Upgrade Plan on NIFS Superconducting Magnet Test Facility*)

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In 1991, the superconducting magnet test facility had been constructed in National Institute for Fusion Science. The facility consists of a helium liquefier/refrigerator with the cooling capacity of 600 W at 4.5 K, large cryostats, a mechanical testing machine, DC power supplies with the maximum current of 75 kA and a distributed control system. So far, the development of the superconducting coils for the Large Helical Device had been conducted and many collaborative works have been carried out. However, the test facility with higher bias filed is needed to develop superconducting coils for fusion reactors and the cooling system, which can supply coolant of various temperature to test samples, is required to apply HTS to large-scale conductors. Therefore, the test facility will be upgraded to promote the development of superconducting coils for fusion reactors. The maximum bias field will be upgraded from 9 T to 15 T to investigate the performance of superconductors under the higher bias field and the existing helium liquefier/refrigerator will be replaced with a variable temperature one to test those under various temperature environment. Consequently, it is expected to progress the development of the superconductors for fusion reactors and the development of large-scale HTS conductors.

Keywords: helium liquefier/refrigerator, variable temperature, fusion reactor, superconducting coil, test facility

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1. Introduction

In 1991, the superconducting magnet test facility had been constructed in the National Institute for Fusion Science (NIFS) to develop large-scale superconductors and superconducting magnets. The test facility consists of a helium refrigeration and liquefaction system, experimental cryostats, a mechanical testing machine, ancillary DC power supplies with the maximum current of 75 kA and a distributed control system [1]. So far, superconductors and superconducting coils for helical coils (HC) and poloidal coils (PC) of the Large Helical Device (LHD) had been developed successfully and a lot of collaborative works with universities, research institutes and companies have been conducted, using the test facility [2–8].

However, the bias filed higher than the present maximum bias field of 9 T is needed in order to develop superconductors for fusion reactors [9]. A helium liquefier/refrigerator, which can supply coolant of various temperature to test samples, is also required to apply advanced materials such as MgB_2 or high temperature superconductors (HTS) to superconducting magnets for fusion reactors. Therefore, the NIFS superconducting test facility will be upgraded to promote the development of the large-scale superconductors and superconducting magnets for fusion reactors. The existing helium liquefier/refrigerator will be replaced with a variable temperature helium liquefier/refrigerator to examine superconductors and superconducting magnets under various temperature environment. The maximum bias field will be upgraded to 15 T to investigate the performance of superconductors under the higher bias field. The control system will also be replaced with a new one from the viewpoint of maintainability and expandability [10].

In the present paper, the existing test facility and its major research achievements are introduced and then contents of the upgrade of the test facility are described. Future research plan is also discussed.

2. Existing Superconducting Magnet Test Facility

Figure 1 is a photograph of the helium liquefier/refrigerator and the large-size experimental cryostats in the test facility. The helium refrigeration and liquefaction system for the NIFS superconducting magnet test facility consists of the helium liquefier/refrigerator with the cooling capacity of 600 W at 4.5 K corresponding to liquefaction of helium of 250 liters per hour or generation of supercritical helium (SHe) of 50 g/s at 4.5 K, two compressors which are 1.52 MPa main compressor with mass flow rate of 99.2 g/s and 1.77 MPa recovery compressor with mass flow rate of 7.44 g/s, an SHe heat exchanger, a purifier, a distribution box, six helium gas storage tanks, a helium gas bag and 10 m^3 liquid helium (LHe) storage tank [11].

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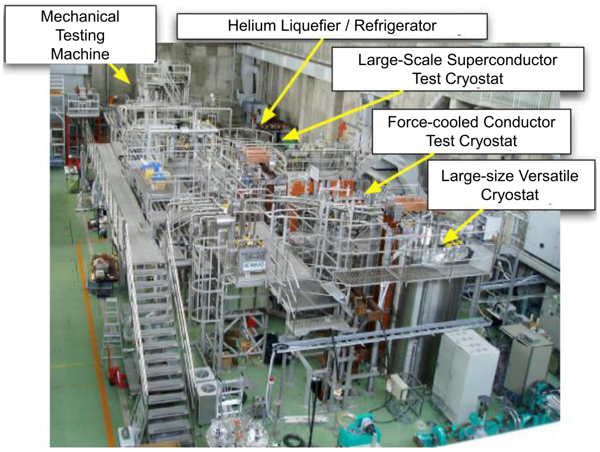

Fig. 1 Photograph of NIFS superconducting magnet test facility.

