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 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 supports plasma diagnostic devices and radiation measurement devices, and takes charge of radiation control. Finally, the Control Technology Division concentrates on the central control system, the cryogenic system, the current control system, and the NIFS network.

The engineering department welcomed five newcomers in April and October. The total number of staff is 57 (2018.10). We are in charge of the development, the operation, and the maintenance of the LHD and its peripheral devices together with approximately 57 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 requests for machining was 144, and the total number of produced parts was 369 in this fiscal year (FY). The number of electronic engineering requests was 14, and the total number of produced electric articles was 77. The details of some of this division's activities follow below.

(1) Injection pipe for TESPEL

We have fabricated injection pipe for TESPEL. (Fig. 1) The injection pipe consists of two kinds of pipes. One is an outer pipe, which is a stainless steel pipe with an outer diameter of 11mm. The other is an inner pipe with an outer diameter of 3mm and a thickness of 1mm. The inner pipe is welded to the tip part. The welding is TIG welding. We placed a guide block at the center of the pipe to prevent the inner pipe from bending.

(2) 56GHz ECH power monitor

We have fabricated power monitor (Fig. 2) for ECH. Power monitor has 21 small diameter holes on the reflection surface of the microwave. The small diameter holes are five different sizes in DIA 0.75mm to 0.87mm. The microwave passed through the small diameter holes is transmitted to the detector by the sub waveguide. The sub waveguide is rectangular in cross section, whose size is 1.88 mm length and 3.78 mm width.

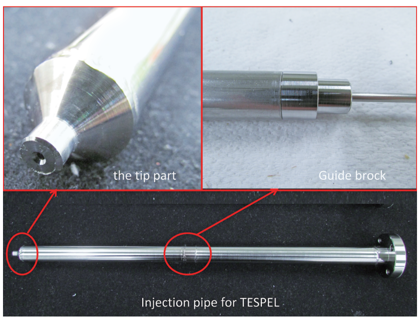

Fig. 1 Injection pipe for TESPEL

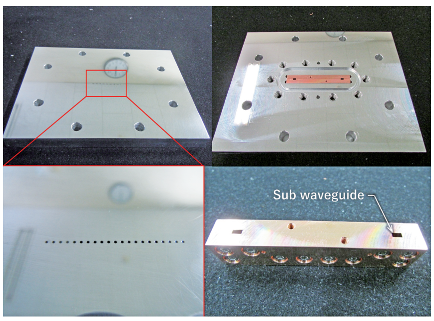

Fig. 2 56 GHz ECH Power monitor

(3) 35ch PIN photo diode amplifier

The amplifier circuit of the 35 channels PIN photo diode array for a fast spectroscope, which detects a visible light from the high-density plasmoid, is shown in Fig. 3. The voltage gain of the amplifier is from 20 to 40 dB and frequency bandwidth is DC to 2 MHz. The upper three layers of the board are the 35 channels PIN photo diode array and fixed gain preamplifiers, and the lower two boards are variable gain main amplifiers.

(4) Wire bonding

Wire bonding is a technique of electrically connecting among MMICs and a printed circuit board by using thin gold wires. We applied the technique to making our original antenna of the ECEI (electron cyclotron emission imaging) system. Fig. 4 shows the wire-connecting-MMICs of active frequency multipliers and mixers on our receiver board. This technique has made it possible to reduce the size and the cost of our microwave circuits, and has contributed to the development of multichannel imaging system.

