First Results with Dual Heavy Ion Beam Probes on Low Density Discharges in CHS Plasma

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Abstract

Installation of the second heavy ion beam probe has been completed in Compact Helical System (CHS) stellarators. In a low density plasma, simultaneous measurements of dual HIBP systems have been applied and have just obtained new results related with two interesting phenomena; *electric pulsation* and *high frequency coherent mode* supposed to be an Alfven eigen mode. The paper presents the results of spatio-temporal evolution in electric pulsation and correlation between HIBP signals in high frequency modes.

1. Introduction

Structure and dynamics of radial electric field (E_r) is one of the central issues for toroidal plasma research since a change in E_r -structure could bring about confinement improvement with a transport barrier. In CHS, an heavy ion beam probe (HIBP) was installed to clarify the E_r bifurcation nature of a toroidal plasma, and revealed a lot of interesting features [1], such as bifurcated potential [2], electric pulsation [3], Neoclassical transport barrier [4], and so on. Another HIBP has been prepared for further understanding of unsolved physics problems for a few years, and the results have just started to be obtained.

As the first operation, both HIBP systems were applied to measure plasmas of low density ($n_e \sim 0.5 \times 10^{13}$cm^{-3}) with a combined heating of electron cyclotron resonance (ECR) and neutral beam injection (NBI.) In these discharges, self-organized oscillation, *electric pulsation*, and *high frequency coherent fluctuations* (could be identified with Alfven-eigen (AE) modes [5,6]) were observed in both HIBP signals. This paper presents exactly the first results obtained in simultaneous use of the dual HIBP systems.

2. Experimental Set-up

The CHS is a heliotron/torsatron device whose major and minor radii are 1.0m and 0.2m, respectively [7]. The magnetic field configuration has a rotational symmetry of 45 degree in the toroidal direction. Four pairs of poloidal coils are provided to modify the plasma shape and shift the magnetic axis. The strength of magnetic field is up to 2T at present. The CHS owns two co- NBI systems and gyrotron systems as heating apparatus; the frequency of a gyrotron used in the experiments is 53.2 GHz. The maximum power of each NBI is approximately 1MW. Different heating schemes produce a wide variety of plasmas belonging to quite different regimes in plasma parameters, and allow investigation of behavior of the plasmas in various regimes of collisionality.

The two HIBPs (maximum beam energy: 200keV) are installed at toroidal positions apart from each other by 90 degree. The observation points of both HIBPs are located at almost symmetric positions in the toroidal rotational transformation of the angle (90 degree). The HIBP can be operated in two different manners. The first one is to scan radial position by sweeping the beam trajectory continuously in order to obtain the potential profile (scanning mode). Time evolution of potential profile can be measured in every a few millisecond at the fastest. The second one is that the beam orbit, or observation point, is fixed in order to investigate dynamics or fluctuation of plasma (fixed-point mode). In this mode, the temporal resolution is up to a frequency of 250kHz presently.

3. Experimental Results

3-1.Target Discharges

The measurements were performed in a low density plasma with a combined heating of NBI and ECR. The discharges are performed on the magnetic configuration whose axis is located on R_{ax}=0.921cm with its strength of 0.88T. The ECR is exactly on the magnetic axis at the gyrotron frequency of 53.2GHz. The necessary beam energy to observe this configuration is ~70keV when cesium beam is used.

The waveforms of line-averaged density and central potential are shown in Fig. 1. After ECR-heating is turned on, the density starts to decreases and relaxed to the steady state value of $n_e \sim 0.5 \times 10^{13} cm^{-3}$. In the steady state, the potential signal shows pulsation behavior with a quasi-coherent frequency of ~750Hz. After the NBI is turned off, the pulsation amplitude starts to decrease and disappears in ~10 ms. The pulsation behavior has been regarded as repetitive transitions between two bifurcated states[3]. Similarly, high frequency mode is developed after the ECR-heating is launched. In this combined heating phase, the mode is continuously observed in potential fluctuation of the HIBP, and the mode disappears in ~10ms after the NBI is turned off.

