16. Department of Engineering and Technical Services

The Department of Engineering and Technical Services covers a wide range of work in the design, fabrication, construction, and operation of experimental devices in the fields of software and hardware.

The department consists of the following five divisions. The Fabrication Technology Division oversees the construction of small devices and the quality control of parts for all divisions. The Device Technology Division works on the Large Helical Device (LHD) and its peripheral devices except for heating devices and diagnostic devices. The Plasma Heating Technology Division supports the ECH system, the ICRF system, and the NBI system. The Diagnostic Technology Division develops, operates, and maintains all diagnostic devices. Finally, the Control Technology Division concentrates on the central control system, the cryogenic system, the current control system, and the NIFS network.

The total number of staff is 54 (2017). We are in charge of the development, the operation, and the maintenance of the LHD and its peripheral devices together with approximately 58 operators.

1. Fabrication Technology Division

The main work of this division is the fabrication of experimental equipment. We also take care of technical consultation and experimental parts supplies related to the LHD experiment. In addition, we manage the administrative procedures of the department.

The number of machined requests was 50, and the production parts total number was 233 in this fiscal year (FY). The total number of electronic engineering requests and articles were 8 and 22, respectively. Details of some of this division’s activities follow below.

(1) Phase detection circuit

The circuit shown in Fig. 1 is to use the CO2 laser dispersion interferometer. It is constructed of ADC (5Ms/s, 16bit, AD7625), FPGA board (EDX-301, Spartan6), and DAC (DA9754). The FPGA calculates the arctangent of the output IQ complex signals from the interferometer in real time.

(2) Corrugated Resonator

We have fabricated a grating mirror (as shown in Fig. 2) to divide a microwave at the frequency of 82.7 GHz and 165.4 GHz. The mirror has 70 gratings. The parameter of the grating is line spacing 1.878 mm and 30 degree blaze angle.

Fig. 1 Phase detection circuit

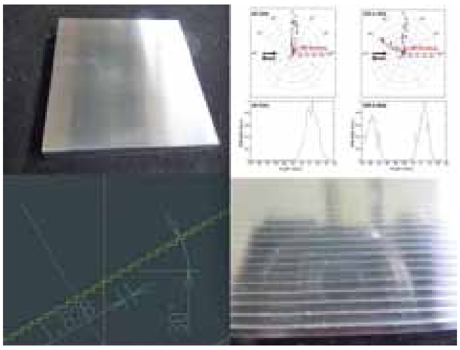

Fig. 2 Grating mirror

2. Device Technology Division

The Division supports the operation, the improvement, and the maintenance of LHD.

(1) Operation of LHD

The LHD 19th plasma experimental campaign began on February 8, 2017, and continued through August 3, 2017. In this experimental cycle, we generated plasma using deuterium gas.

We started to evacuate the air from the cryostat vessel for cryogenic components on December 15, 2016, and the plasma vacuum vessel on December 16. During this experimental campaign, our vacuum pumping systems were able to evacuate the air from both of the vessels without trouble. The LHD operation was completed on September 26, 2017. The number of days of the plasma experimental period was 92 days in total.

(2) Operation of the exhaust detritiation system

In fiscal 2017, the exhaust detritiation system (EDS) was operated continuously except for the inspection period.

The EDS consists of two systems. One is the vacuum gas detritiation system (MS type system) and the other is the purge gas detritiation system (PM type system). After the LHD 19th plasma experimental campaign, the tritium contained in the purge gas from the vacuum vessel was removed by PM type system for workers to enter the vacuum vessel. After the removal operation for 4 weeks, the concentration of the tritium decreased below the specified value and workers could enter the vacuum vessel.

(3) Access control system of vacuum vessel

After the Deuterium Experiment, only permitted people can enter the vacuum vessel. To strictly manage entrance into the vacuum vessel, an electric lock was installed in the door of the entrance of the vacuum vessel. This door is unlocked by a card key, FeliCa.

When an admitted person holds the card key over a card reader, the lock is unlocked if the key has already been registered. The card reader is connected to a small computer named Raspberry Pi. An administrator can register and delete the information of the card keys through the Raspberry Pi from the remote control room. By watching monitors (Fig. 3) which are in the entrance of the vacuum vessel and the control room, workers are able to know who is in the vacuum vessel.