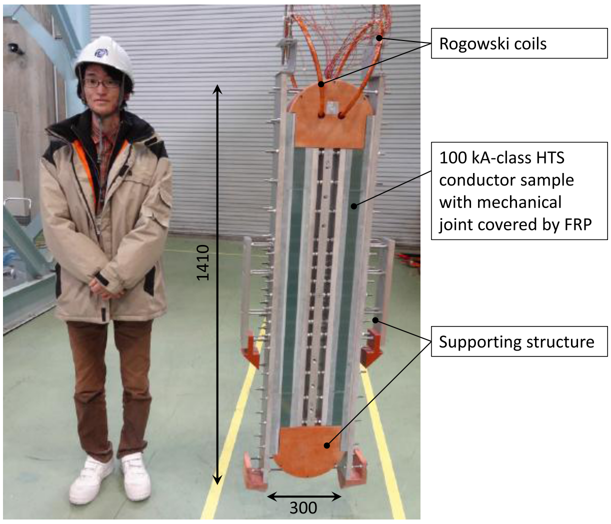

Fig. 2 Photograph of 100 kA-class HTS conductor sample with mechanical joint.

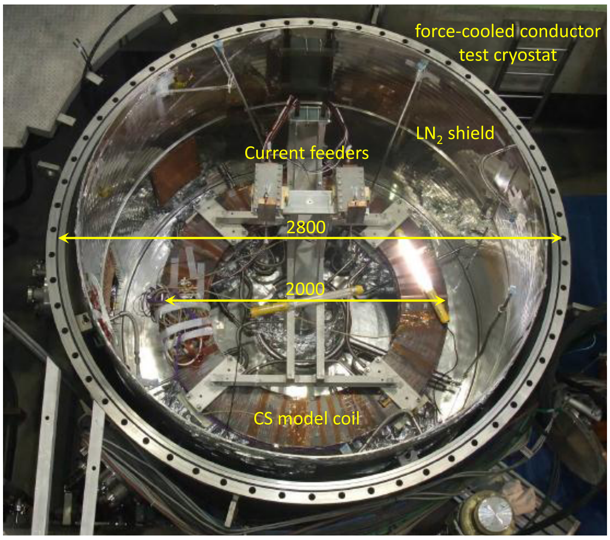

Fig. 3 Photograph of CS model coil installed in the force-cooled conductor test cryostat.

In the large-scale conductor test cryostat, the excitation test of large-scale superconductor up to 75 kA can be performed in liquid helium with the maximum bias filed of 9 T [12–14]. In the force-cooled conductor test cryostat, superconducting magnets, wound with cable-in-conduit (CIC) conductors, can mainly be tested with SHe forced circulation up to 50 g/s and the test current up to 30 kA at steady state [15]. The large-size versatile cryostat can be provided to various experiments and has actually been utilized not only as an LHe bath but also as a liquid nitrogen (LN_2) bath or a vacuum vessel [6, 16–18]. Cryogenic compression tests can be conducted up to 5 MN at LHe temperature, using the mechanical testing machine with the hydraulic servo-control system [19]. In addition to these cryostats, the large-size superfluid helium cryostat with the cooling capacity of 36 W at 1.85 K has been installed [20].

3. Major Research Achievements

Recent achievement with the large-scale conductor test cryostat is the development of the 100 kA-class HTS conductor. One turn loop of the conductor with the mechanical joint, as shown in Fig. 2, was tested in LHe and the maximum transport current induced by reduction of the bias field reached 118 kA [5, 21]. In 2007, a modification was carried out to provide the cryostat to excitation tests for large-scale CIC conductors cooled with SHe [22]. As the result, a lot of collaborative researches on CIC conductors have been progressed, for example, conductor and joint tests for both NbTi equilibrium field (EF) coils and Nb_3Sn central solenoid (CS) of the JT-60SA and examinations of three joints for the ITER toroidal field (TF) coil [23, 24].