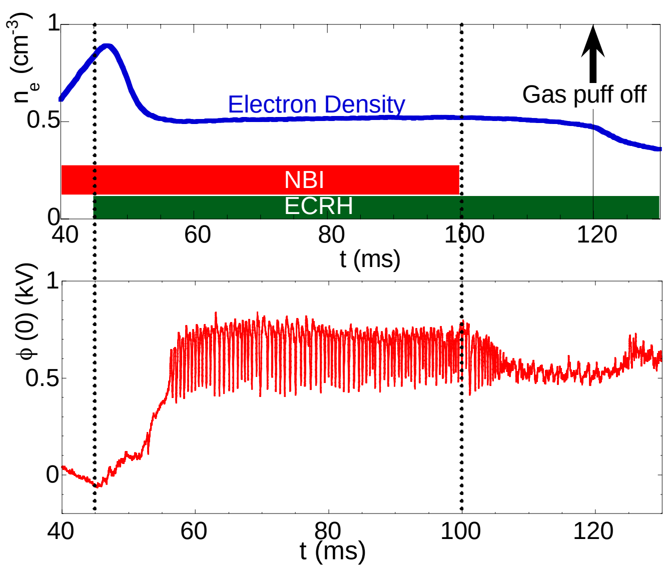

Figure 1: (upper) The waveform of line-averaged density.. (lower) The waveform of central potential which exhibits quasi-coherent activities, termed *electric pulsation*.

3-2.Potential Pulse Propagation during Electric Pulsation

The waveforms from both HIBP potential signals have been found to show coherent pulsation behavior. Figure 2(a) shows the waveforms of the HIBPs, where one is operated with the observation point being fixed at the plasma center and the other in scanning mode; the triangular waveform in the figure indicates the observation point as a function of time. While scanning potential, several sharp dips are found with synchronized with a corresponding potential pulse at the central potential. Utilizing the good correlation, the upper state profile of bifurcation can be deduced by removing the effects of pulse-like events. On the other hand, the lower state profile also can be approximately constructed by picking up potential values at the scanning radius when the pulse at the plasma center takes minimum values. The bifurcated potential profiles are shown in Fig. 2(b).

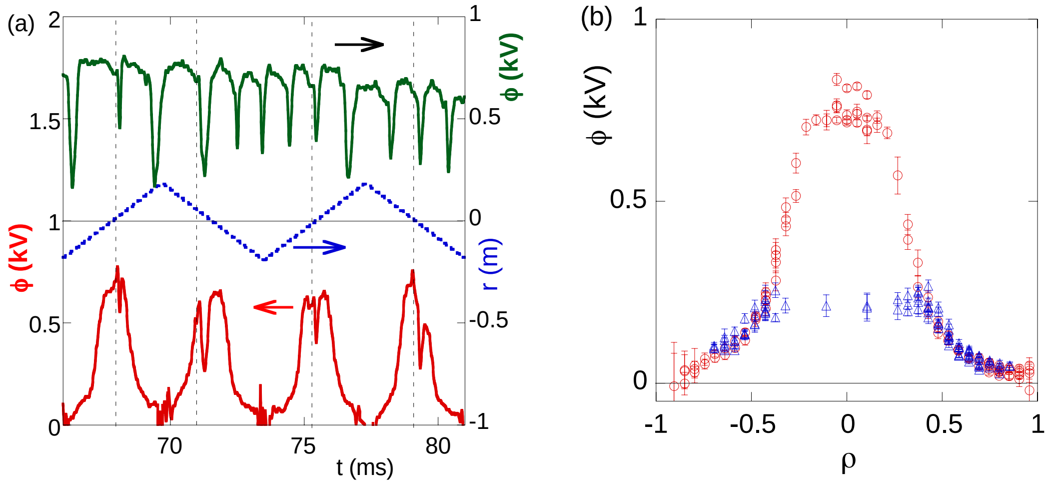

Figure 2: (left) Potential pulsation waveforms. The 1st HIBP is used as radial scan, while the observation point of the 2nd HIBP is fixed at center. The dashed line shows the observation radius for the scanning. (Right) Potential profiles after the effects of pulse-like-event is removed. The images of two bifurcated states during pulsation emerge.

