Local Measurement of Energetic Particles in a Core Plasma by a Directional Probe Method

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Abstract. A directionnal probe method is applied for energetic particle measurements in outer and inside the last closed flux surface. The two experimental demonstrations have been performed in the compact helical system (CHS). One is neutral beam modulation experiment and the other is the measurement of MHD burst induced loss of energetic ions. The spatial variation of energetic particle response to MHD burst can be observed, which is considerd as a first experimental observation.

1. Introduction

Energetic particle transport is one of the most important issues for burning fusion plasmas, for example, international thermonuclear experimental reactor (ITER). In particular, the interaction between energetic particles and MHD instabilities is a key issue for energetic particle confinement. The significant enhancements of energetic particle loss due to MHD instabilities have been experimentally observed in many fusion devices, and the MHD instabilities have been strongly studied both experimentally and theoretically [1]. In these researches, it is considered that the distribution function of energetic particles is important, because the excitation of MHD instabilities is very sensitive to the distribution function of energetic particles [2]. However it is difficult to experimentally observe the spatial distribution of energetic particles in the core plasmas by conventional diagnostic tools, for example, neutral particle analyzer (NPA), lost ion probe (LIP), and so on, because of insufficient spatial resolution. In this paper, the application of directional Langmuir probe (DLP) method for energetic particle measurement is proposed in order to measure energetic particles with high spatial resolution in section 2, and the directional probe and two experimental demonstrations of this method are presented in sections 3 and 4, respectively.

2. Diagnostic Principal

A directional probe method is able to obtain deviations of the ion (electron) velocity distribution function from the dependence of ion (electron) current on the angle of normal vector of the particle-collecting surface. And it is well known as a plasma flow measurement method. However it also has sensitivity to beam component for ion and electron in case that beam component is relatively stronger than flow component, for example, toroidal plasmas sustained by tangentially injected neutral beam. In such case, the difference of the ion current measured with the angle of probe surface collecting flux flowing co-direction, I_{co}, and that flowing counter-direction, I_{ctr}, is assumed here to be proportional to the energetic ion current, I_b;

$$I_{co} - I_{ctr} \simeq I_b \qquad (1).$$

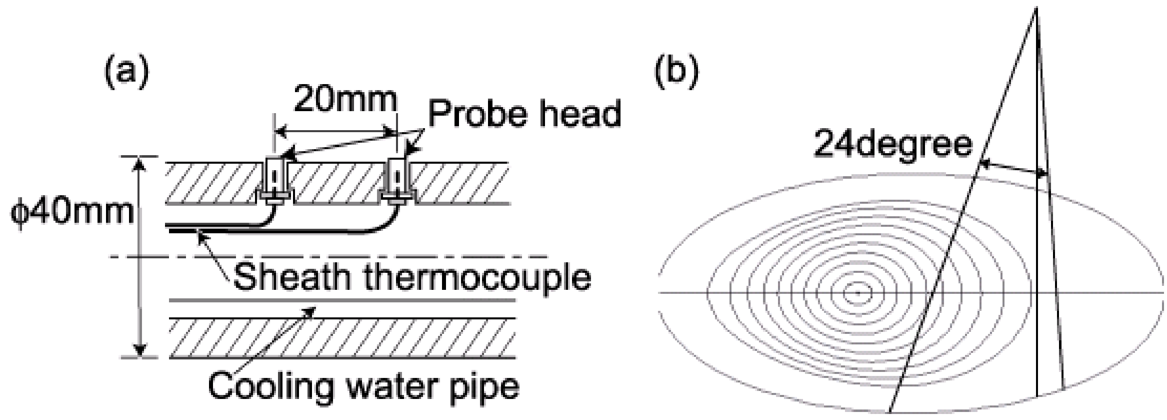

Fig. 1. (a)The schematic view of cross section of the DLP, and (b) the horizontally elongated cross section of CHS standard configuration and the area in which the DLP can scan.

The accuracy of this relation must b experimentally e confirmed by calibration for the high energy beam.

2. Experimental

A ten-channel probe array has been installed on a directional Langmuir probe (DLP), and each probe head set up a thermocouple. This probe is useful as a conventional DLP and a thermal probe measuring local heat flux (which is not mentioned in this paper). The water cooling channel is installed inside the probe and removes the heat load from energetic particles and the plasma. This probe has been vertically installed from upside in a horizontally elongated cross-section of CHS, and it can move in the directions of vertical, *z*, and major radius, *R*. The schematic and scan region of this probe are shown in Fig. (1). Moreover, this probe can be rotated along the probe axis, so measure co- and ctr-going fluxes separately. In this experiment, the probe head is negatively biased with the voltage of –120V to collect ion current. The temperature increase of the probe head is also measured as a monitor in order to prevent from melting down of the DLP, and is about 100 degree at maximum in the region of $r/a>0.8$. The scale of this probe is 40mm in diameter and the collector area of each probe tip is 4mm in diameter, so the spatial resolution of this probe is about 4mm. The sampling speed of data acquisition system is 1MS/sec and the time resolution of this probe system is <10μsec.