Recent achievement with the force-cooled conductor test cryostat is the excitation test of the CS model coil for the JT-60SA. The CS model coil consists of two double pancakes wound with Nb_3Sn CS conductor and a pair of current feeders. It was installed in the cryostat as shown in Fig. 3 and then the cooling and excitation test was performed. Consequently, the requirements were satisfied and fabrication processes were validated [6].

Figure 4 is the photograph of the experimental arrangement for the largest coil in the test facility, which was the real lower inner vertical (IV-L) coil for the LHD PC, tested in 1995. It was wound with CIC conductors. The center diameter is 3.6 m, the height is 0.47 m and the weight is 16 tons. The purpose-built cryostat was utilized for the experiment because it was too large to install in the existing cryostats. After it was cooled down for approximately 250 hours, the validity of the design and the fabrication was demonstrated from the successful excitation of the specified current of 20.8 kA [4].

Other than the experiments mentioned above, various experiments have been conducted, for example, the development of the 1.8 K current feedthrough using YBCO bulk conductor, the examination of the 20 kA current lead using Ag/Au stabilized Bi2223 tapes and the performance test of the helium subcooling system before the installation in the cooling system for the LHD HC [17, 18, 25, 26].

4. Contents of Renewal

Figure 5 shows a schematic layout of the test facility after upgrade and red objects display four pieces of equipment which are to be renewed. It is scheduled that the helium liquefier/refrigerator, the main helium compressor and the control system will be renewed from December

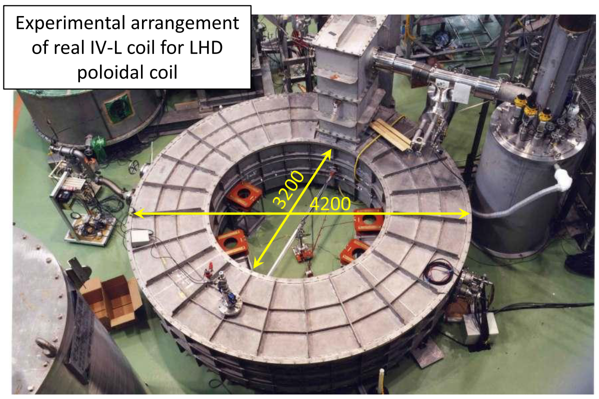

Fig. 4 Photograph of experimental arrangement of real IV-L coil for LHD poloidal coil.

2014 to February 2015 and the integrated commissioning of the refrigeration system will be taken in March 2015. It is also planned that a 13 T solenoid coil will be installed in the large-size versatile cryostat by March 2015 and it is to be upgraded to 15 T in the future [9].

The helium liquefier/refrigerator will be replaced with a Claude cycle helium liquefier/refrigerator (modified LR280) manufactured by Linde Kryotechnik AG. The cooling capacity is 600 W at 4.5 K, corresponding to liquefaction of helium of 250 liters per hour or generation of SHe of 50 g/s at 4.5 K, with the same performance as the existing liquefier/refrigerator. However, the new liquefier/refrigerator has a new function, added by the modification, that can supply temperature-controlled helium gas and SHe from room temperature to liquid helium temperature. The each cooling capacity at the typical temperature is in the case of use of LN_2 as supplementary coolant as follows; 1.0 kW at 20 - 30 K and 1.5 kW at 40 - 50 K.

The main compressor will be replaced with an oil injection type screw compressor manufactured by Kaeser Compressors, Inc. The discharge pressure will decrease from 1.52 MPaG to 0.95 MPaG and the mass flow rate will increase from 99.2 g/s to 101.7 g/s. The helium refrigeration and liquefaction system will be exempted from the application of the High Pressure Gas Safety Act (domestic low) by the reduction of the discharge pressure to less than 1.0 MPaG, except for the helium recovery and purification systems. The control system will also be replaced with DeMPICS developed by Taiyo Nippon Sanso Corporation. As well as the helium refrigeration and liquefaction

