15. 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. This year, a pair of FAIT antennas were installed to LHD for the ICH system. The Diagnostic Technology Division supports plasma diagnostic devices and radiation measurement devices, and oversees 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 one new member in April. The total number of staff is now 59 (2019). We have carried out the development, the operation, and the maintenance of the LHD and those peripheral devices together with approximately 57 operators.

1. Fabrication Technology Division

In this division, the main work is the fabrication of experimental equipment. And, supplies of experimental parts and technical consultations are provided for many researchers. In addition, the administrative procedures are managed for the department.

The detailed activities of this division follow below.

(1) Fabrication of Corrugated Resonators

A cylindrical cavity wall with periodical corrugation, which excites a cylindrical Bloch wave at the frequency of 100 GHz or 200 GHz, was fabricated for the collaboration with Niigata University (Fig. 1).

The cylindrical cavity has 80 corrugations. The parameters of the rectangular corrugation for the frequency of 100 GHz are a width of 0.3 mm, a depth of 0.6 mm, and a periodic length of 0.5 mm. Also, the parameters of the other rectangular corrugation are a width of 0.15 mm, a depth of 0.3 mm, and a periodic length of 0.25 mm.

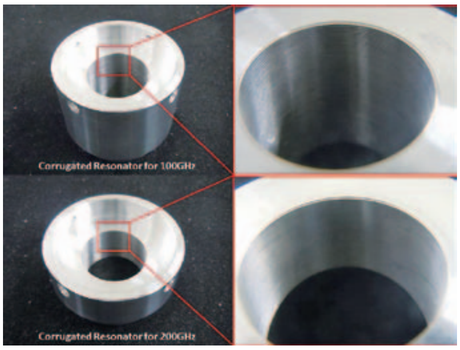

Fig. 1 Corrugated Resonator

(2) Fabrication of 77GHz notch filter

A 77GHz notch filter was fabricated for the Collective Thomson Scattering (Fig. 2). It consists of 24 cavities and waveguides in the internal space.

The cavity has a cylindrical shape with a diameter of 6.3mm, and each depth of cavity is adjusted with a screw. The parameters of rectangular waveguide are a length of 5.69mm, and a width of 2.845mm.

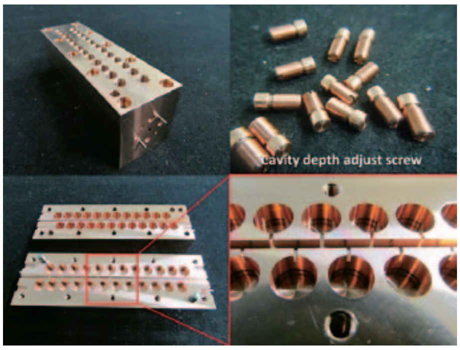

Fig. 2 2 77 GHz notch filter

(3) Fabrication of high gain filter amplifier

A high gain filter amplifier is used for a real-time measuring of the superconducting critical current (Fig. 3). This circuit has the following specifications. The voltage gain is 100dB, the frequency bandwidth is DC to 2 kHz, the band elimination frequency is 50 dB from 60 Hz to harmonics of until order 5, and the voltage of input referred noise is 0.6 μV.

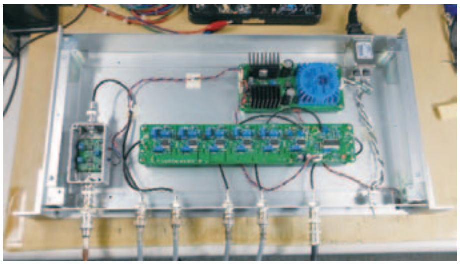

Fig. 3 High gain filter amplifier

(4) Fabrication of controller for 2.45GHz solid-state power amplifier

An introduced amplifier is a 2.45GHz 200W solid-state power amplifier (SSPA). The model number is TME-201B00. The manufactured controller for the SSPA is shown in Fig. 4. It has a graphic display module (TG12864B-02WWBV) and a rotary encoder inside the front panel. This controller is operated by pushing or rotating the encoder. Then the display shows the set and output voltage. The monitoring of rotary encoder value and the output voltage control is enabled by an Arduino Mega 2560.