The propagation in the potential pulse can be determined by operating both HIBPs in the fixed-point modes that is, by moving the observation point of an HIBP system with the other observation point being fixed as a reference. Figure 3(a) shows the waveforms of different radial positions in comparison with the central potential waveform as a reference. The comparison reveals that the potential pulse propagates outward and the negative pulse inside changes its sign (positive pulse) outside the normalized radius of r/a~0.5, that corresponds to the pivot point for the bifurcated profiles shown in Fig. 2(b). If the statistically averaged delay time is plotted as a function of radius, the dependence appears to obey a parabolic nature. The result suggests that the wavy of potential propagation could be diffusive inside the pivot point. A rough estimation gives a diffusivity of approximately D~100m^2/s, that could be anomalously larger (can be more than 10) than the thermal diffusivity. The definite conclusion, however, awaits further experiments including sufficient ensemble.

Apart from the core behavior, quite intriguing observation is obtained if attention is paid on a relation between the plasma core and a region near edge. The detected beam intensity from the region around r/a~0.7-0.8 shows quite large changes (more than 50%) in a synchronized way with central potential pulsation. In this low-density discharge, a change in beam attenuation should have a sufficiently small contribution on a change in detected beam intensity. Therefore, the change in the beam intensity is allowed to be a local density change. Figure 3(b) shows the good correlation between the central potential and density in the outer regime. Moreover, the timescale of the change is as fast as the transition timescale of the central potential; the transition timescale from upper to lower state is ~50 μs, that of the opposite is ~80μs. This correlation could be a manifestation of non-local nature of the phenomena, providing an interesting future subject to be investigated.

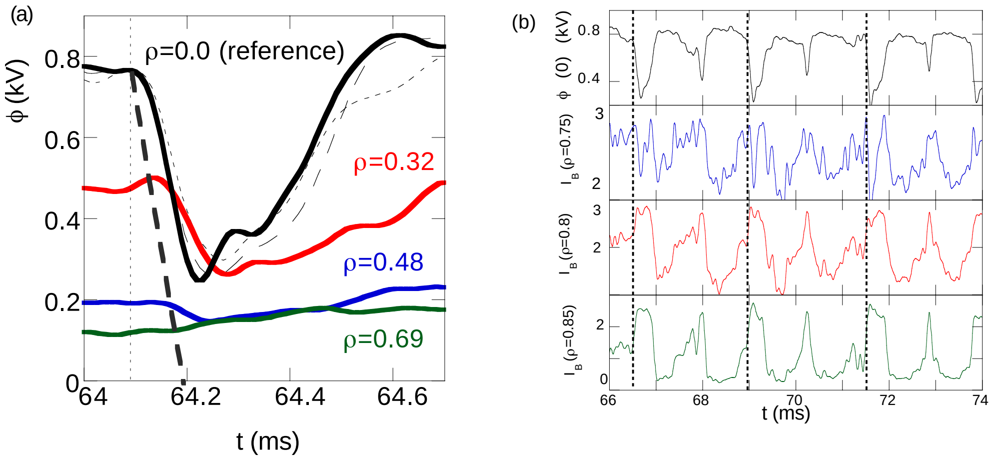

Figure 3: (a) Fashion of potential propagation during a pulse-like-event. The pulse propagates outward. (b) Correlation between beam intensities (densities) of outer radii (simultaneously measured) and central potential. Intensity decreases at r/a~0.75 with a rapid decrease of potential, while the other outer intensities increase.

3-3. High Frequency Modes

In the same discharges, a high frequency (~180kHz) fluctuation has been found in both density and potential signals of HIBP. In particular, the coherent mode can be clearly identified in potential fluctuation. The fluctuation has been found to well correlate with magnetic field pick-up signals. Figure 4(a) shows FFT spectra of these potential fluctuations at three normalized radii of r/a~0.49, 0.59 and 0.69. The fluctuation appears in potential fluctuation spectra as a clear peak of which bandwidth is ~10kHz. The amplitude increases toward the outer regime in this range. Potential fluctuations at the frequency from two HIBP show quite high coherence of ~0.7 at the same normalized radius of r/a~0.69, as is shown in Fig. 4(b), while the density fluctuations do not show any significant coherence.