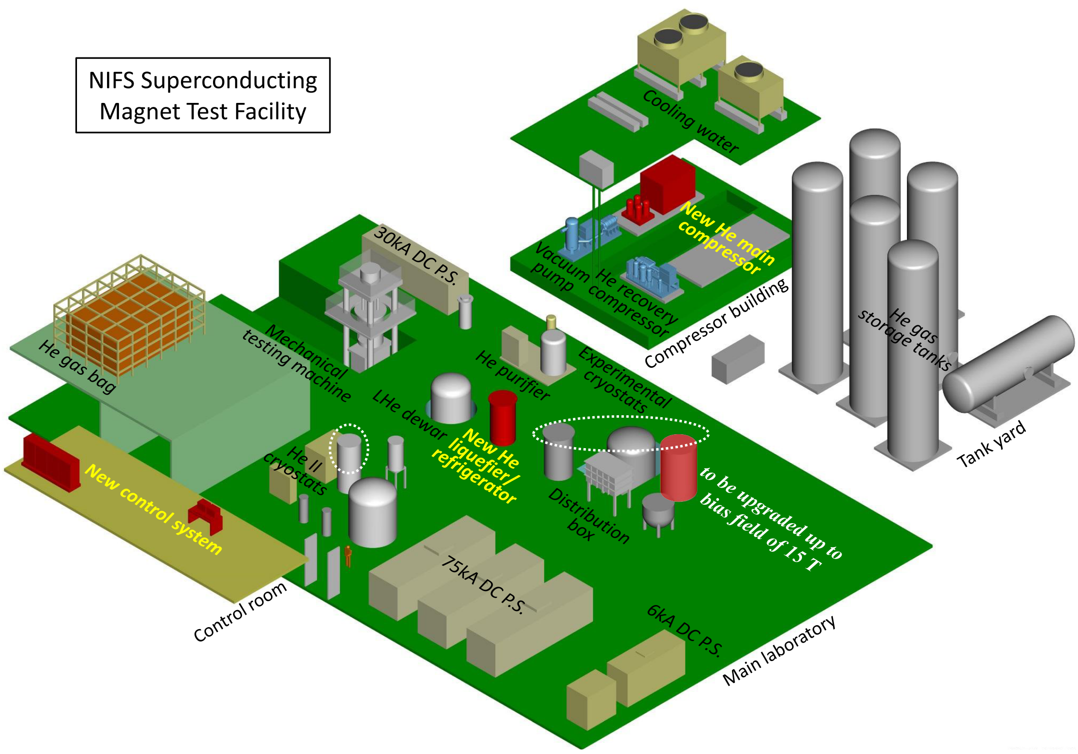

Fig. 5 Schematic layout of NIFS superconducting magnet test facility after upgrade.

system can be operated by remote control from the control room, it will become possible to monitor the system from outside of the laboratory through the Web.

5. Future Research Plan

Planed experiments are after the commissioning as follows; the cooling and excitation test of a real CS module for the JT-60SA, examinations of eight joints for the ITER TF coil and the experiment of large-scale Nb_3Sn conductor jacketed with aluminum alloy for indirect cooling [27]. The CS module, which is to be completed first, will be examined in the test facility before it will be installed in JT-60SA. The outer diameter is 2.0 m, the height is 1.6 m and the weight is 20 tons. It will be the highest and heaviest among coils tested in the test facility ever. Therefore, it is scheduled that some modifications of the force-cooled conductor test cryostat will be made.

After the upgrade of the test facility, large-scale superconductors will be able to get examined up to 75 kA under the bias field of 13 T (15 T in the future). That is so valuable in the development of superconductors for fusion reactors because the performance should be validated under conditions close to actual environment. Besides, the operating temperature of test samples will be able to get varied by using the new liquefier/refrigerator. It will become possible to promote researches and developments that advanced superconductors such as HTS or MgB_2 will be applied to large-scale superconductors for fusion reactors, accelerators and the other high magnetic field generating devices.

6. Summary

In the NIFS superconducting magnet test facility, the development of the superconducting coils for the LHD which was the initial target had been accomplished successfully and then a lot of the collaborative works have been conducted with universities, research institutes and companies, for example, the experimental contribution to JT-60SA and ITER program. To advance research to the next stage, we decided to upgrade the helium refrigeration and liquefaction system partially and to increase the bias field applied to the test samples. Consequently, it is expected to make remarkable progress both in the development of superconductors for fusion reactors and the development of large-scale HTS conductors.

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