3. Results and Discussions

3.1. Neutral beam modulation experiment

The application of the directional probe method for energetic particle measurement has been performed using the neutral beam modulation discharges in CHS. The NBI has been injected into the co-direction and repeated turn on and off in a discharge. The DLP has been inserted in the plasmas and the co-and ctr-going ion current have been measured at $r/a= 0.84$. The modulation pattern and the probe currents are shown in Fig. 2-(a) and -(b), respectively. The co-going ion flux measured by the DLP is larger than the ctr-going one in the NBI heating phase, while the two fluxes are almost same in electron cyclotron heating (ECH) phase without NBI heating. The energetic particle flux evaluated by eq.(1) (which is shown in Fig.2-(c)) is synchronized with the neutral beam pattern and also consist with the energetic

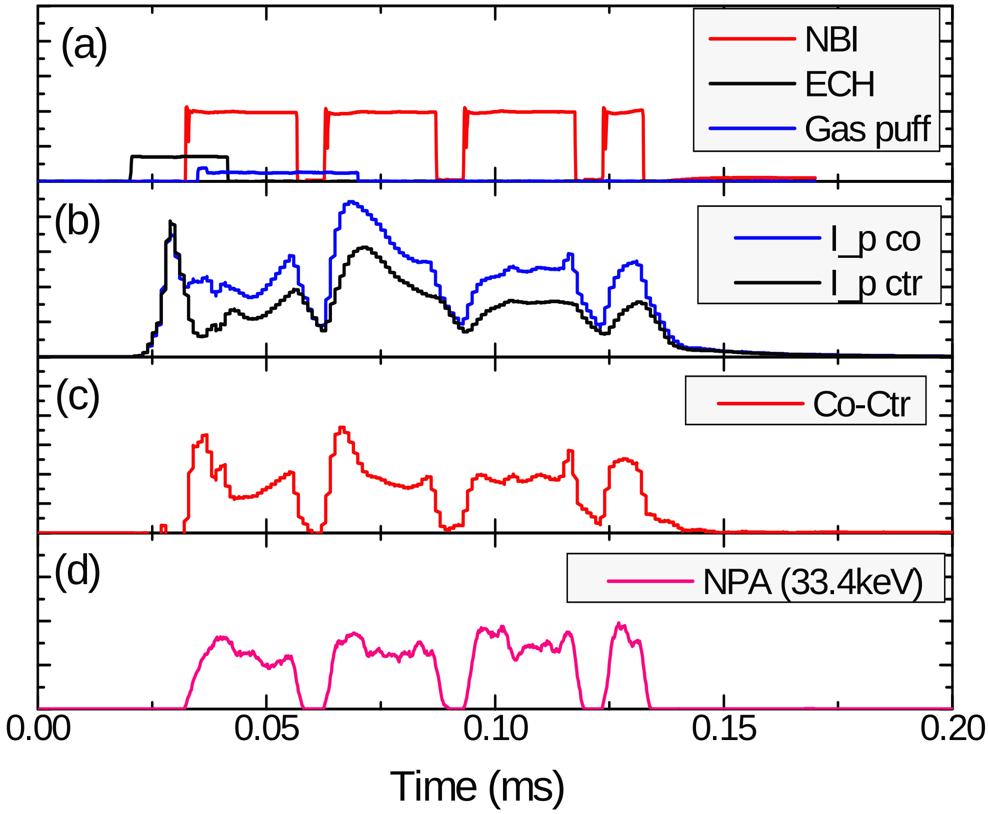

Fig.2 The wave form of neutral beam modulation experiment; (a) electron cyclotron heating and NBI heating, (b) ion currents measured by HP, I_{co} and I_{ctr}, (c) The difference of I_{co} and I_{ctr}, and (d) neutral particle flux with the energy of 33.4keV measured by a neutral particle analyzer.

particle fluxes measured by a neutral particle analyzer (the sample is shown in Fig.2-(d)). This result means that it is possible to evaluate energetic particle flux using eq.(1).

3.2. MHD burst experiment

The excitations of toroidal Alfven eigenmodes (TAE) and energetic particle mode (EPM) have been observed [3,4] and energetic particle losses synchronized with EPM bursts have been also observed by a lost ion probe (LIP) in CHS [5,6]. The energetic particle measurements by the DLP have been performed in plasmas in which EPM bursts are excited. The EPM burst I chirping down with the frequency range of 10-50kHz (The frequency range of TAE is >100kHz.) has been observed in NBI heating phase (80msec<t<180msec), and the significant increases of the co-going ion flux measured by the DLP have been also observed, while no response has been observed in ctr-going flux, which are shown in Fig.3-(a) and –(c), and each magnified figures are shown in Fig. 3-(b) and -(d), respectively. The perturbation amplitudes of the magnetic field are also shown in the magnified figures. The response of the co-going ion current is attributable to the energetic ion behavior by the EPM burst, because such response can not be observed in ctr-going one.