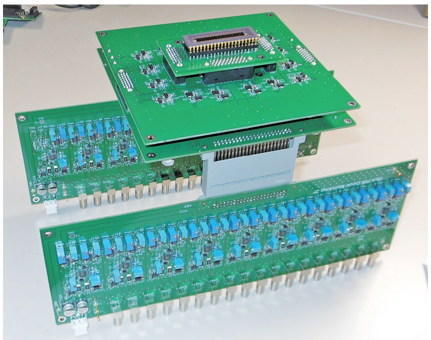

Fig. 3 35ch PIN photo diode amplifier

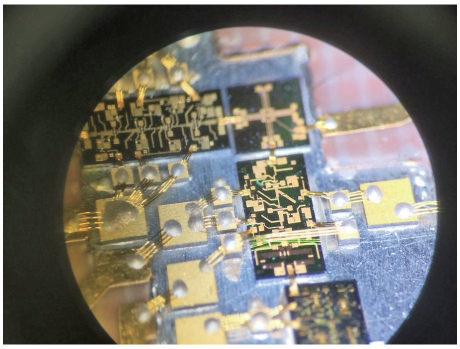

Fig. 4 Wire Bonding

2. Device Technology Division

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

(1) Operation of LHD

We started pumping of the cryostat vessel for cryogenic components on August 23, 2018 and pumping of the plasma vacuum vessel on August 24. Subsequently, we checked air leaking from the flanges of the plasma vacuum vessel. The number of checked flanges was 54. As a result, we found leaks in 4 flanges and repaired those flanges.

The pressure of the cryostat vessel reached the adiabatic condition ($< 2 \times 10^{-2}$ Pa) on August 25 and the pressure of the plasma vacuum vessel reached below 1×10^{-5} Pa on September 4.

The LHD experiment of the 20th experimental campaign began on October 11, 2018 and was implemented continuously until February 21, 2019. The number of days of the plasma experiment was 63 in total.

During this experimental campaign, the vacuum pumping systems could eliminate air from both vessels without trouble. In addition, the utilities (compressed air system, water cooling system, GN2 supply system, etc.) of LHD, and Exhaust detritiation system did not report any major problems. The LHD operation was completed on March 15, 2019.

(2) Engineering analysis in the fields of electromagnetic and structural development

A magnetic shielding is widely used to protect sensitive equipment from magnetism in magnetic field. We tried to develop some existing magnetic shields by ANSYS using finite element method software. To design the magnetic shield with higher shielding performance, both the analysis and the measurement of the magnetic shield are needed. Therefore, we introduced the Helmholtz coils which create a uniform magnetic field between two coils, and investigated the property of the magnetic shield. The magnetic shield is composed of the multi-layer structure as shown in Fig. 5, and these materials are stainless (SUS316) and aluminum (A5052). Based on the results of ANSYS analysis and measurement by using the Helmholtz coils, it was shown that both distributions of magnetic field became almost uniform.

CFQS device is going to be built as a part of a joint project conducted by NIFS in Japan and Southwest Jiaotong University (SWJTU) in China. We concluded the MoU in 2017 on NSJP (NIFS and SWJTU Joint Project) for CFQS experiment. In addition, we are working together with Keye Electro Physical Equipment Manufacturing Co., Ltd. in Hefei with their contribution in engineering design and manufacture of the device. In advance of manufacturing, the Department of Engineering in NIFS has contributed to this project with analysis work. Fig. 6 shows one example, the stress analysis of vacuum vessel. In order to ensure the reliability of the CFQS vacuum vessel, stress analysis has been performed using ANSYS, FEM software by ANSYS, Inc. The result was reported to the project member in China at the 2nd steering committee meeting in May, 2019.

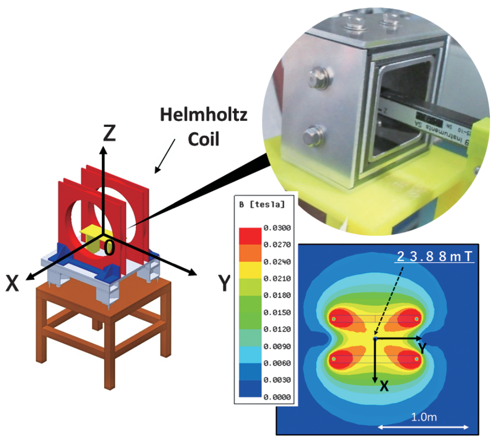

Fig. 5 Arrangement of the Helmholtz coil system, a mockup of magnetic shield, and distribution of magnetic flux density.