In the vacuum vessel, the state of the oxygen concentration and the ventilation are very important for workers. A monitoring system (Fig. 4) monitors the values of oxygen concentration and ventilation, and bans entrance when the values become out of range.

Fig. 3 Access display monitor

Fig. 4 Monitoring system

(4) Thermal analysis of the newly designed pumping system using NEG pumps in the closed helical divertor (CHD) in LHD

For the effective divertor function, the Saes getters NEG (Non-Evaporable Getter) pump module, HV400 module, was selected as a hopeful candidate for the vacuum pump in the CHD on the basis of experimental results in the test facility.

In the CHD configuration, the vacuum pumping system is installed behind the dome structure on the inboard side of the torus as shown in Fig. 5. The super-conducting magnet coils are located on the back side of the vacuum vessel (VV). In the operational aspect, for the activation of the HV400 module, the getter material in the module requires heating process by passing a suitable AC current. Therefore, one of the thermal issues in designing the pumping system is the evaluation of heat load by radiation due to the activation process of the HV400 modules in order to ensure the heat insulation reliability to the super-conducting magnet coils.

To evaluate the temperature rise of the VV against the radiation heat flux, the heat load was analyzed using a finite element method based software for multi-physics analysis (ANSYS). The model geometry is shown in Fig. 6. For reducing the heat intrusion due to plasma radiation, the VV is covered with protection plates 10 mm in thickness, and it is cooled by the cooling channels attached on the inner surface of the VV. Regarding thermal boundary conditions, the surface temperature of an HV400 module during an activation process reaches 400 °C according to an actual measurement value. The water temperature in the cooling channel is assumed to be 22 °C in a normal temperature. We can approximate the value for the heat transfer coefficient between the inner surface of the cooling channel and the coolant water with a constant value of 1000 W/m2K because the coolant velocity is close to constant. Fig. 7 shows calculated temperature distributions of protection plates and the VV. The maximum local temperature of the VV is less than 70 °C at the location far from cooling channels, even though the maximum temperature of the protection plates is approximately 160 °C. As a result, it is shown that the maximum local temperature of the VV can be kept below 95 °C, which is an allowable temperature of the VV from the viewpoint of heat insulation properties.

Regarding the above results, the thermal shielding performance of protection plates is adequate for protecting the VV from the heat flux from HV400 modules. Lessons learned from this work can be included in the operation plan.

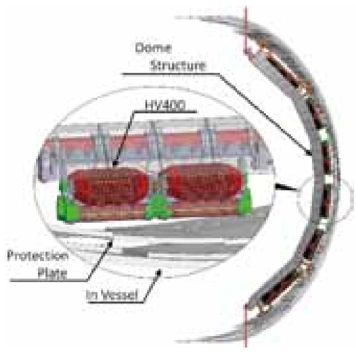

Fig. 5　Geometry of the pumping system using Saes getter NEG pump modules. These modules are connected to the cooling pipe of the dome structure by the support structure.

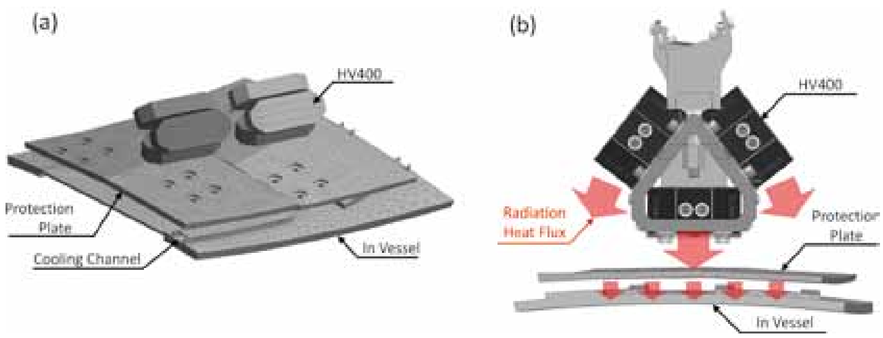

Fig. 6　(a) Model geometry and (b) schematic view of heat flux due to the radiation heating