Fig. 4 The controller for SSPA

2. Device Technology Division

This 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 15, 2019 and pumping of the plasma vacuum vessel on August 16. Subsequently, we checked air leaking from the flanges on the plasma vacuum vessel. The number of checked flanges were 37. As a result, we found leaks at 3 devices and repaired those devices.

The pressure of the cryostat vessel reached the adiabatic condition ($< 2\times10^{-2}$ Pa) on August 16 and the pressure of the plasma vacuum vessel reached below 1×10^{-5} Pa on August 25.

The LHD experiment of the 21st experimental campaign began on October 3, 2019 and was implemented continuously until February 6, 2020. The number of days of the plasma experiment was 52 in total. Due to trouble with the divertor plates in the plasma vacuum vessel, the experimental days were reduced from 61 to 52 days.

During this experimental campaign, the vacuum pumping systems could eliminate air from both vessels without trouble. In addition, no major trouble was reported with the utilities (the compressed air system, the water-cooling system, the GN2-supply system, etc.) of the LHD, and the exhaust detritiation system. The LHD operation was completed on February 28, 2020.

(2) Design of CFQS baking heater

The world's first quasi-axisymmetric stellarator CFQS is under construction as a joint project between NIFS and SWJTU (South West Jiaotong University). We have finished the fabrication of the mockup coil, and conducted various performance tests, such as the heat run test and the breakdown test. Now, we are working on detailed designs for the actual coil. In addition, the construction of the vacuum vessel is also ongoing.

As a part of the design work of the vacuum vessel, we are considering specification of baking heater. Fig. 1 shows a moment where strings are wound directly on a 3D printer model to estimate the heater length. Based on this result, the voltage and the capacity were determined as well. We will continue the design work to finish the detailed analysis.

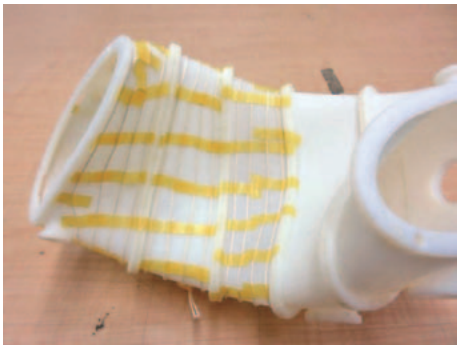

Fig. 1 Estimation of heater length using a 3D model of vacuum vessel.

(3) Upgrading of voltage waveform output systems

The fuel gas of a fusion plasma is injected via a piezo valve. Both the piezo valve and the amount of gas are controlled by a voltage waveform output system.

The voltage waveform output system comprises a graphical user interface (GUI) and an analog output unit as shown in Fig. 2(a) and Fig. 2(b), respectively. The GUI creates the control voltage waveform, while the analog output unit delivers voltage in the range from 0 to 5 V. The driving voltage of the piezo valve ranges from 0 to 150 V.

After the voltage waveform output system delivers the voltage, it is amplified 30 times by a piezo driver.

The conventional system sometimes stops running. Therefore, to avoid this problem, a new system that operates safely is required.

In the new system, the GUI was developed with LabVIEW and the hardware is built with CompactRIO, a product of National Instruments.

The new system has operated safely without stopping in the 21st experiment. Previously, the feedback control for the gas amount was carried out by an electronic circuit. It adopts an FPGA, so that the device size could be reduced.

In the future, we will expand the function of the system and improve the accuracy of the feedback control.

Fig. 2 Voltage waveform output system:
(a) GUI and (b) hardware (CompactRIO, product of National Instruments).

(4) Inspection and repair of an LHD vacuum vessel after the 21st experimental campaign

After the 21st experimental campaign, a damage analysis for the in-vessel equipment was conducted. The main damages were 1) damage of the tiles for the part B of NBI#1 (NBI 1-B) armor (Fig. 3(a)), 2) melting and deformation of vacuum vessel (VV) protection plates, and 3) impurity deposition on diverter tiles and melting of fixing bolts.