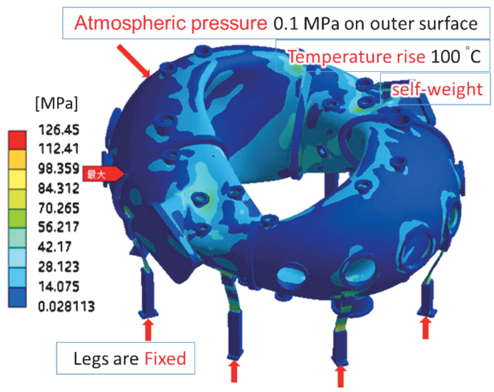

Fig. 6 The stress distribution on vacuum vessel

(3) A water bubbler system

To monitor tritium in the exhaust gas from LHD, we designed and constructed a water bubbler system. A flow diagram of the water bubbler system is shown in Fig. 7.

This system can distinguish chemical forms of tritium. In addition, this system can also change to a simplified sampling line without the distinction of chemical forms in order to reduce the load on an operator and the number of tritium water samples.

The evaporation from sample water was controlled by a cold bath using aluminum beads.

To verify the consistency of the date from this system, we compared this with the measuring result by a commercially available bubbler system (MARC7000, SDEC France).

As a result, the tritium concentration measured by this system was almost the same as the tritium concentration measured by MARC7000.

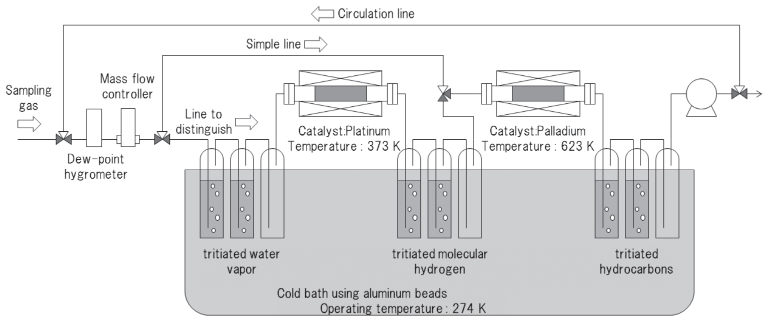

Fig. 7 Water bubbler system flow chart

3. Plasma Heating Technology Division

The main tasks of this division are the operation and the maintenance of individual three different 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 modification for a deuterium plasma experiment. The details of these activities are as follows.

(1) ECH

(a) Gyrotron Operation & LHD experiment

During the 20th experimental campaign, we injected the power of 5 MW to assist plasma experiments. That contributed to accomplish the plasma with 10 keV of high ion temperature, and before that, operated by long pulse discharge to clean the wall of vacuum vessel with low power. Some trouble occurred but they did not affect experiments. ECH technical staff of LHD experimental group achieved to contributing to the various plasma experiments.

(b) Support to cooperative research (Optical Vortex)

We improved some parts of our experimental device for achieving high vacuum, because we could not achieve the working vacuum which could operate the electron gun. The improvements include expanded MOU connecting new transmission line and relocation of the 82.7 GHz Gyrotron.

(2) ICH

In order to increase the injection power per antenna, we developed a power combination system and installed it in the Heating Power Equipment Room. The system was inserted in the transmission line for the 4.5L antenna and connected with the #6A and the #6B oscillator. We successfully injected the power of more than 2MW for 6 seconds and 1MW for 10 minutes in an injection test using a dummy load.

(3) NBI

(a) The operation and maintenance of NBI in the 20th campaign of LHD experiments

In the 20th campaign, approximately 8,000 beam shots were injected into the LHD plasmas with three negative-NBIs (BL1, BL2, and BL3). The injection history of the total injection power for the negative-NBIs is shown in Fig. 8. The maximum injection power in this campaign was 14MW. As for the positive-NBIs (BL4 and BL5), about 4,500 beam shots were injected into the LHD plasmas. The maximum total injection power of positive-NBI was 12MW by hydrogen beam, 18MW by deuterium beam.