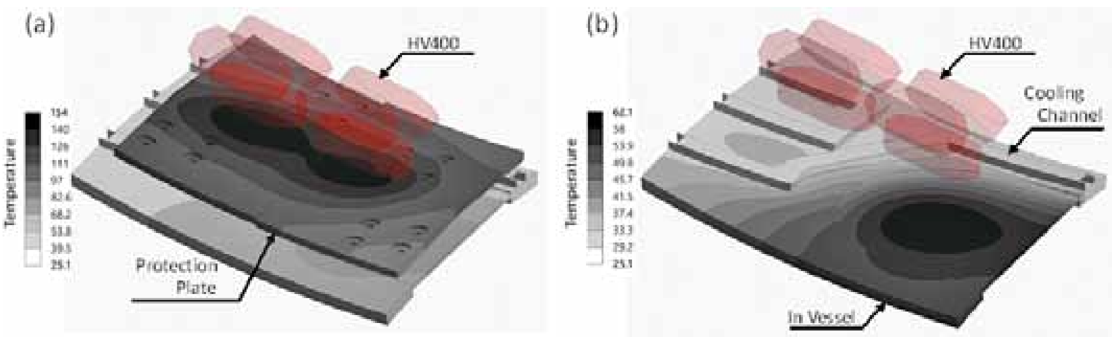

Fig. 7　Temperature profiles of (a) protection plates and (b) in vessel

3. Plasma Heating Technology Division

The main tasks of this division are the operation and the maintenance of the three different individual types of plasma heating devices and their common facilities. We have also performed technical support for improving, developing, and newly installing these devices.

In this fiscal year, we mainly carried out device improvement and modifications that enable the deuterium plasma experiment and plasma injection. The details of these activities are as follows.

(1) ECH

(a) Gyrotron Operation and LHD Experiment

During the 19th experimental campaign, we injected the power of 5.3MW to assist deuterium plasma experiments continued from last year. That injected power contributed to accomplishing the plasma with 10keV of high ion temperature with that power, and before that, operated by long pulse discharge to clean the wall of the vacuum vessel with low power. Some trouble halted operation of the gyrotrons. However, ECH technical staff of the LHD experimental group contributed to the plasma heating of all experiments.

(b) Support of cooperative research

ECH group started cooperative research study of optical vortex generation experiments using our gyrotron and related devices. We supported installation of these devices, operated the gyrotron, and acquired the data that shows the vortex radiation generated by interaction with electron accelerated by microwave from gyrotron and external magnetic field.

(2) ICH

ICRF antennas removed from LHD were stored in the Heating Power Equipment Room. Among the antennas, we planned to modify the inner conductor of HAS antennas to adapt impedance transformers which were designed to reduce the voltage along the transmission line such as that of the FAIT antennas (Fig. 8). As the preparation for this modification, we disassembled the HAS antennas in order to divide the inner conductors into the parts for reuse, such as a pivot section, and other parts.

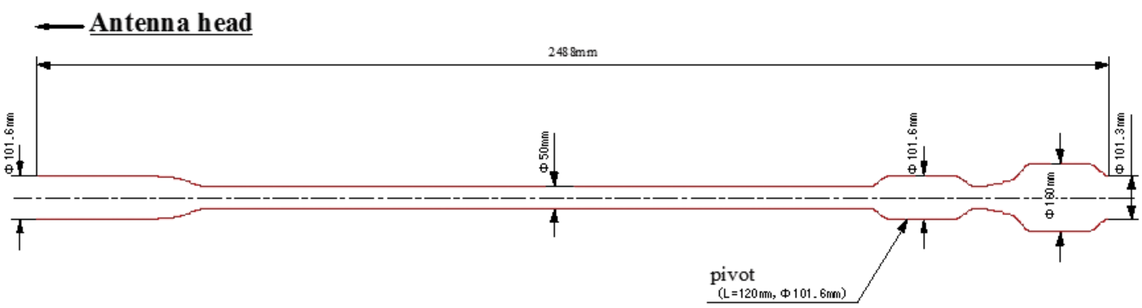

Fig. 8 The design of impedance transformer for HAS antenna

(3) NBI

(a) Maintenance of ion sources in maintenance room

The 19th experimental campaign of LHD was finished in August 2018. Every year, ion sources of NBI are maintained by manufacturers in their factories after the campaign. However, after the deuterium experiments, we cannot take ion sources outside of the radiation controlled area. Thus, we installed a maintenance room in the radiation controlled area in 2016.