The NBI 1-B armor tiles had cracks caused by the thermal shock force as shown in Fig. 3(b). Therefore, the tile material (isotropic graphite) was replaced with carbon fiber composite, which could withstand thermal shock. Furthermore, we redesigned the tile structure such that the shear stress did not concentrate at locations that have been subjected to thermal shock. In the second case, the NBI beam was deflected due to the mirror effect, and the VV protection plates were heated. Thus, the material of the protective plate (SUS316 and copper) was changed to molybdenum, which is a high-melting-point material, and five protective plates were replaced. In the third case, in addition to the deposition of impurities such as iron and carbon on divertor tiles, sublimation and cracks on the heat-receiving surface were confirmed. Thus, the tiles that were severely damaged were replaced, and the SUS bolts that had melted and were damaged were replaced with molybdenum bolts.

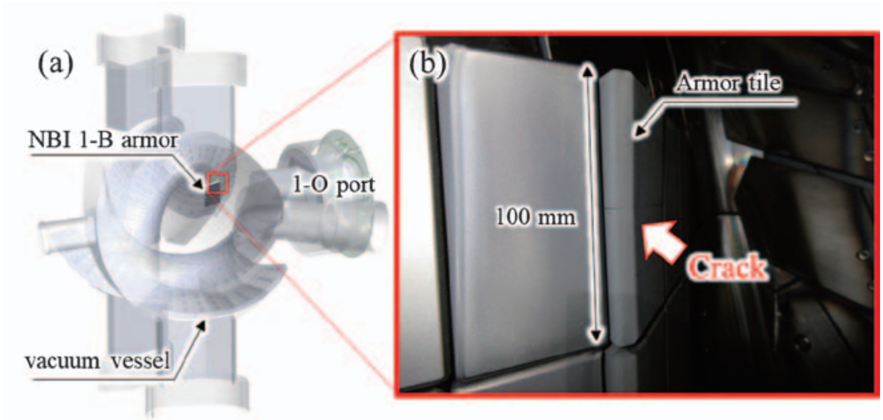

Fig. 3 Damage on NBI 1-B armor: (a) Bird's eye view of NBI 1-B armor and vacuum vessel of the LHD; (b) crack on the NBI 1-B armor tile.

(5) Replacement of power supply for glow discharge cleaning system in LHD

A DC power supply for a glow discharge cleaning system required a replacement because one of the parts was broken. The unit is composed of two programmable DC power supplies, an interlock system with indicators and circuit breakers. Specifications of the selected DC power supply are the output voltage of 1500 V, the output current of 30A, and the output capacity of 15kW. These DC power supplies have to be connected to the LHD central control unit via the interlock system for safe operation of the glow discharge cleaning system. The interlock system was newly designed to send status signals of DC power supplies and receive signals of LHD operating permission from the LHD central control unit. In addition, the system indicates status and warnings of DC power supplies on a front panel as shown in the photograph, which is also designed for the new system only, and can shut off circuit breakers in an emergency, such as over current.

Fig. 4 New power supply for glow discharge cleaning system in LHD

3. Plasma Heating Technology Division

The main tasks of this division are the operation and the maintenance of three individual 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

During the 21st experimental campaign, we injected the heating power up to 4 MW to assist plasma experiments. That contributed to accomplishing the plasma with both 6.8 keV high ion temperature and 13 keV electron temperature simultaneously. And long pulse discharge by low power ECH helped to clean the wall of the vacuum vessel so to achieve the high potential plasma. Some trouble occurred, but all of the ECH technical staff of the LHD experimental group have contributed to the various plasma experiments.

(2) ICH

In the 21st experimental campaign, ICRF heating was carried out using the FAIT (Field-Aligned Impedance-Transforming) antenna installed at the 4.5U&L ports of the LHD for the first time in the deuterium experimental period.

We used two RF transmitters with fixed wave frequency (38.47 MHz) in the experiments. The #6A transmitter was connected to the 4.5U antenna and the #6B transmitter was connected to the 4.5L antenna.

The total injection power with the two antennas into the plasma reached 2.3 MW in the short pulse of 3.5 seconds.

(3) NBI

(a) The operation and maintenance of NBI in the 21st campaign of the LHD experiments

In the 21st experimental campaign, approximately 8,000 shots of beams 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. 1. The maximum injection power in this campaign was 11.5 MW. As for the positive-NBIs (BL4 and BL5), about 4,500 shots of beams were injected into the LHD plasmas. The maximum total injection power of positive-NBI was 12 MW by hydrogen beam and 18 MW by deuterium beam.