NBIs had several problems. BL1 had air leak in the ion source. BL3 had cold leak at LN2 piping in the cryo-pump system. BL3 and BL5 had failures of the power supply unit in the arc power supply system and filament power supply system, respectively. These troubles lowered the injection power a little, but did not lead to serious problems in the plasma experiments. These troubles are now under repair for the next campaign.

(b) A vacuum-vessel inspection for NBI beamline

After every experimental campaign, we have inspected the vacuum vessel of the NBI beamline. In the deuterium experiment, some devices inside the beamline are activated with neutrons, and radioactive tritium is generated via deuterium-deuterium reactions in the vacuum vessel. Thus we first measured the concentration of radioactivity and radiation dose in the vacuum vessel and confirmed that there are no problems in the inspection work.

A small room is prepared outside the vessel entrance to avoid leakage of tritium. Inspection work is carried out with wearing dust protection clothing and a mask. At the end of the work, we surveyed the dust protection clothing to ensure that there was no contamination using both a scintillation survey meter and a tritium/C-14 survey meter (Fig. 9).

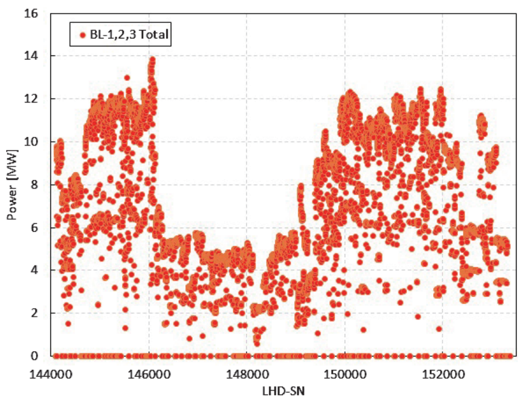

Fig. 8 History of the total injection power for the negative-NBIs


Fig. 9 Dust protective clothing

(4) Motor-Generator (MG)

The MG is used to supply the pulsed power to the NBI and the ECH for LHD. The MG has supplied power for 22,648 shots in this fiscal year and 636,663 shots since its construction. The operation time was 1,195 hours. We updated the excitation control panel and the PLC of speed control panel before the 20th experimental campaign (fig. 10, Fig. 11).

Fig. 10 The updated excitation control panel

Fig. 11 The updated PLC of speed control panel

4. Diagnostics Technology Division

This division mainly supports the development, the operation, and the maintenance for plasma diagnostic devices and radiation measurement devices for LHD. In addition, we also are in charge of radiation control.

(1) Plasma diagnostic device

Fig. 12 shows diagnostics racks installed where some intelligence controller units are located. In order to shield those racks from neutron radiation, we surrounded those racks by 10 cm thick high density borated polyethylene blocks, as shown in Fig. 13. Because total weight of the polyethylene blocks is about 800 kg, we reinforced the rack by using some nonmagnetic angles, and fixed the polyethylene blocks in the angle.

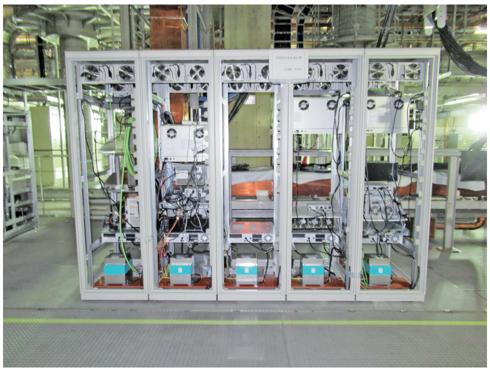

Fig. 12 Diagnostics racks installed with some intelligence controller units

Fig. 13 Radiation shielding by high density borated polyethylene blocks

Some plasma diagnostics devices have worked for about 20 years, and require maintenance. For the Nd:YAG Thomson scattering system and the far-infrared (FIR) interferometer, we carried out the replacement of cooling system for lasers. Those cooling systems are a water-cooled chiller refrigeration unit with the cooling capacity of 10 kW as shown in Fig. 14 and an air-cooled chiller refrigeration unit with 10 kW, respectively.

