Renewal of control system and reliable long term operation of LHD cryogenic system

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Contents

* Introduction to LHD cryogenic system
* Reliable long term operation of LHD
* Renewal of the LHD cryogenic control system
* Summary
The Large Helical Device (LHD) is a heliotron-type fusion plasma experimental machine. LHD consists of a fully superconducting magnet system cooled by a helium refrigerator having the total equivalent cooling capacity of 9.2 kW@4.4 K. 17 times of plasma experimental campaigns have been performed successfully from FY1997 with high reliability of 99%. The improvements have been done to prevent serious failures and to pursue further reliability.
Large Helical Device (LHD) heliotron-type fusion plasma experimental machine

LHD cryostat / superconducting coils

Plasma vacuum vessel

Plasma major radius: 3.9 m
Plasma minor radius: 0.6 m
Plasma volume: 30 m³
Magnetic field: 3 T
LHD superconducting coils

- LHD Cryostat
- Outer dia. 13.5 m
- Height. 8.8 m
- Poloidal Coils
- IV Coils
- IS Coils
- OV Coils
- Helical Coils
- Cold mass 822 t
- Total weight 1500 t

822 t
1500 t
LHD cryogenic system

- LHD cryostat / superconducting coils
- He refrigerator
- Superconducting bus-lines
- Power supplies
- He compressors
- He gas storage tanks
- LHD experiment building

LHD experiment building
LHD helium refrigerator

- He refrigerator: 5.7 kW @ 4.4K, 20.6 kW @ 80 K
- LHe: 650 L/h
- He drier: 50 g/s
- He purifier: 50 g/s
- LN₂ storage: 50,000 L
- LHe Dewar: 20,000 L
- He gas storage tanks: 2,200 m³, 2 MPa
- 8 Screw compressors: 750 g/s + 210 g/s
- HC V.B.
- PC V.B.
Operation time of LHD cryogenic system

- **Total operation time:** 74,595 h
- **Steady state operation time:** 48,031 h
- **Stop time:** 742 h
Availability of LHD cryogenic system

Availability (\%) vs Operation cycle

Availability = \frac{MTBF}{MTBF + MTTR}

MTBF: mean time between failures
MTTR: mean time to repair

- 14th cycle operation thrust bearings of screw compressors broke down
- 16th cycle operation electric insulation tube of poloidal coil generated a cold leakage
## Failure analysis of LHD cryogenic system

<table>
<thead>
<tr>
<th>Cause of failure</th>
<th>Number of failures</th>
<th>Total down time (h)</th>
<th>MTTR (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control system</td>
<td>11</td>
<td>287.4</td>
<td>26.1</td>
</tr>
<tr>
<td>Compressors</td>
<td>5</td>
<td>268.2</td>
<td>53.6</td>
</tr>
<tr>
<td>Superconducting coils</td>
<td>1</td>
<td>169.0</td>
<td>169.0</td>
</tr>
<tr>
<td>Loss of electric power</td>
<td>5</td>
<td>10.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Utility</td>
<td>4</td>
<td>7.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Miss operation</td>
<td>1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>27</strong></td>
<td><strong>742.2</strong></td>
<td><strong>27.5</strong></td>
</tr>
</tbody>
</table>
Improvements of LHD cryogenic system

* Addition of redundant compressors
  * Two kinds of redundant compressors were added to back up even when which one of 8 compressors breaks down

* Renewal of cryogenic control system
  * Down-sizing of control devices has been done from VME controllers to compact PCI controllers in order to simplify the system configuration and to improve the system reliability
Problems of existing cryogenic control system

* Expansion and complication of control system
  * Distributed, redundant system with automated fault diagnosis
  * 12 VME controllers
    AI:1045, Ao:216, Di:896, DO: 768

* Advantage of open system is losing
  * Reliability depends on products of a specific manufacture (Reflective memory)
Existing cryogenic control system

Programing PC

Operating terminals

LAN

Optical communication line for Reflective memory

VME controller (active)

VME controller (standby)

CPU

Reflective memory

IO Board

Analog Input

Analog Output

Digital Input

Digital Output

Signal conditioners
Changing-over switch

He refrigerator

VME controllers for Helical coils, Poloidal coils, SC bus-lines, Integrated VME

IO Board

CPU

Reflective memory

IO Board

Analog Input

Analog Output

Digital Input

Digital Output

Signal conditioners
Changing-over switch

Helical coils / Poloidal coils / SC bus-lines
Renewal of cryogenic control system

* New system is composed of compact PCI controller and remote I/O connected with EtherNet/IP
* Making the system redundant by doubling CPU, LAN, and Remote I/O respectively
Summary

* Highly reliable operations of the LHD cryogenic system have been achieved during 16 years from 1997
  * Total operation time: 74,595 hours
  * High availability: 99 %
* Smooth renewal of the cryogenic control system completed successfully in 2013
  * Development of new control system was executed in 2011
  * Field tests have been done in 2012
* It is necessary to establish the diagnostic working beforehand the aging of the superconducting coils.