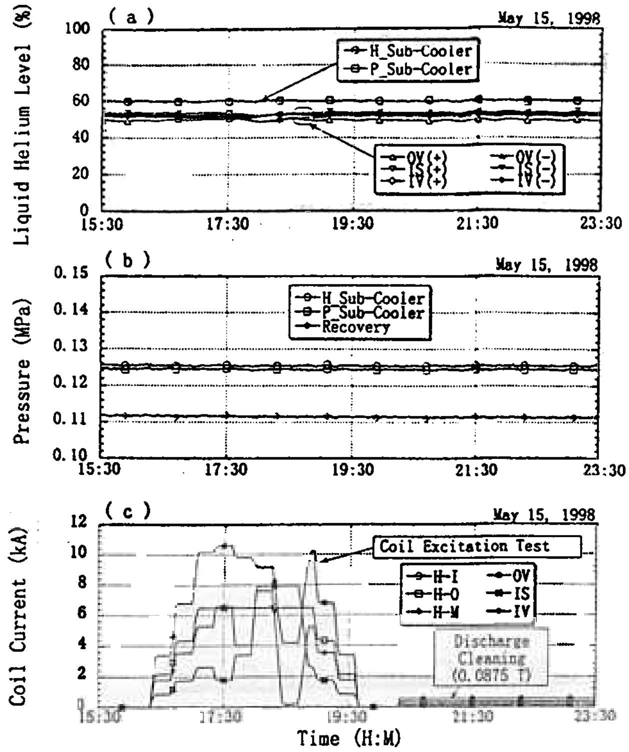


Fig. 5. Typical examples of stable operation for the current-leads.

Table 3 Dominant mass flow rates and heat loads into the SC bus-lines.

Parameters	for H/C	for P/C
Mass flow rate of SC bus-lines	60 g/s	31.5 g/s
Mass flow rate of current-leads	10.8 g/s	6.0 g/s
Heater power	780 W	410 W
Heat Load into SC bus-lines	~220 W	~90 W

3. FIRST CYCLE EXPERIMENTS

3.1 Steady State Operations

The experiments for the plasma confinements under 1.5 T and the wall conditioning for the vacuum vessel under 0.0875 T had been performed alternately during the first cycle. Cryostable condition of the SC coil excitations, as shown in Table 2, had been kept continuously in this period. Figure 4 shows a typical example of steady state operation; (a) heater powers in the sub-coolers, (b) liquid helium levels in the sub-coolers and current-leads, (c) pressures in the sub-coolers and recovery line, and (d) coil currents for the plasma experiments.

Both liquid helium levels in the sub-cooler tanks were well controlled in constant value of 60 % by the heaters. The pressure difference between the sub-cooler and recovery line influences the liquid helium levels in the current-leads. When the current flows through the current-leads, liquid helium levels will be decrease, because of the Joule heating. Therefore, the pressures in the sub-cooler tanks had been adjusted to the suitable values between 0.124 MPa and 0.132 MPa, for keeping a liquid helium in the current-leads.

3.2 Heat Balance and Heat Load

The heater powers in the sub-cooler tanks depend on the mass flow rates of the SC bus-lines and current-leads. The total heat load into the bus-lines including Joul heating at the terminal connections, thermal conductions from control valves and measuring sensors can be estimated by the heat balance between the inflow and outflow coolants. Mass flow rate of the SC bus-line had been kept from 10 g/s to 11g/s in a

Table 4 Measured heat-load at 80 K into the SC bus-lines.

Name	Length	Measured heat load
OV	53.1 m	92 W
IS	49.4 m	81 W
IV	50.2 m	150 W
H1-I	60.8 m	138 W
H1-M	51.9 m	118 W
H1-O	61.7 m	113 W
H2-I	59.6 m	150 W
H2-M	59.3 m	149 W
H2-O	50.5 m	162 W

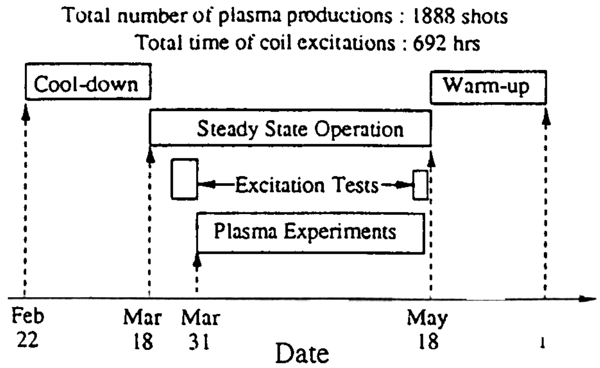


Fig. 6 Summary of a first cycle experiments on the LHD.

most part of the first cycle. The heat load into the two-phase helium of the helical and poloidal SC bus-lines are estimated to be 220 W and 90 W. These results are summarized in Table 3.

Measured heat loads into the SC bus-lines at 80 K are listed in Table 4. Averaged heat loads are less than designed value of 3.0 W/m. Heat flux into the current-lead cryostats were also measured to be 5.4 W. These values agree with that of design value.

3.3 Effective Current-Leads Control

The stable operation for current-leads could be obtained, when the valve VX shown in Fig. 3 is open. A typical example is shown in Fig. 5; (a) liquid helium levels in the sub-cooler tanks and current leads for the poloidal coils, (b) pressures in the sub-coolers and recovery line, and (c) coil currents for the coil excitation test.

The liquid helium between the sub-cooler and current-leads will be equalize by the siphon method. Therefore, the liquid helium level of the current-leads could be kept in constant without pressure adjustment in the sub-cooler tanks, whenever the current flows in the current-leads.

3.4 First Cycle Experiments

Figure 6 displays the summary of the first cycle experiments on the LHD. First cool-down started in February 23, and all SC coils including SC bus-lines became cryostable conditions on March 18. Experiments for the plasma confinements were performed from March 31 to May 17.

Mode changes of the coil excitations for the plasma experiments, power shut-down test for the coil protection, long term excitation for the discharge cleaning (five days) were carried out in this period. Total shot numbers of plasma production were 1888, and total times of the coil excitation were 692 hours. The SC current feeder system had been operated with no trouble during the first experimental period.

4. CONCLUSION

Cool-down and current carrying properties of the SC current feeder system were investigated. The results are concluded as follows: (1) Normalized heat loads into the SC bus-lines at 80K was less than 3 W/m, and the average heat flux into the three current-lead cryostats was 5.4 W. (2) Mass flow rates, pressures and liquid helium levels of the SC bus-lines and current-leads are well controlled automatically in the steady state operation. (3) A stable operation of eighteen paralell current-lead could be obtained by using a siphon method. (4) We have demonstrated successfully that the SC current feeder system with high current capacities was useful for the SC experimental fusion device.

REFERENCES

[1] Motojima, O., et al, Fusion Engin. and Design, Vol. 20, (1993) 20, 3-14.
[2] Motojima, O., Satoh, S., Presented in 17th ICEC, Bournemouth, UK, July 14-17 (1998) F-1.
[3] Yamada, S., Mito T., et al, Fusion Technology 1994, (18th SOFT, 1994, Karlsruhe) .913-916.
[4] Mito, T., Yamada, S., et al, IEEE Trans. on Magn. (1994) 30, 2090-2093.
[5] Takahata, K., et al, IEEE Trans. on Appl. Supercond. (1997) 7 477-480.
[6] Yamada, S., Miot, T., to be published in Proc. of MT-15, Beijin, Oct. 20-24 (1997) PB-32.