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Measurement of Energetic Electron Flow with Langmuir Probe in QUEST

QUESTにおける静電プローブを用いた高速電子流計測

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In spherical tokamak (ST), non-inductive current start-up with RF injection has been an important matter. Although it was suggested that energetic electrons confined in open magnetic field configuration (OMFC) play an important role for spontaneous formation of closed flux surface (CFS) in numerical manners, quantitative estimation was inadequate. This time, the current carried by these energetic electrons was directly measured with a newly-developed Langmuir probe and measured results were well fitted with values estimated numerically. The temperature of these energetic electrons was about 4~5keV and total carried current was estimated to reach about 1.4kA, which seemed large value enough to affect the formation of CFS with pressure driven current.

1. Introduction

For realization of commercial future fusion power plant, Spherical Tokamak (ST) is one of the promising candidates because of its cost efficiency. In tokamak including ST, toroidal loop current should be driven in plasma for confinement of it in closed magnetic flux surface (CFS) and inductive method with central solenoid (CS) coil has been conventionally used to start-up the plasma current. However, in ST, CS-less structure is required because of its tightly restricted special margin of central part of a machine. Thus, non-inductive current start-up is one of the most important matters for ST. Especially, the method with radio frequency wave (RF) injection has been widely used and researched in many ST devices such as CDX-U[1], LATE[2], TST-2[3] and MAST[4]. In current start-up with RF injection, energetic electrons were focused in that current carried by these electrons seemed to play an important role for spontaneous transition from open magnetic field configuration (OMFC) to CFS [5]. Although the presence of the current carried by energetic electrons was suggested in numerical manners [6], no one has confirmed it experimentally and quantitative estimation was inadequate to judge whether the current caused by these energetic electrons has large amount enough to affect the formation of CFS. This time, the current carried by energetic electrons was directly measured with newly-developed Langmuir probe for the first time. Besides, quantitative estimation of the total value of the current was done in numerical manners based on the measurement results. This time, we report the results mentioned above and discuss the effect of the current for formation of CFS.

2. Experimental Apparatus

The experiments were done in Q-shu Univ. Experimental Steady-State Spherical Tokamak (QUEST), which is medium-sized ST in Kyushu University [7]. RF system with 8.2GHz up to 400kW was used for plasma current start-up and driving. In Fig 1, the schematic view of probe head used for measurements of the current caused by energetic electrons is shown. The head has insulator wall between two tungsten tips and one tip is set on the wall. Half surfaces of tip A and B are covered by insulator and tip C is full stripped. The head was set as the wall perpendicularly crossed toroidal direction and tip A faced to co-directional electron flow, where co-direction is defined by electron

velocity in toroidal direction, v_{toro} and plasma current I_p as follows; $-v_{toro}I_p > 0$. Close pieces of information to obtain the current and the temperature caused by energetic electrons with this probe head are introduced in [8].

3. Experimental Results and Analysis

In the discharges for measurements of energetic electrons with Langmuir probe, time-constant vertical field B_v was set at about 1.5mT with positive and negative N-index, n~0.35 and n~-0.07 respectively at the center of the vacuum vessel. About 30kW RF power was injected and I_p~4kA resulting in the formation of CFS was obtained in positive N-index configuration (PNC), while only about 1.2kA plasma current was obtained in negative N-index configuration (NNC). It should be noted that energetic electrons are confined only in PNC. In PNC, the large magnitude of floating potential more than hundred volts was detected in tip A, while that in tip B was only several volts in OMFC region out of last closed flux surface (LCFS). This asymmetric floating potential suggested presence of co-directional flow of energetic electrons. To measure the current caused by the flow, floating potential measurement with tip A, C and ion saturation current measurement with tip B were done and the data was analyzed with the method mentioned in [8]. As a result of the measurements, temperature of energetic electrons, T_{eh} of 4~5keV and current, j_{ehp} of 1~2kA/m^2 was obtained at several positions of probe head as shown in Fig. 2. To evaluate total value of the current caused by energetic electrons, the distribution of the current was estimated with orbit calculation. In the calculation, fundamental, 2nd and 3rd ECR layers were assumed as the source of energetic electrons and temperature and density at the source were decided as the calculated temperature and current agreed with measured value at each position of probe head as shown in Fig. 2. In this calculation, total amount of current estimated at 1.4kA, which reached about 35 % of whole plasma current. The parameters at the source of energetic electrons were applied to calculation in OMFC at initial phase of discharge. The current by energetic electrons seemed not to be enough to lead to formation of CFS only by itself. But, with pressure driven current in OMFC, which was detected in negative N-index configuration, CFS was formed with current caused by energetic electrons.

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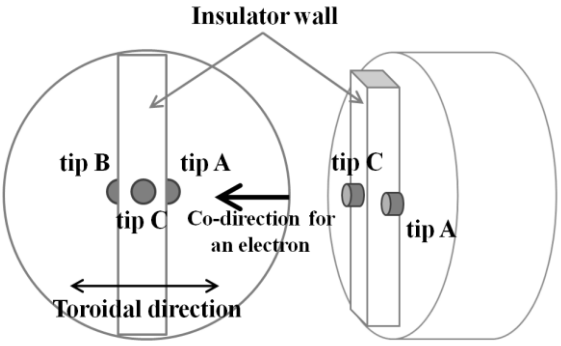

Fig.1. A schematic view of the probe head

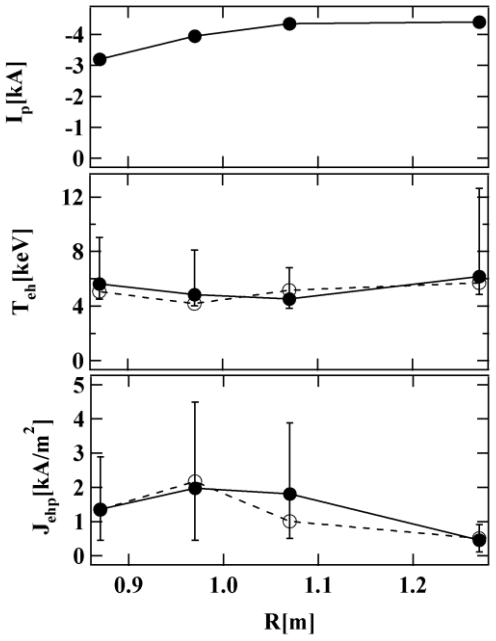

Fig.2 The plasma current, the temperature and current caused by energetic electrons at each probe position are shown. Closed circles and solid line show measured values and open ones show calculated values.

References

[1] C. B. Forest *et al.*, Phys. Rev. Lett. **68**, 3559 (1992).
[2] T. Maekawa *et al*., Nucl. Fusion **45**, 1439 (2005).
[3] A. Ejiri et al., Nucl. Fusion **49**, 065010 (2009).
[4] V. F. Shevchenko et al., Nucl. Fusion **50**, 022004 (2010)
[5] T. Yoshinaga et al., Phys. Rev. Lett. **96**, 125005 (2006)
[6] A. Ejiri and Y. Takase, Nucl. Fusion **47**, 403 (2007).
[7] K. Hanada et al., Plasma and Fusion Research **5**, S1007 (2010)
[8] M. Ishiguro *et al.,* submitting to Rev. Sci. Instrum.