(3) LHD Device Engineering Experiments

1. Introduction

The LHD is the world's largest superconducting system that consists of a pair of pool-cooled helical coils (H1 and H2 coil), three pairs of forced-flow-cooled poloidal coils (IV, IS, and OV coils), nine superconducting bus-lines, a helium liquefier and refrigerator of 10 KW class, and six DC power supplies. Availability higher than 98% has been achieved in a long-term continuous operation both in the cryogenic system and in the power supply system since the first cool-down in February 1998.

One big problem is shortage of cryogenic stability of the helical coils. In order to improve the stability by lowering temperatures of the coil, a subcooling system was installed before the tenth cool-down. It consists of an additional cooler, two-stage cold compressors, a cryostat, three control valves, a safety valve, ten heaters at the coil outlet, and diagnostics. Its performance tests were carried out in the first half of the period of plasma experiments. After that, higher excitation tests were carried out. Results of device engineering experiments and the operations in the tenth cycle are summarized.

2. Tenth Cycle Operation of LHD

The history of the tenth cycle operation of LHD is shown in Table 1. Main compressors of the cryogenic system started on August 18, 2006 and stopped on March 16, 2007. The total operating time was 5,037 hrs, and the availability in this cycle was 100%.

Table 1 The history of the tenth cycle operation.

Operation mode	Date
<Vacuum pumping system>	
Pumping a cryostat	8/7/2006-3/8/2007
Pumping a plasma vacuum vessel	8/8/2006-3/2/2007
<Cryogenic system>	
Purification	8/18/2006-8/29/2006
Cool-down	8/30/2006-9/25/2006
Steady state operation	9/26/2006-2/15/2007
Warm-up	2/16/2007-3/16/2007

3. Device Engineering Experiments

Excitation tests of the superconducting coils before plasma experiments were conducted on September 28, 29, and October 2. The following values, same as the previous cycle, were attained without propagation of a normal zone;

(1) *#1-o, B*=2.70 T @ 3.75 m (H-O/M/I = 11.25 kA)
(2) *#1-d, B*=2.846 T @ 3.60 m
(H-O/M/I = 11.6/11.55/11.0 kA)
(3) *#1-d, B*=1.257 T, γ=1.156
(H-O/M/I = 0.214/2.877/12.0 kA)
(4) *#1-d, B*=2.783 T @ 3.60 m
(H-O/M/I = 11.4/11.0/11.0 kA)
(5) Mode transition at 11.0 kA of the helical coil.
(radii of the plasma axis were 3.42 to 4.1 m,
quadruple components were 72 to 200%)
(6) Slow charge and discharge to *#1-d* 2.85 T (γ=1.258)
for strain measurements

In performance tests of the subcooling system, a method to maintain the flow rate of 50 g/s to the helical coil was investigated at first. Since the output of the orifice flow meter at the inlet of the heat exchanger fluctuated widely, we selected the method to fix the open ratio of the inlet valve of the helical coil. The liquid level in the outlet tank was controlled with the ten outlet heaters. Next, the performance of the subcooling system was examined, and its operational scheme was studied. The nominal refrigerating power of 280 W of the cold compressors was attained at the rotating speed of about 1,500 Hz that is 95% of the maximum. When the mass flow was 50 g/s and the temperature in the evacuated tank was 3.0 K, the inlet and outlet temperatures of the helical coil were lowered to 3.2 K and 3.8 K, respectively, as planned.

The device engineering experiments were conducted on the following schedule while the helical coils were cooled by subcooled helium.

<u>November 28, 2006</u>

(1) Measurement of AC losses of the helical coil from the temperature increase by charge and discharge to *#1-o* 2.7 T by 0.05 T/min (H1, H2: 11.25 kA by 3.5 A/s)

(2) Charge to 11.25 kA as the helical coil current by 3.5 A/s and to 11.45 kA by 0.7 A/s

<u>November 29, 2006</u>

(1) Charge to 11.25 kA by 3.5 A/s and to 11.5 kA by 0.7 A/s. The 18th propagation of a normal-zone was observed at H2 coil at 11.44 kA.

<u>November 30, 2006</u>

(1) Charge to 11.25 kA by 3.5 A/s and to H-O/M/I= 11.8/11.4/11.4 kA by 0.7 A/s.

(2) Plasma axis shift between 3.5 m and 3.9 m at 11.4 kA.

<u>December 1, 2006</u>

(1) Measurement of loop currents decaying with a very long time constant in the poloidal coils by charge and discharge to #1-d 2.5 T by 0.2 T/min

(2) Experiments of the current control for the pulse operation

4. Summary

New achievement by device engineering experiments and operations are summarized as follows;

(1) The performance of the subcooling system was confirmed to attain the design values.

(2) Improvement of the cryogenic stability of the helical coils by being subcooled was less than it was expected. The reason is under consideration.

(3) It was confirmed that the loop currents with a very long time constant were not induced by the fast charge and discharge.

(4) Influence to the balance voltage of the coils at the pulse operation was investigated. It will be allowable for the quench detection systems.

(5) It was confirmed that the helium refrigerator had enough power to maintain the mass flow of helical coil up to 50g/s.

(Imagawa, S.)