We started maintenance of ion sources in September 2017. The maintenance includes polishing grid and insulating tube. Dust comes out in the polishing work, thus we perform this work in the greenhouse installed in the maintenance room. The greenhouse has a dust collector. The maintenance of ion sources of NBI by NIFS was finished in May 2018. Fig. 9 shows the polishing work on the insulation tube.

Fig. 9　The polishing work in the greenhouse

(b) Maintenance for the facility of liquid nitrogen in LHD-NBIs

The transfer tube for liquid nitrogen consumed in the cryopumps of LHD-NBIs has a double-layered structure composed of an inner tube and an outer tube. The space between the layers is evacuated in order to thermally insulate the inner tube from the outer tube. During the 19th plasma experimental campaign, the vacuum insulation of the transfer tubes of NBI #3 was reduced. Thus, after this campaign, the vacuum insulation layer in the transfer tubes of NBI #3 was evacuated up to 1×10^{-3} Pa by the turbo-molecular pump.

(4) Motor-Generator (MG)

The MG supplies the pulsed power to the NBI and the ECH for LHD. The MG has supplied power for 17,135 shots in this fiscal year and 614,015 shots since its construction. The operation time was 975 hours. The MG was overhauled, and lower oil-cooling pipe unit was exchanged (Fig. 10, Fig. 11). Peeling was found on thrust metals, and replaced with a spare (Fig. 12).

Fig. 10　Motor disassembly (A motor is on the stay. There is a generator under the stay)

Fig. 11　The lower oil-cooling pipe unit (Removed from a generator)

Fig. 12　Penetrant test for thrust metal

4. Diagnostics Technology Division

The main tasks of this division are radiation control and support of the diagnostic devices. There was no serious trouble in our managed equipment during the 19th LHD experiment. After the experiment campaign, we made an annual inspection of the integrated radiation monitoring system, the access control system, ITV system, the NFM (Neutron Flux Monitor), and the RMSAFE (Radiation Monitoring System Applicable to Fusion Experiments).

(1) Radiation control

This fiscal year is the first year after the deuteron experiment. Thus, necessary procedures of radiation control have been considered and established. For example, the way of collecting RI waste from maintenance work has been considered and started. RI waste was delivered to JRIA (Japan Radioisotope Association) on January 23, 2018, for the first time. The Fig. 13 shows the collection of RI waste by the JRIA.

(2) Installing a multichannel collimator for the radial profile measurement

The second multichannel collimator unit was installed to measure the emission profiles of neutrons and neutral particles in the open mouth with 2 m depth on the floor of the torus hall. Fig. 14 shows the collimator unit with apertures of 13 channels with 1.5 m length and inner diameter of 50 mm. The collimator unit was made by a hematite-doped heavy concrete whose specific gravity is above 3.5 to block off neutrons and weighs more than 6 tons.

Fig. 13 The collection of RI waste by the JRIA

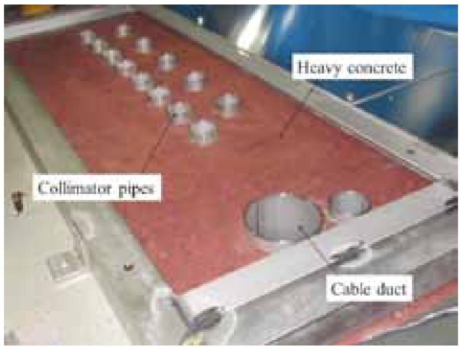

Fig. 14 Multichannel collimator unit made by heavy concrete

(3) Electric lock installation for a laser room

FIR laser interferometer and YAG Thomson scattering system each have a laser room, respectively. In order to improve personnel safety and to control persons entering into the laser rooms, we installed electric locks and emergency stop buttons on the laser room doors. Only listed persons can enter these rooms. The construction of this control system is given in an account of the Control Technology Division section.

(4) Data processing of diagnostic devices

For the LHD Data Acquisition (DAQ) System, we released the new version of the LHD data management library "Retrieve+dbStore ver.19.2.0" which can manage new data of the two additional digitizers. And we have been developing the new FPGA modulator instead of the old VME modulator for the DAQ timing system.