For the LHD Data Acquisition (DAQ) System, we have added SSD storage system in front of the existing HDD storage system as shown in Fig. 15. We have also applied 40GbE network. Consequently, the throughput of the DAQ system has increased significantly in the situation of accessing ‘Hot Data’.

Fig. 14 Water cooled refrigeration type chiller for YAG Thomson scattering system

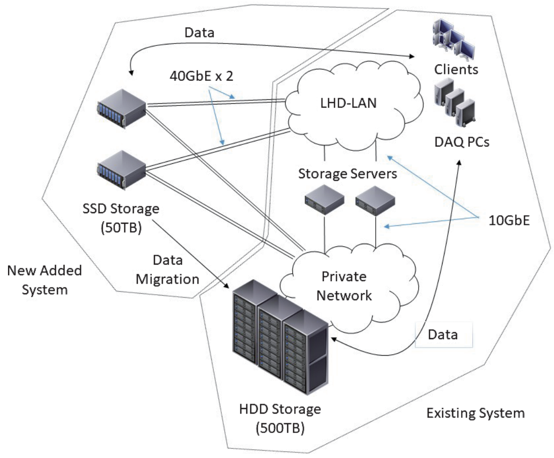

Fig. 15 New DAQ system added SSD storage

(2) Radiation measurement and radiation control

In order to control the safety of radioactivity, we carry out the operation and the maintenance for three high-purity germanium (HPGe) detectors, seven liquid scintillation counters, three stack tritium monitoring systems, two gas monitor systems and the drain water monitor. In particular, two gas monitor systems have been installed to measure gas in the torus hall and the stack of the LHD building, respectively. However, because the gas monitor system for the torus hall, which is installed in the LHD basement, is affected by radiation of the deuterium experiments, we installed the 3rd gas monitor in the air conditioning room. This monitor is isolated with concrete wall of 2 m thick from the torus hall (Fig. 16). The gas is sampled from a circulating air duct for the torus hall.

In order to exit paper-based system for radiation worker registration, we are now developing the WWW registration system to apply, update, approve, and manage radiation workers in NIFS. Fig. 17 shows the front page of WWW registration system.

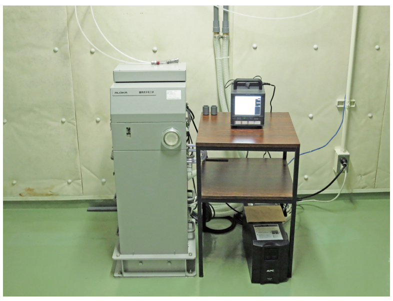

Fig. 16 3rd gas monitor in air conditioning room

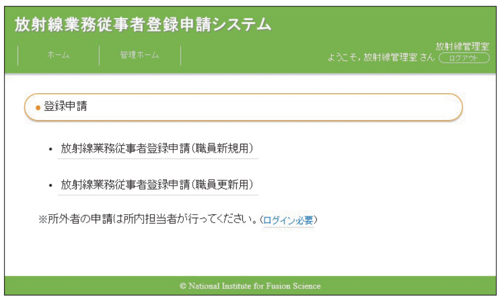

Fig. 17 The front page of WWW registration system (in Japanese)

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 to central control system, cryogenic system, coil power supply, and super-conducting coils.

We are also responsible for the IT infrastructures, e.g., 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.

The essential topics of the activities for the last fiscal year are described below.

(1) The operation of the LHD cryogenic system

The completion of the cooling operation in the 20th experimental campaign was delayed by 4 days due to a cooling failure at the final stage. The cause of the cooling failure was vacuum degradation in the adiabatic vacuum chamber of the superconducting bus line H2-I system. Then, sufficient vacuum evacuation could not be carried out. The vacuum evacuation could be successful by several opening and closing operations. Consequently, the cooling operation could be completed.

