(4) 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.

A subcooling system was installed before the tenth cool-down to improve the cryogenic stability of the helical coils by lowering temperatures of the inlet cryogen. Its continuous operation has been demonstrated, and excitation tests to the higher field have been carried out. Results of device engineering experiments and the operations in the eleventh cycle are summarized.

2. Eleventh Cycle Operation of LHD

The history of the eleventh cycle operation of LHD is shown in Table 1. Main compressors of the cryogenic system started on August 17, 2007 and stopped on March 21, 2008. The total operating time was 5,184 hrs, and the availability in this cycle was 99.5%. The control system of the cryogenic system was stopped by a failure of a VME reflective memory board. It took 20 hours to restart the system by replacement of the failed board. Vaporized helium of about 12,000 Nm^3 was vented to atmosphere during the stop time. It took 16 days to cool-down to the steady mode with charging helium.

Table 1 The history of the eleventh cycle operation.

Operation mode	Date
<Vacuum pumping system>	
Pumping a cryostat	8/2/2007-3/14/2008
Pumping a plasma vacuum vessel	8/3/2007-3/12/2008
<Cryogenic system>	
Purification	8/17/2007-8/28/2007
Cool-down	8/29/2007-9/20/2007
Steady state operation	9/21/2006-2/21/2008
Warm-up	2/22/2008-3/21/2008

3. Device Engineering Experiments

Excitation tests of the superconducting coils before plasma experiments were conducted from September 25 to 28. In the first excitation to #1-o 2.70 T to examine the change of conductor movement of the helical coils, finite-length propagation of a normal zone was observed at 11.17 kA and 11.21 kA of the helical coil currents. Therefore, the field was lowered to 2.65 T in the second and third excitations. Besides, short propagation of a normal zone was observed at 11.0 kA at plasma-axis of 4.1 m that is the similar condition as the 17th propagation in 2003. The cryogenic stability of the helical coil is not deteriorated. In subcooling operation, a normal zone was propagated at the same position at 11.4 kA, and the propagation length is the shorter than that at 11.0 kA in saturated helium. Then, improvement of cryogenic stability by subcooling was confirmed. The following values were attained;

(1) *#1-o, B*=2.65 T @ 3.75 m (H-O/M/I = 11.042 kA)
(2) *#1-d, B*=1.257 T, γ=1.156
(H-O/M/I = 0.214/2.877/12.0 kA)
(3) *#1-d, B*=2.783 T @ 3.60 m
(H-O/M/I = 11.4/11.0/11.0 kA)
(4) 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%)
(5) Slow charge and discharge to *#1-d* 2.85 T (γ=1.258) for strain measurements,
(6) *#1-d, B*=2.883 T @ 3.60 m (H-O/M/I = 11.8/11.4 /11.4 kA) and plasma axis shift from 3.5 m to 3.75 m at 11.4 kA of the helical coil in subcooled helium.

The higher field excitation tests were conducted at the evening on the following days while the helical coils were cooled by subcooled helium.

<u>October 16, 2007</u>
H-O/M/I = 12.4/11.7/11.0 kA
<u>October 23, 2007</u>
H-O/M/I = 12.4/11.7/11.1 kA
<u>November 16, December 18, and December 26, 2007</u>
H-O/M/I = 12.4/11.85/11.1 kA
<u>January 29, 2008</u>
H-O/M/I = 12.4/12.0/11.1 kA

4. Research activities

We have promoted device-engineering researches using the LHD. Their main purpose is optimization of the subcooling system. The titles of the researches are listed in the following;

(1) Optimization of the control of the subcooling system of the LHD. (Okamura, T. (Tokyo Tech.))
(2) Monitoring and state estimation of LHD coils. (Ishigohka, T. (Seikei Univ.))
(3) Improvement of cryogenic stability of LHD helical coils by lowering the outlet temperature from 4.4 K to 3.9 K. (Imagawa, S. (NIFS))
(4) Achievement of 2.9 T@3.6 m operation with sophisticated monitoring of balance-voltage signals in the LHD superconducting helical coils. (Yanagi, N. (NIFS))
(5) Operation and control of the subcooling system in the 11th LHD experiment campaign. (Hamaguchi, S. (NIFS))
(6) Temperature evaluation of the LHD helical coils cooled by subcooled helium under coil excitation. (Obana, T. (NIFS))
(7) Construction of high voltage power supply for pulsated excitation of superconducting coils of the LHD. (Chikaraishi, H. (NIFS))

(Imagawa, S.)