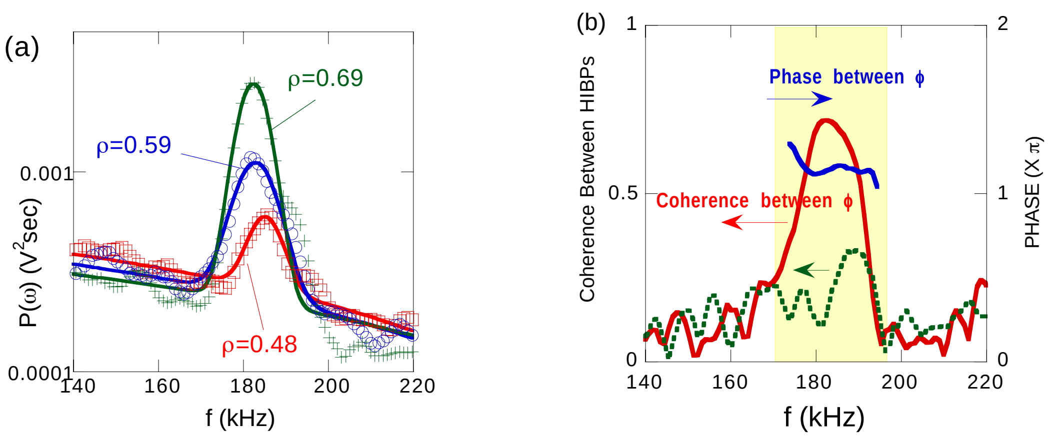

Figure 4: (left) Fourier spectra of potential fluctuation from three radial points. High frequency of ~180kHz is found to be correlated with magnetic field fluctuation, (center) Coherences between intensity (or density) and potential fluctuations from two HIBP systems, together with phase difference between potential fluctuations

The potential fluctuations assure rather long distance correlation. Estimated phase difference between the two signals is approximately 180 degree, that suggests toroidal mode number should be n=2 since the observation points are apart by 90 degree in toroidal direction with almost the same poloidal position..

The power of the coherent mode can be estimated using a Gaussian fitting to the peak with removing the background level. The fluctuation power is plotted as a function of normalized radius in Fig. 5. The potential fluctuation is localized on outside region, with its maximum amplitude around r/a~0.7. The long correlation of potential fluctuation supports an assumption that the potential contour should fluctuate together with magnetic field surface distortion. Then, corresponding plasma displacement ξ can be estimated using the potential fluctuation amplitude divided averaged-E_r, or the distortion of magnetic surface can be evaluated by a formula, $\delta\phi \sim E_r\xi$. In this discharge, the plasma stays in the state with the upper potential profile in Fig. 2(b). Therefore, the E_r-profile of the upper state can be used to estimate the plasma displacement. The simple estimation yields that the plasma displacement should be order of a few mm with increasing toward the edge. Further analysis will be possible to deduce more complete structure of the mode including the phase information, then the impact on the high energy particle can be estimated.

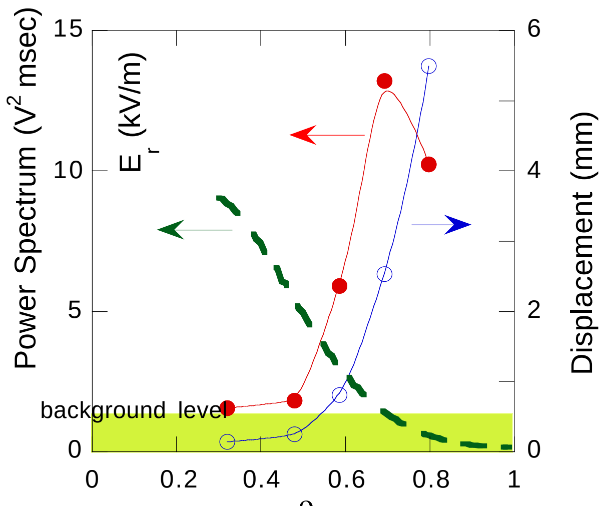

Figure 5. potential fluctuation power and estimated plasma displacement as a function of normalized minor radius

4. Summary

The dual HIBPs system has just begun to work in CHS. The first results have been just obtained from low-density discharges, where pulsation and high frequency modes are observed. The major results are as follows. I) In electric pulsation, potential pulse propagates outward inside r /a< ~0.5, however, II) central potential and density at outer radius of r/a~0.8 is found to be well correlated, and time scale of the changes are similar in a few dozen microseconds. III) For the high frequency mode, internal structure of the mode is being preliminary deduced, and more complete analysis will be done including phase information. In summary, twin HIBP systems presenting quite new observations of phenomena happening deeply inside the high temperature plasma. The initial results could be still preliminary, but future experiments will promise to give valuable observations to develop plasma physics and fusion research.

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