During the steady operation period (129 days, 3097 hours), the monitoring system was improved by monitoring the vacuum degree in the adiabatic vacuum chamber and the surface temperature on the bus line by the IR camera. As a result, the 20th cycle operation could be finished without any trouble for one year.

(2) Development of Velocity-measuring Pulse Generator

A new idea to electromagnetically accelerate an object is investigated using high-temperature superconductors and magnetic coils, which is called the "superconducting linear catapult". In the Summer Student Program of SOKENDAI held in August, 2018, a program regarding this technique was prepared. In the program, a magnetically levitated small vehicle equipped with high-temperature superconducting bulk materials was accelerated using magnetic coils (Fig. 18). For this acceleration, the timing when the magnetic field is applied is important. Therefore, to precisely control the timing, we developed a pulse generator system using Arduino (an open-source electronics platform) (Fig. 19). The generator can trigger TTL signals to switch on electrical currents to magnetic coils by measuring the velocity of the vehicle using laser optical sensors. It was successfully demonstrated to accelerate the vehicle by using the generator, with the result that the velocity of the vehicle became approximately doubled compared to that obtained without using the generator (by manual control). The superconducting linear catapult may become a good tool for ice pellet injection in fusion plasmas and for the study of space debris.

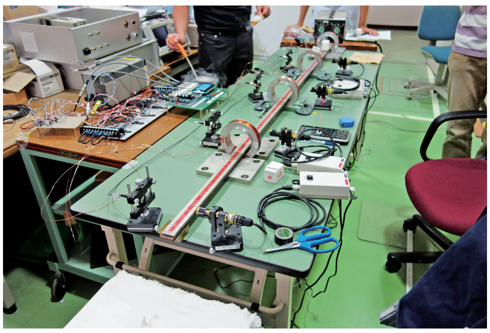

Fig. 18 Accelerating system

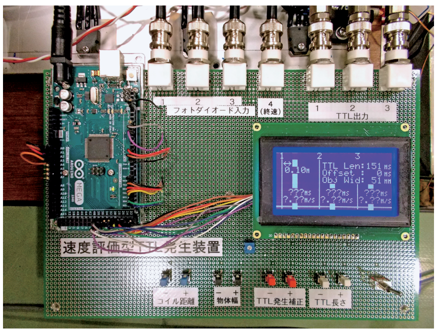

Fig. 19 Pulse generator

(3) Network management for NIFS-LAN and LHD-LAN

The NIFS campus information networks consist of several clusters, i.e., Research Information Cluster (NIFS-LAN) and LHD Experiment Cluster (LHD-LAN).

New contributions in FY 2018 are as follows:

(a) Renewal of the backup system for the virtual server system

A backup system for the virtual server system has been upgraded with Veeam Backup & Replication.

(b) Renewal of the targeted attack detection system

A targeted attack detection system has been replaced with FireEye NX 4500. This system can detect malware and unknown threats.

(c) Update of the core switch of the LHD control LAN

The core switch of the LHD control LAN on the LHD experimental cluster has been updated by configuring a virtual router using VRF (Virtual Routing and Forwarding), which is a function of the existing LHD-LAN core switch (Nexus 7009). There were no failures after upgrade and it resulted in a cost reduction.

(4) Development of the Helmholtz Coil Operation System for Magnetic Shielding Tests

This project was conducted as the technical training program for 6 new members of the department of technical service and technology. Fig. 20 is the overall view of the Helmholtz coil operation system and a control panel of coil operation program developed by LabVIEW (Fig. 21).

The operation system consists of a Helmholtz coil, a chiller for coil cooling, DC power sources with up to DC200A (maximum magnetic flux density: 23.5mT) and a Note PC for coil energization control, and operational parameters monitoring. The operational parameters, i.e., the coil energizing duration and sampling frequency are variable, and the initial settings are 10s and 1Hz, respectively. Interlock programs for coil energization are implemented as well. They are triggered in case the surface temperature of the coolant outlet tube exceeds the limit value. The Helmholtz coil device was built not only for the magnetic shielding tests, but also for a summer student program in NIFS.

