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Transport barrier physics study in Compact Helical System

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1. Introduction

CHS (Compact Helical System) is a middle size low aspect-ratio stellarator, which has a major radius 1 m and a toroidal period number 8. Main objective of CHS experiment has been the physics study of plasma confinement, namely, the turbulent transport study and the exploring of improved confinement modes. CHS has found various types of transport barriers: the internal transport barrier (ITB) with the electric field shear created by the neo-classical flow balance as well as the edge transport barrier (ETB) which is common for the H-mode discharges.

H-mode was first found in CHS in 1996 [1] with the assistance of the ohmic current for the edge transform control. Owing to the improvement of the NBI heating systems and the compilation of the experiences in experiments, the range of the operation of H-mode discharges has been extended in the magnetic field configuration and the field strength. We do not need ohmic current now for getting the H-mode [2]. We have been accumulating database for the parameter dependence of the heating power threshold for H-mode, which appeared to be very similar to the scaling for tokamak except for the dependence on the magnetic configuration [3].

New aspects of physics have been investigated for H-mode in CHS with various diagnostics: AXUV for the impurity dynamics [4] and the beam emission spectroscopy (BES) for the edge harmonic oscillation (EHO) study [5]. In this paper, we report new data for the spatial structure of EHO in H-mode and the new operation of high density H-mode in CHS. For ITB physics, a new measurements of ion temperature gradient is also reported.

2. Local mode excitation during H-mode

Figure 1 shows diagnostic trances of a typical H-mode discharge in CHS. An initial plasma is created by ECH and heated by two NBIs (both in the arrangement of co-injection). The plasma density is increased by the gas puffing, which initiates the H-mode transition at 64 msec in the figure. The delay time of the transition after the start of NBI heating clearly depends on the magnetic configuration (the magnetic axis position or the rotational transform value at the edge). Hα emission monitor shows a sudden drop, which is very similar to tokamak H-mode. The plasma energy increases and the radiation from the bulk plasma also starts to increase at the transition. Figure 1(f) shows BES signals for the local density information at the plasma edge. Five channel measurements in a range of the normalized radius (r/a)=0.76 to 1.10 clearly show the dynamic behavior of the local density pedestal formation in the edge region: just after the transition, the local density outside the barrier drops once but quickly recovers with the formation of the pedestal structure.

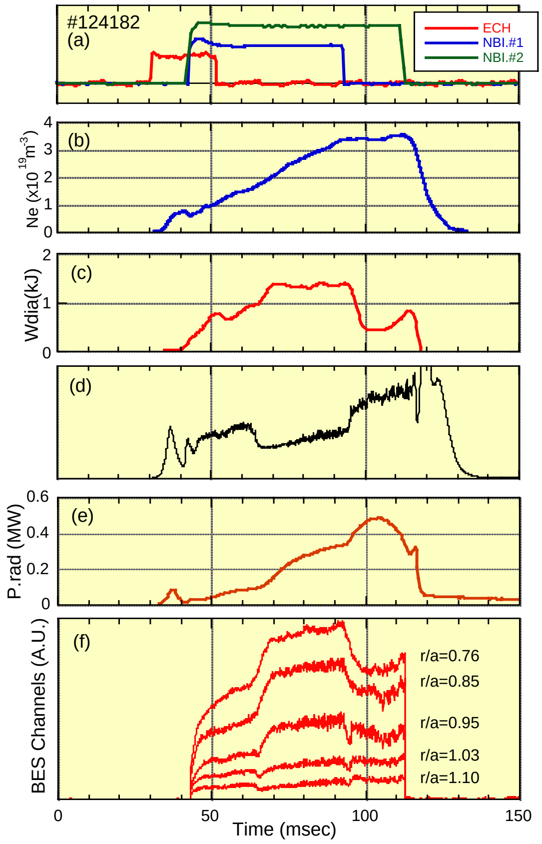

Fig. 1 Global parameters of H-mode discharge: (a) timings of heating, (b) line-averaged density, (c) diamagnetic energy, (d) Hα emission, (e) radiation power and (f) BES signals.

A strong coherent mode appears in the magnetic probe signal in the later phase of the H-mode, where the increased density gradient is established. This mode has the second and third harmonics which is very similar to the EHO observed in the H-mode in tokamaks [6]. Figure 2(a) shows the local density gradient at the beginning of the H-mode (63 msec) and the later phase (80 msec). The EHO appears for the higher density gradient at 80 msec. The RMS profile of

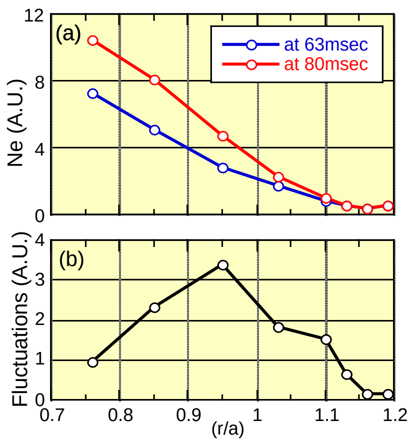

Fig. 2 Development of local density gradients and RMS profile of EHO oscillation.

the EHO oscillation is shown in Fig. 2(b). Within the mode structure, very high coherence is measured. It is shown that this EHO mode is localized within the high density gradient region at the edge.