NBIs had no troubles that led to serious problems in the plasma experiments.

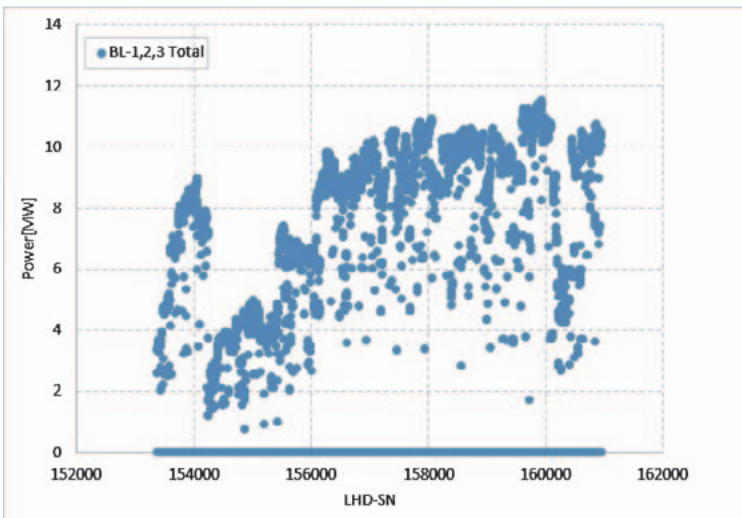

Fig. 1 History of the total injection power for the negative-NBIs

(b) Maintenance of ion sources for NBIs

Six negative ion sources and eight positive ion sources were maintained at the maintenance work room only for activated materials for the next experimental campaign. The main maintenance content was as follows: wiping off cesium from plasma-grid and arc chamber, polishing the extraction-grids and acceleration-grids, changing the tungsten filament, and helium leak test of ion sources, etc. Fig. 2 shows the work of wiping off the plasma-grids. We have continued an effort to acquire the maintenance technology for ion sources.

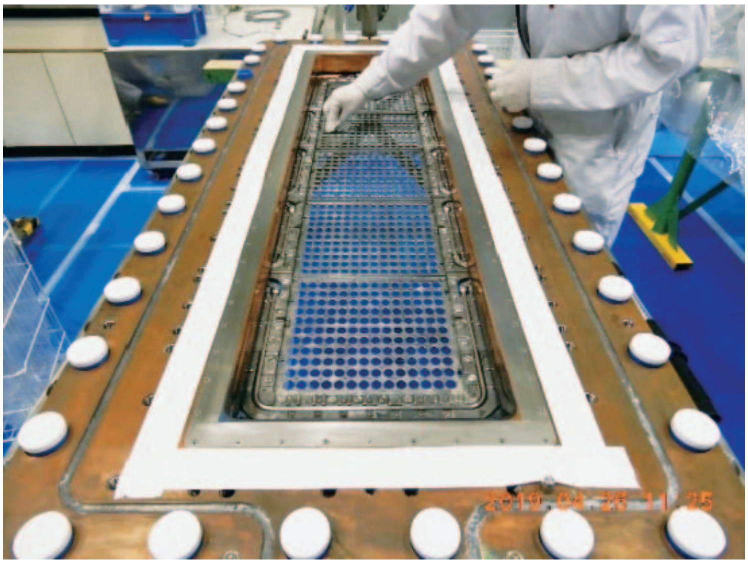

Fig. 2 Wiping off cesium from plasma-grid

(4) Motor-Generator (MG)

The MG is used to supply the pulsed power to the NBI and the ECH in the LHD plasma experiment. The MG has supplied power for 17,070 shots in the last fiscal year and power for 653,733 shots since its construction. The operation time was 928 hours. The control terminals were updated after the 21st experimental campaign.

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 have taken charge of radiation control.

(1) Plasma diagnostic device

Some plasma diagnostics devices have functioned for more than 20 years and thus require maintenance. For the Nd:YAG Thomson scattering system, we replaced two high-performance type noise cut transformers for the data acquisition system power supplies with new ones, as shown in Fig. 1. We also augmented a standard-performance type transformer and outlets for the data acquisition system.

