8. Bilateral Collaboration Research Program

Kyushu University

Research activities on QUEST in FY2016.

We will summarize the activities on advanced fusion research center, research institute for applied mechanics in Kyushu University during April 2016-March 2017. The QUEST experiments were executed during 24th May-1st Sep. (2016 Spring/ Summer; shotno 32165-33441) and 24th Sep.-27th Jan. (2016 Autumn/Winter; shotno 33442-34699). It should be noted that the toroidal magnetic direction was inverted from shotno 34029. Main topics of the QUEST experiments in FY2016 are listed below.

1) The longest discharge was reached at 6 hours (shotno 34321). Plasma current of the discharge was fluctuating in the range of 2kA-6kA and it is difficult to confirm to keep a steady closed-flux surface. The most important achievement of the discharge is clear observation of neutral compression helping enhancement of external pumping.
2) The discharge of more than 2 hours (shotno 33866) was achieved with a hot wall temperature at 273K. The plasma current was approximately 4 kA measured with a developing hall generator array, being significantly lower than the value expected to be in high β on spherical tokamak configuration.
3) Simulation study of the plasma flow in the Scrape-off layer in the simple magnetized plasma configuration has been carried out. The influence on the flow reversal by the intersection angle of magnetic file lines on the plate, $E \times B$ drift, sheath physics and up-down pressure asymmetry are investigated.
4) As to the permeation probe research led by NIFS, using a reduced activation ferritic steel alloy(F82H), the effect of sputter-coated tungsten (SP-W) on the plasma-driven hydrogen permeation behavior has been investigated in this fiscal year. Similarly to the data taken in VEHICLE-1, a linear plasma facility operated at NIFS, the plasma-driven permeation through F82H with SP-W coatings on the plasma side has been found to be significantly enhanced compared with that without coatings.
5) Electron temperature and density profiles for the discharges sustained by the ECH with a frequency of 28 GHz were measured by a Thomson scattering system. The plasma current was about 60 kA, and the temperature was about 5 eV, and the maximum density was $1.3 \times 10^{18} m^{-3}$.
6) Detailed time evolution of density profiles after CT injection were obtained by a Thomson scattering system. The target plasmas have plasma currents of 20-30 kA, and we observed a clear density increment at the peripheral region.
7) A visible spectroscopic system was installed to measure impurity ion toroidal rotation on the mid-plane. The system was applied to 8.2 GHz limiter discharges (shotno 33701-33705). The measured toroidal velocities were compared with velocities calculated from a collision-less thermal ion orbit-loss model, and the radial variation was found to be qualitatively consistent.
8) Stainless steel type 316L (SS316L) was used as a model sample of tritium retention study, which was exposed to the plasma experiments in QUEST. Tritium retention drastically increased at the degassing temperature prior to tritium exposure above 573K, indicating that the surface properties significantly changed by degassing at high temperature in vacuum.
9) Permeation probes (PP) with PdCu membrane have been developed and installed at top and bottom target plates and around the outer mid-plane of QUEST, in order to measure atomic flux to the plasma facing component in-situ. The flux oscillation of order of 10^{17} H/m^2/s is observed according to the change of plasma position.
10) The hydrogen isotope retention behavior for tungsten (W) placed at top wall or bottom wall of QUEST device during 2015 A/W (Autumn / Winter) or 2016 S/S (Spring / Summer) campaign was evaluated by additional D_2^+ implantation. In 2015 A/W campaign, amorphous carbon deposition layer was formed, although metal impurities were contaminated in deposition layer for the sample exposed to 2016 S/S campaign. H retention was clearly reduced for 2016 S/S.
11) In-situ measurement of the optical reflectivity change under the long-pulse operation was performed for mirror polished stainless steel using a super continuum white laser. The reflectivity change could not be discriminated due to an optical axis deviation caused by temperature rise of the mirror sporting tool and wall. However, the detectable change of the reflectivity has been observed for the mirror exposed to the whole plasma of this campaign.
12) Electron temperature and density profiles for the discharges sustained by the ECH with a frequency of 28 GHz were measured by a Thomson scattering system. The plasma current was about 60 kA, and the temperature was about 5 eV, and the maximum density was $1.3 \times 10^{18} m^{-3}$.
13) Detailed time evolution of density profiles after CT injection were obtained by a Thomson scattering system. The target plasmas have plasma currents of 20-30 kA, and we observed a clear density increment at the peripheral region. The time evolution was consistent with the estimate based on a rough model of the CT fueling process.
14) A new type of divertor biasing was tested for control of edge of the core plasma, scrape-off layer (SOL) plasma and divertor heat load. For this divertor biasing, 4 biasing plates are arranged every 90 degrees toroidally on the upper divertor plate of QUEST. Only 5 % of the total currents driven by the biasing passed through the grounded lower divertor plate. Most of currents driven by the biasing will flow into the grounded vacuum vessel crossing the SOL without reaching to the lower divertor plate. It was found that the particle flux to divertor target plates expands radially during the biasing.