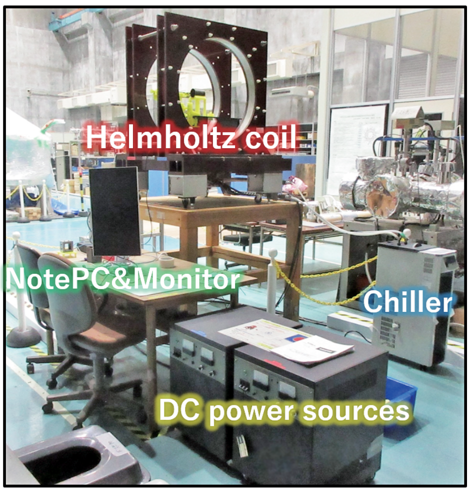

Fig. 20 Overall view of the Helmholtz coil operation system

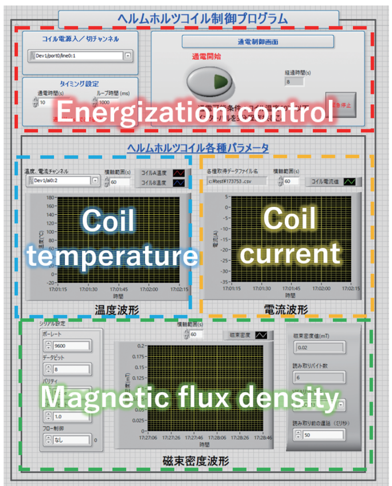

Fig. 21 Control panel of coil operation program

6. Exchange activity on the analysis technology using the finite element method

We are holding technical exchange meetings that have contributed to future technological improvements over the past few years. The purpose is sharing knowledge obtained in the field of design and manufacture of equipment and technical information in control program development by the technical staff of each university/research institution.

On March 1st, 2019, the 2nd exchange meeting (Fig. 22) on the structural analysis technology using the finite element method was held in NIFS. A total of 38 guests attended the meeting including the participants by using the ZOOM (communications software for online meetings). The breakdown of the participants was as follows: High Energy Accelerator Research Organization (7), National Institutes for Quantum and Radiological Science and Technology (1), Institute for Molecular Science (6), National Astronomical Observatory of Japan (5), NIFS (14), and private enterprises: Kurihalant CO., LTD. (5). The special lecture regarding a utilization of the finite element method in a fusion reactor conceptual design was given by Associate Professor Tamura at the beginning of the meeting. Then, six speakers introduced each analysis case and its difficulties. After each presentation, fruitful and active questions and answers were held. Through this exchange meeting, it was possible to build a human network of engineers involved in analysis technology.

On 3–7 Dec 2018 and 24–27 Jan 2019, a student from Kyoto University stayed at NIFS to carry out electromagnetic analysis in the framework of technical cooperation (Fig. 23). The analysis target was the ECH microwave of Heliotron J, and the electric field strength distribution in the vacuum vessel was calculated. It is planned to calculate the orbit of electrons based on this result.

Fig. 22 Technical exchange meeting

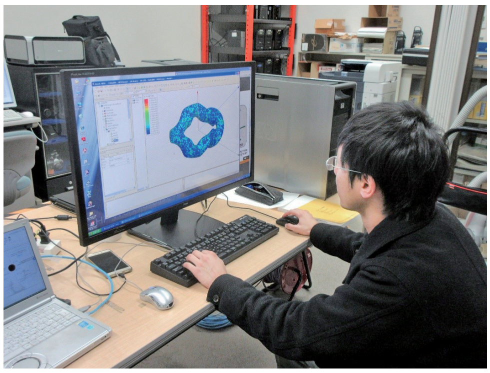

Fig. 23 Technical cooperation