The responses of energetic particles to the EPM burst can be observed in wide area inside and outside of the LCFS (0.8<r/a<1.05, which is limited by the probe drive system), and is classified in two types; one is fast response in the burst glowing phase, and the other is slow response in the decay phase of the burst, which can be clearly seen in Fig. 3-(c). The fast response of energetic particle to the EPM burst can be observed only inner region of r/a<0.96,

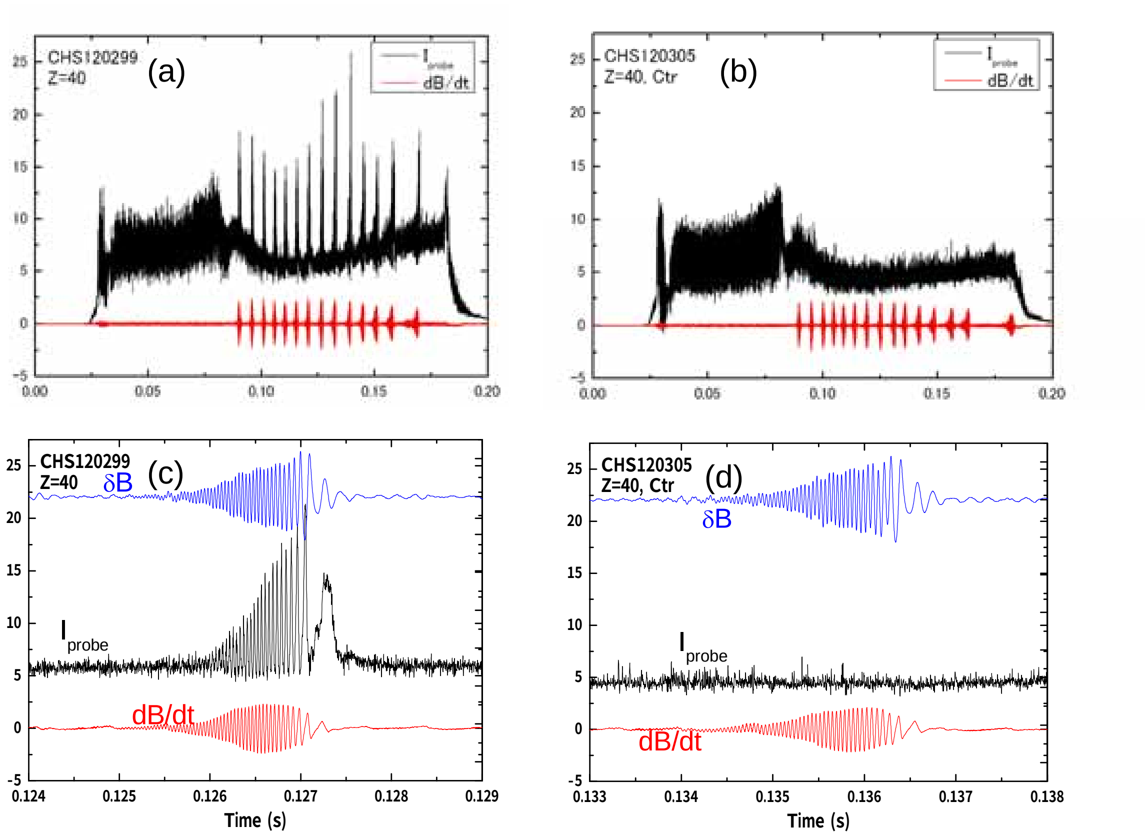

Fig.3. (a) The co- and (b) ctr-going ion fluxes measured by the DLP and magnetic field fluctuation measured by a magnetic coil. (c),(d) The magnified graphs of (a) and (b), and the amplitude of the magnetic field perturbations are also shown in (c) and (d).

and the amplitude of energetic particle flux of this fast response have a linear relation to the amplitude of magnetic field perturbation of the EPM and is also sensitive to the population of the energetic particles at the point, while further analysis is necessary for confirmation of these relation. Thus the fast response has information about distribution of energetic particle in the plasma and the eigenfunction of the EPM. The spatial profile of the fast response amplitude seems to be consistent with the EPM burst profile measured by a heavy ion beam probe [7].

On the other hand, the slow response can be observed in wide spatial area of $0.8<r/a<1.05$ and seems to be sensitive to the envelop of the burst, in particular, to that of the decay phase. The slow response of energetic particles observed by the DLP outside of the LCFS agrees well with the energetic particle loss measured by the LIP. So the spatial distribution and propagation of the slow response is significantly important for understanding the rule of energetic particle transport due to EPM bursts in toroidal fusion plasmas, which is left for future study.

4. Conclusion

In order to measure energetic particles with high spatial resolution, the application of directional probe method for energetic particle measurement was proposed, and two experimental demonstrations confirmed that this method is useful for high energy particle measurement inside the LCFS. Moreover, the new feature of energetic particles can be observed using this method, that is, the dynamic responses of energetic particles to EPMs and their spatial profile have been observed. The further investigation is necessary for understanding of energetic particle transport due to EPMs, which is left for future study.

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