15) A high-presence remote participation graphics terminal and the augmented reality (AR) applied software have been successfully developed. The AR software has been made by revamping a free software “VideoLAN VLC media player” to show the real-time camera view on the PC desktop background. More than 1 Gbps network bandwidth will be necessary to adopt this system to the remote participation for the experiment.
16) To examine surface modifications and hydrogen retention, samples of vacuum plasma spray (VPS) and atmospheric plasma spray (APS) tungsten were exposed to plasma in QUEST in 2016 spring-summer and autumn-winter experimental campaign together with those of sintered bulk tungsten after degassing in vacuum. No noticeable damage was found after the plasma exposure. Surface analysis and hydrogen retention measurement are in progress.
17) Conceptual study of a neutral beam injector (NBI) for the QUEST was conducted. In conclusion, 10 keV beam current density of more than 50 mA/cm^2 will be got and NBI power of around 100kW will be possible with ion source beam extraction area of 200 cm^2.
18) A new 28 GHz transmission line with polarizer and launcher systems has been developed for local ECH/ECCD experiments. Two corrugated $\lambda/4$ and $\lambda/8$ polarizer plates were developed with careful attention to reduce Ohmic losses at the corrugated plates. The launcher system with two quasi-optical mirrors has been also developed. A large plasma current of 70 kA was non-inductively ramped up along the slow vertical field ramp-up by the strongly focused X-mode beam (SN:33004).
19) A new type of magnetic probe, which is called “AT (advanced technology) probe”, consisting of laminated ceramic plates with metalized tungsten was developed for JT-60SA. These AT probes with newly developed connectors have been installed in QUEST for test of noise and reliability.
20) Co-axcial helicity Injection has been investigated on QUEST. In 2016, we could achieve plasma production with good reproducibility and finally plasma current reached up to 29 kA. It should be investigated how to make a closed flux surface. It is a future work.
21) Possibility of merging fueling using the CHI system has been considered. After CHI plasma current start-up experiments will be successful, this type of experiments could be conducted.
22) Considering the toroidal flow, the equilibrium is fitted within nested magnetic surfaces by SU-EFIT. Though the plasma magnetic axis shifts outward due to the centrifugal force, the opposite polarity current does not disappear in the high-field region.

[1] K.Hanada *et al.*, 26th IAEA Fusion Energy Conference, Kyoto, Japan, Oct. 17-22, EX/P4-49 (2016).
[2] K. Hanada *et al.*, 2017 Nucl. Fusion 57 126061
[3] N. Fukumoto, *et al.*, 26th IAEA Fusion Energy Conference, Kyoto, Japan, Oct. 17-22, PDP-16 (2016).
[4] Y. Takeiri, Investigation on a continuous operation NBI for the QUEST, Annual report of 2008 NIFS bilateral collaboration
[5] Kengoh KURODA, Roger RAMAN *et al.*, Plasma and Fusion Res. 12, 1202020 (2017)

Kazuaki Hanada (Kyushu University) 1), 2)
Hideki Zushi (Kyushu University) 3)
Yoshihiko Hirooka (NIFS) 4)
Akira Ejiri (University of Tokyo) 5),6)
Taiichi Shikama (Kyoto University) 7)
Masao Matsuyama (University of Toyama) 8)
Masahiro Kobayashi (NIFS) 9)
Yasuhisa Oya (Shizuoka University) 10)
Mitsutaka Miyamoto (Shimane University) 11)
Naoyuki Fukumoto (University of Hyogo) 12), 13)
Kazuo Toi (NIFS) 14)
Hideya Nakanishi (NIFS) 15)
Yuji Hatano (University of Toyama) 16)
Masanobu Tanaka (Kumamoto University) 17)
Hiroshi Idei (Kyushu University) 18)
Manabu Takechi (QST) 19)
Roger Raman (University of Washington) 20)
Osamu Mitarai (Institute for Advanced Fusion and Physics Education) 21)
Kazuo Nakamura (Kyushu University) 22)

(K. Hanada)