Modification of neutron energy spectra as requested using the neutron spectrum shaping assembly (NSSA) is important owing to enhancing joint research using neutron. We modified one of the irradiation ends of the neutron activation system from the 2.5-L port to the 10-O port for finding a space to construct NSSA. Subsequently, we built a new base in order to support NSSA on A-stage in the torus hall (Fig. 2).

The LHD DAQ system acquired the diagnostics data of 7797 plasma shots in the 21st experimental campaign.

The system worked also in the situation of long-pulse shots, and the size of the stored data was about 100.7TB in total after compression.

Fig. 1 Two noise cut transformers for Thomson scattering system

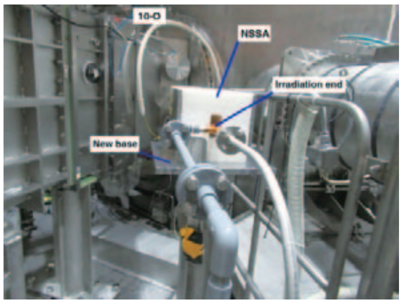

Fig. 2 Neutron spectrum shaping chamber installed at the front of 10-O port.

(2) Radiation measurement and radiation control

In order to control the safety of radioactivity, we carried out the operation and the maintenance for three high-purity germanium (HPGe) detectors, seven liquid scintillation counters, three stack tritium monitoring systems, two gas monitoring systems, two dust monitoring systems, and the drain water monitoring system. Especially, the smear test in the measurement of surface contamination has used a 2π gas-flow counter and an auto well gamma system. We carried out the smear test about 200 times. We also checked the work environmental radiation for the safety of workers using HPGe detector every month.

The tritium monitoring system of the stack monitors the tritium concentration of exhaust gas in the stack by using a tritium sampler every week. Two gas and dust monitor systems require constant measuring of radiation concentration in the stack and the LHD torus hole, respectively.

For the integrating radiation monitoring system, it is important to manage and to search the history of the event signals and the operations from the radiation measurement equipment. We developed a program which works continuously and indicates the history. It is also possible to search for the specific history with this program.

We manage the radiation worker registration. To save labor for manual data entry in the application procedure for registration of radiation workers, we developed a web-based application system and a card-reader system (Fig. 3) that obtains registration information from a NIFS staff card at the radiation education reception. And we have started to register and update the radiation worker information with these systems.

Fig. 3 Application to obtain registration information from a NIFS staff card (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 the central control system, the 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.

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

(1) LHD cryogenic system and power supply system for superconducting coils

The cooling operation in the 21st experimental campaign was conducted without significant accidents. In the power supply system, the logging system as shown in Fig. 1 for collecting each superconducting coil energization signal was partially broken before the beginning of the 21st campaign. Unfortunately, the production of the old model (WE7000) has already been stopped. Therefore, we needed to find the substitute model with almost the same specifications.

To fulfill the requirements for the logging system, two sampling frequencies (1Hz sampling mode and at least 5 kHz sampling mode) and isolated 48 recording channels, we finally adopted EDX-200A which is more compact than WE7000 and has good cost performance.

The new loggers could collect all signals with no severe troubles in the 21st experimental campaign. Before the 22nd campaign, we will implement the logging program with automatic logging start/stop function developed by LabVIEW.