(5) The radioisotope (RI) samples management system

For the D-D experiments, we developed the radioisotope (RI) samples management system that can manage locations, status, etc. of RI samples using secured QR code (SQRC) on the WWW browser.

5. Control Technology Division

The Control Technology Division is in charge of the important engineering tasks in the LHD project, such as operation, management, and development, which are mainly targeted upon the central control system, cryogenic system, coil power supply, and super-conducting coils.

We are also responsible for the IT infrastructures, for example, the LHD experiment network, NIFS campus information network, and internet servers, in every phase of the project including requirements analysis, design, implementation, operation, and user support.

Described below are the essential topics of activities in the last year.

(1) LHD cryogenic control system

The cryogenic system relaunched its operation after replacement of temperature sensors, which were damaged by the fire accident in 2015, in the cold box. The cooling and warming operation periods were 27 days and 22 days, respectively. These periods were the same as the previous operation (18th cycle of operation). Fig. 15 shows cooling operation results. The steady operation was conducted for 179 days (4297 hours), which was the longest period in the past 18 cycles of operation. In the 19th cycle of operation, the first deuterium plasma experiment was performed. No accidents occurred in the 19th cycle of operation with the control system. The total system operating period was 362 days (8688 hours).

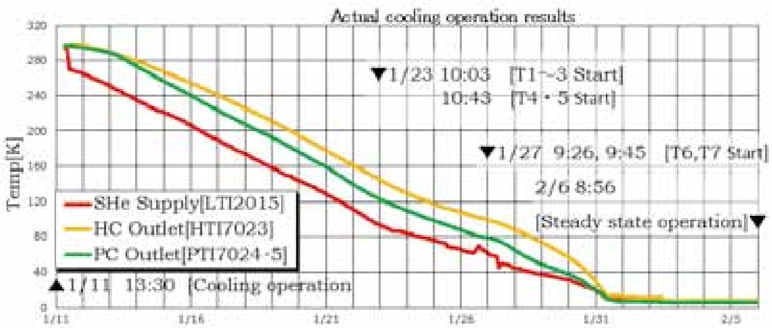

Fig. 15 Actual results of the cooling operation

(2) Laser room interlock system development

We designed and implemented interlock systems in the rooms where laser injection systems, YAG Thomson Scattering System, and Far-infrared Laser Interferometer are equipped in order to improve safety. The system stops laser injection when it detects entry and exit.

We placed FeliCa card readers inside and outside the doors. We then connected them to Windows tablets. To handle our staff ID cards, which are NFC standards, we used WinSCard library. This choice enabled the interlock systems to read FeliCa ID from the staff ID cards to control laser injection by communicating with PLC (Programmable Logic Controller). Fig. 16 shows the entrance of a room where both a monitor and a FeliCa card reader are installed.

(3) Network management

The NIFS campus information networks consist of several clusters. We managed the Research Information Cluster (NIFS-LAN) and the LHD Experiment Cluster (LHD-LAN).

New contributions in FY 2017 are as follows:

(a) Renewal of the virtual server system

The virtual storage for the virtual server system was replaced with the HPE MSA 2050. The virtualization software, VMWare vSphere, was upgraded from version 5.5 to version 6.5 update 1.

(b) Renewal of the LHD Access Gateway

A firewall was installed to limit the connection between NIFS-LAN and LHD-LAN, and its authentication server was renewed from MAG 4610 manufactured by Juniper Network Corporation to PSA 300 manufactured by Pulse Secure (Fig. 17). Since the usage is the same, there were no inquiries from the users. The number of new registrants to the LHD access gateway was 29 people in FY 2017.

Fig. 16 Laser room interlock system in operational check

Fig. 17 Renewed LHD Access Gateway

6. Symposium on Technology

The Symposium on Technology was held March 1-2, 2018, at the Industrial and Cultural Center in Tajimi city, Gifu Prefecture, Japan. The National Institute for Fusion Science (NIFS) hosted this event. There were 170 participants from many Japanese universities, national laboratories, and technical colleges. In this symposium, 32 oral reports and 39 posters were presented in five technical groups. At the same time, we held a technology exchange meeting on the theme of thermal analysis simulation. The 38 participants visited NIFS to see the Large Helical Device. Fig. 18 shows the opening ceremony.

Fig. 18 A photograph of the opening ceremony

(S. Kobayashi)