3. High density H-mode combined with reheat mode

H-mode discharges with high magnetic field became possible only recently. Because the threshold power for the transition increases almost in proportion to the magnetic field, it was difficult to find the operational window of the H-mode in the high magnetic field experiments. Figure 3 shows global parameters of the H-mode discharge with the reheat mode operation. In CHS and LHD, the reheat mode is one of the improved confinement modes which are initiated by stopping the strong gas puffing. The rate of the gas puffing should be sufficiently large so that, if the gas puffing were continued, the plasma would be collapsed after several milliseconds.

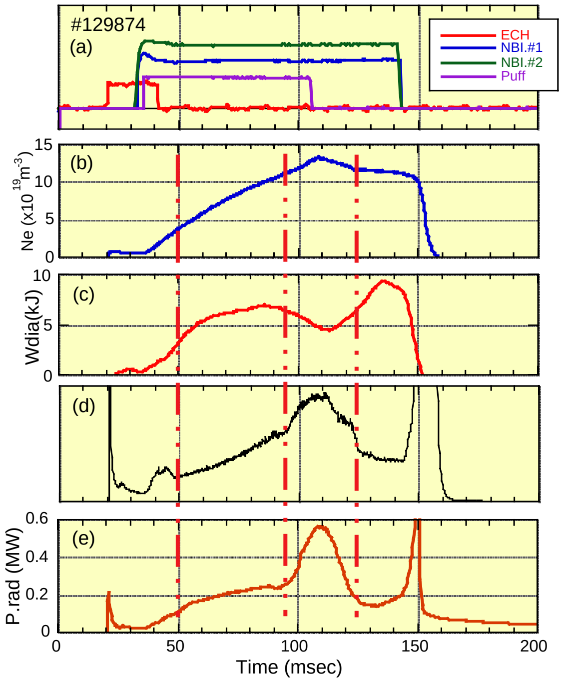

Fig. 3 H-mode discharge combined with reheat mode. Three dotted lines indicate H-mode transition, back transition and the second transition.

Three timings are shown in the figure with red dotted lines. First line shows the first transition to the H-mode. The second timing is the back transition due to the increase of the density. At the time of almost maximum radiation power loss, the gas puffing is stopped and the plasma starts to recover. The Hα emission signal suggests the second H-mode transition at 123 msec, after which the stored energy increases toward the top-level record of the stored energy in CHS.

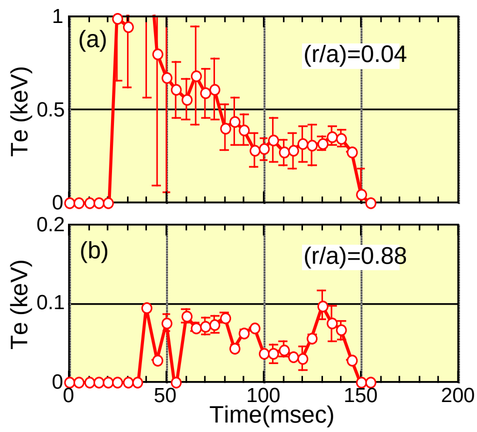

Fig. 4 Time variation of core and edge electron temperature.

Figure 4 shows the evidence of a new confinement improved mode for a very high density. Usually the electron temperature is decreasing with increased density. However the time behavior of the temperature in the plasma edge in Fig. 4(b) shows the increase of the temperature in the second H-mode phase. It has been discussed frequently that the largest problem in the H-mode in stellarators is that the edge temperature does not increase after the transition. The discharge shown here is an example of H-mode with edge temperature increase. It is also very important the operational range for the H-mode has been extended to very high density plasmas.

4. Structure of ITB in CHS with ion confinement improvement

The ITB formation simultaneously for both electrons and ions is a unique feature of CHS among all other stellarators [7]. Figure 5(a) shows electron temperature profiles with ITB (red points). The ion temperature is measured by a new type of charge exchange spectroscopy diagnostic with the spatial sweep mechanism obtaining the temperature gradient with (about ten times) higher precision than the conventional profile measurement. The gradient information is more directly coupled with the reduction of the transport. In this discharge, the ECH is applied on the NBI sustained plasma ($N_e \sim 3 \times 10^{18}$ m^{-3}) at 60 msec, which triggers an ITB formation. Fig. 5(b) shows that the high temperature gradient is formed at 65 msec within a narrow region at (r/a) ~ 0.65, which is clearly different from the enhanced temperature gradient region for electrons.

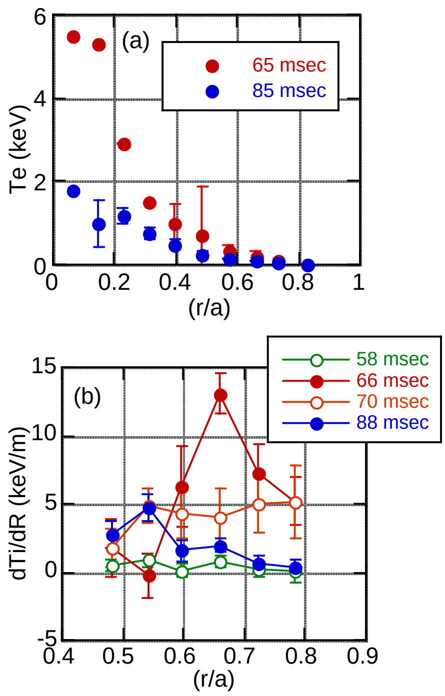

Fig. 5 (a) Electron temperature profile and (b) ion temperature gradient in ITB discharge.

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