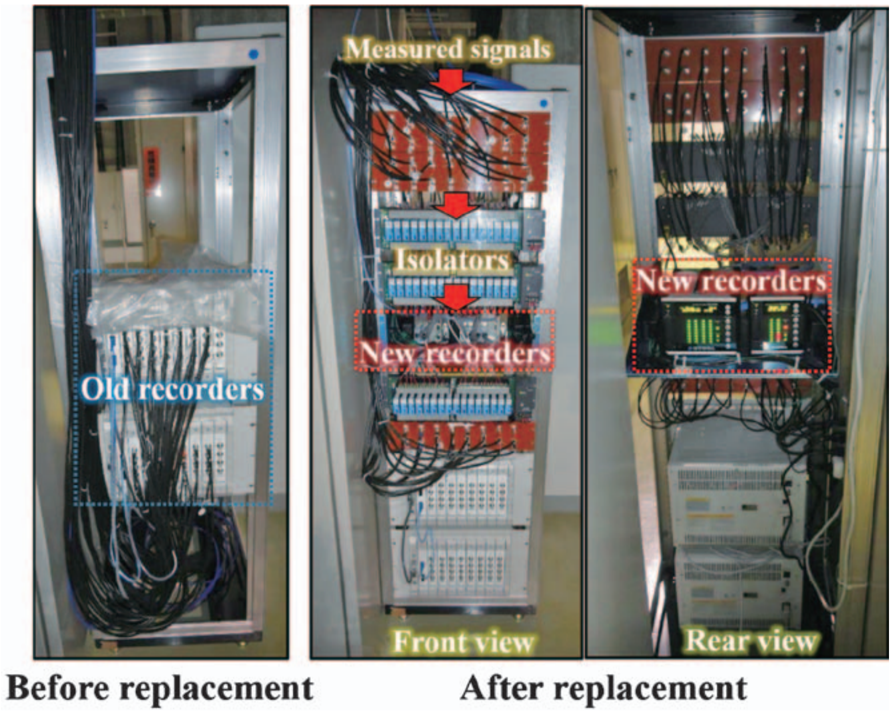

Fig. 1 Replacement results of the logging system.

(2) Development of pulse generator for NBI test stand

The research using a test stand for Neutral Beam Injection (NBI), which is an extremely important device in the LHD experiment, is conducted to improve the device performance.

In the actual experiment, a pulse generator which outputs simulated signals through the LHD Central Control System is used for the operation. However, it is obsolete and has bugs. Thus we have developed another pulse generator using FPGA board called MicroZed, a product of Xilinx, Inc. (Fig. 2). It is able to generate a maximum of 20 x arbitrary length pulses with 1 μs accuracy at arbitrary timing. Users can also select burst mode, which transforms the pulse wave from square to clock signal with selected frequency. These operations are performed through Web-based GUIs.

In the future, we are planning to add a function to demodulate external signals for more ideal operation.

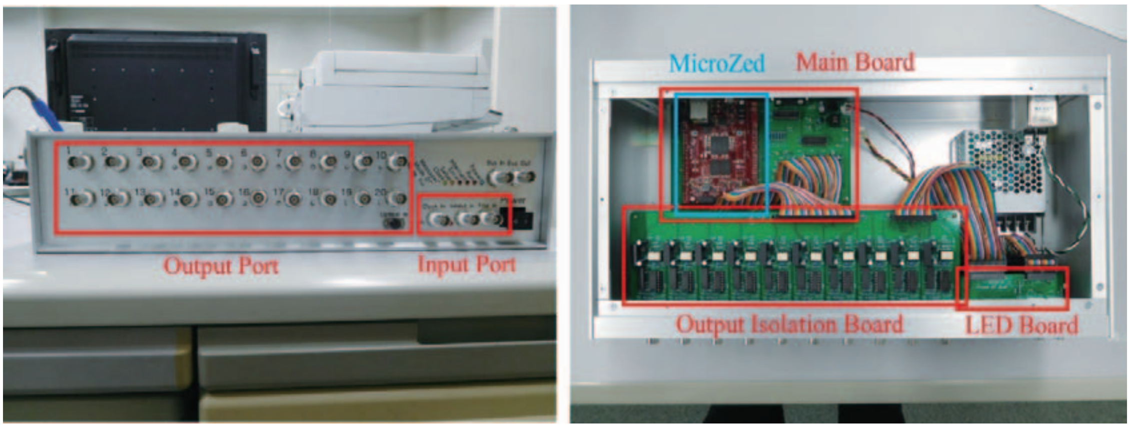

Fig. 2 External and internal view of pulse generator.

(3) Network management

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

The achievements in FY 2019 are as follows:

(a) Upgrade of the NIFS-LAN core switch module

A 48 ports Ethernet module for the NIFS-LAN core switch has been upgraded.

(b) Renewing security servers

A quarantine server and log management server for the PC authentication system has been upgraded

(c) Update of LHD-LAN firewall

Updating from SSG550 (Juniper Networks) to SRX345 (Juniper Networks) was conducted (Fig. 3)/The maximum number of simultaneous sessions has been increased from 256,000 to 375,000.

Also, the connection between the uplink and the LHD-LAN was replaced to LAG (Link Aggregation) connection to improve reliability.

