§2. Highly Reliable Operations of the LHD Cryogenic System

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The LHD cryogenic system consists of superconducting magnets of the helical coils, poloidal coils and superconducting bus-lines cooled by a helium refrigerator having the equivalent cooling capacity of 9.2 kW@4.4 K. 15 times of plasma experimental campaigns have been performed successfully from 1997. The total operation hours of the LHD cryogenic system was 67,278 hours with high reliability of 99.1%. The highly reliable operational history of the LHD cryogenic system are reported with the knowledge obtained in the 14 year operations.

The helium refrigerator of LHD consists of the cold-box, the 50 g/s helium gas purifier, the 20,000 liter liquid helium reservoir, the 50,000 liter liquid nitrogen reservoir. Eight oil-injected screw compressors (960 g/s, 1.9 MPa) are installed in the compressor room, which is 50 m apart from the He refrigerator room, and are connected with pipes running in the underground tunnel. Two 700 m^3 (2.0 MPa) spherical holders and four 100 m^3 (2.0 MPa) cylindrical holders are used as helium buffer tanks to stabilize inlet and outlet pressures of the helium compressors and are also used for balancing the helium inventory in the LHD cryogenic system. Four 100 m^3 (2.0 MPa) cylindrical holders are used as supplying tanks of impure helium gas, which must be purified by the purifier before supplying to the He buffer tanks. The cooling capacities of the helium refrigerator are 5.65 kW at 4.4 K, 20.6 kW from 40 K to 80 K and 650 L/h liquefaction, simultaneously.

The LHD cryogenic system has been designed, constructed and improved aiming for the realization of high reliability and easy operation. Fig. 1 shows the 15th cycle operation as a typical operation of LHD during a year.

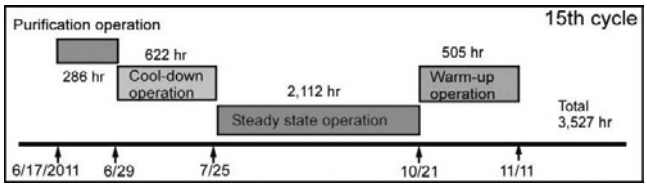

Fig. 1. 15th cycle operation of the LHD cryogenic system.

The total operation hours of the system until the end of the 15th cycle was 67,278 hours, and the steady state operation hours for keeping the system in the superconducting state have reached 44,741 hours. There were 26 times of the failures during the operations caused the system to stop. However, the total of the down time was only 576 hours. The system has achieved high reliability of 99.1% and there has been no serious failure that terminates the stable operation.

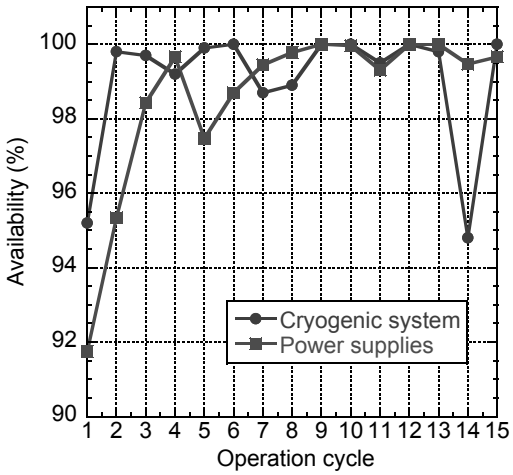

Fig. 2. Availability of the LHD superconducting system.

A: Availability

$$A = \frac{MTBF}{MTBF + MTTR} \quad (1)$$

MTBF: Mean Time Between Failures
MTTR: Mean Time To Repair

Table 1. Mean time to repair according to cause

Cause of failures	Number of failures	Total down time (h)	MTTR (h)
Control system	11	280.9	25.5
Compressor	6	278.2	46.4
Utility	4	7.5	1.9
Loss of power	4	10.0	2.5
Miss-operation	1	0.1	0.1
Total	26	576.7	22.2

14 years have passed from the beginning of the system operation, and it has become time when the aged degradation is feared. Fig. 2 shows the availability of each operation cycle for the cryogenic system comparing with that of the coil power supplies. Here, the availability is calculated by expression 1 by using the mean time between failures and the mean time to repair. After the early failure period of the start of operation, both the cryogenic system and the coil power supplies have achieved a high availability. The availability of the cryogenic system decreased at the 14th cycle, and the effect by the aging was feared. However, a high availability is recovered in the 15th cycle operation.

The failure count that arrived at system stop, the down time, and MTTR are listed in Table 1 according to the failure cause. It is understood that the failure of the compressor with long MTTR and the failure of the control system with a lot of counts have the majority of the failure cause to the system stop.

As a result of highly reliable operations of the LHD cryogenic system, LHD keeps offering the stable fusion plasma experiment environment for 14 years. The excitation count of the superconducting coils until the end of the 15th cycle was 1463 times, the total excitation time was 8,505 hours, the plasma experiment time was 6,403 hours, and the number of plasma shots has reached 112,107.