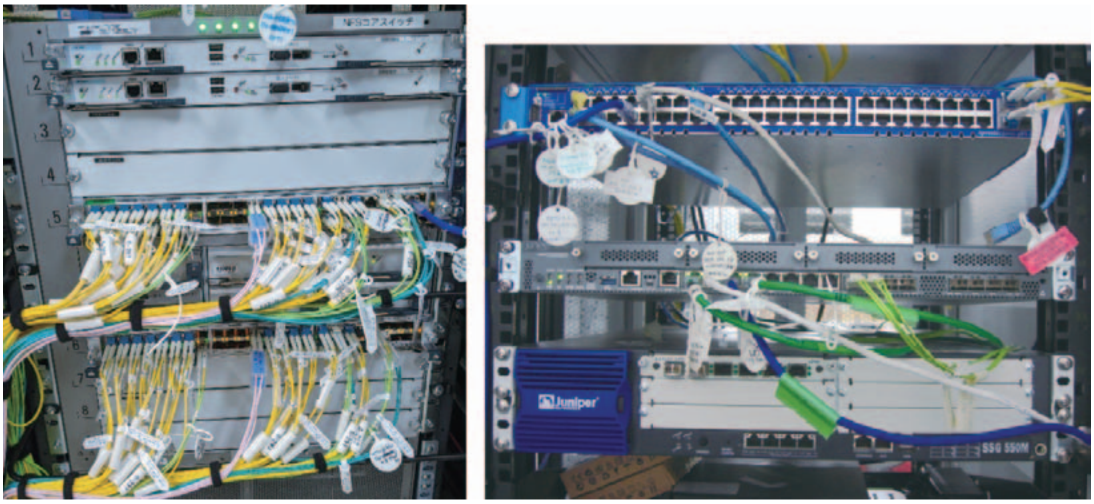

Fig. 3 Upgraded core switch and firewall.

6. Technical exchange and cooperation activities

(1) Third technical exchange meeting: “Structural analysis technology using finite element method”

On February 21, 2020, we held a technical exchange meeting on structural analysis technology based on the finite element method (FEM) as shown in Fig. 1. This was the third meeting. There were 7 presenters and 27 participants, including those who joined remotely with a Web conference application (ZOOM).

In this meeting, four outside presenters presented the comparisons between electromagnetic (EM) analysis software (ANSYS HFSS) and multi-physics analysis software (COMSOL), the analysis of growing polycrystalline silicon for solar cells using a developed FEM cord, and the development of a new electron spectroscopic device using FEM and substitute charge method. Three presenters within NIFS presented EM shield performance evaluation including numerical and shielding analyses, analysis and fabrication of microwave notch filter using ANSYS HFSS, structural analysis on quasi-axisymmetric stellarator CFQS, and EM analysis of magnetic shield performance using ANSYS Emag. We had engaging discussions related to all presentations.

Fig. 1 Technical exchange meeting.

(2) Technical cooperation program: “Analysis of electromagnetic force in the fusion experimental device RELAX”

As part of the technical cooperation program, the EM analysis of the fusion experimental device, RELAX, at the Kyoto Institute of Technology was conducted. At RELAX, in addition to the conventional reverse pinch-type magnetic field, there is a plan to make a modification to enable the tokamak-type magnetic field configuration that is planned to be used for core plasma confinement of the first-generation fusion reactor. To enable the tokamak configuration, the soundness of the magnetic field generation coil needs to be verified.

During March 9–13, 2020, a fourth-year undergraduate student pursuing electronic system engineering at the Plasma Basic Engineering Laboratory of the Kyoto Institute of Technology stayed in NIFS. He investigated the magnetic field generated by the coils and the EM force generated between the coils using ANSYS together with technical staffs in NIFS. First, a 3D analysis model as shown in Fig. 2(a) was created based on the 2D drawings of RELAX using 3D-CAD software (SolidWorks). We then created an appropriate calculation mesh and set boundary conditions that matched the actual phenomenon. The magnetic field distribution, as depicted in Fig. 2(b), in the total analysis region and the EM force generated by the magnetic field generation coils were calculated. Based on the results, we plan to study the modification of the magnetic field generation coils in the next step (Fig. 2(c)).

Fig. 2 Technical cooperation program: (a) 3D-CAD model of RELAX; (b) distribution of magnetic field in a vertical section; (c) technical discussion regarding the modification of magnetic field coils.