§4. Necessary Conditions for Core Density Collapse in IDB Discharges

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A super-dense core of the order of 10^{20} m^{-3} is formed inside the internal diffusion barrier (IDB) during the reheat phase of the central pressure after pellet injection in LHD [1]. Typical waveforms in an IDB discharge are shown in Fig. 1. Large Shafranov shift of the plasma center measured on a horizontally elongated slice, R_0^{h}, is observed during the reheat phase and it reaches roughly 50 % of the plasma minor radius. In some cases, abrupt flushing of the central density takes place (t ~ 1.13 s in Fig. 1). Here, we call this event as "core density collapse (CDC)". CDC must be suppressed since it inhibits further increase of the central pressure and the fusion triple product. Hereinafter, necessary conditions for CDC are discussed.

In Fig. 2, R_0^{h}, $R_{90}^{h\_in}$, and $R_{90}^{h\_in}$ are plotted against β_0* for outward-shifted plasmas of R_{ax} = 3.75 – 3.85 m, where $R_{90}^{h\_in}$, and $R_{90}^{h\_out}$ denote the radial positions of $\beta* = 0.1\ \beta_0*$ at inboard side and outboard side of a horizontally elongated slice, respectively. Here, β_0* is defined as the central plasma pressure normalized by the magnetic pressure at the magnetic axis in the vacuum configuration. Open circles denote the points where CDC takes place. CDC is observed when β_0* increases to 3.5 – 5.5 %. The R_0^{h} moves outward as β_0* increases and finally saturates to 4.1 – 4.2 m. Therefore, both of $\beta_0* \geq 3.5$ % and $R_0^{h} \geq 4.1$ m are the necessary conditions for CDC. However, there are many data exceeding these thresholds without CDC. It can be seen from Fig. 2 that $R_{90}^{h\_in}$ monotonically increases with β_0* and CDC takes place when $R_{90}^{h\_in}$ exceeds $R_1^{v\_in}$, where $R_1^{v\_in}$ is the inboard side radial position of the last-closed-flux-surface (LCFS) at a vertically elongated slice in the vacuum configuration. Therefore, a better threshold to distinguish the CDC data is given by $R_{90}^{h\_in} > R_1^{v\_in}$. Qualitatively, the physical meaning of the condition $R_{90}^{h\_in} \sim R_1^{v\_in}$ as a CDC threshold is that CDC takes place when the inboard side plasma edge on the equatorial plane becomes circular in the toroidal direction, as is shown in Fig. 3.

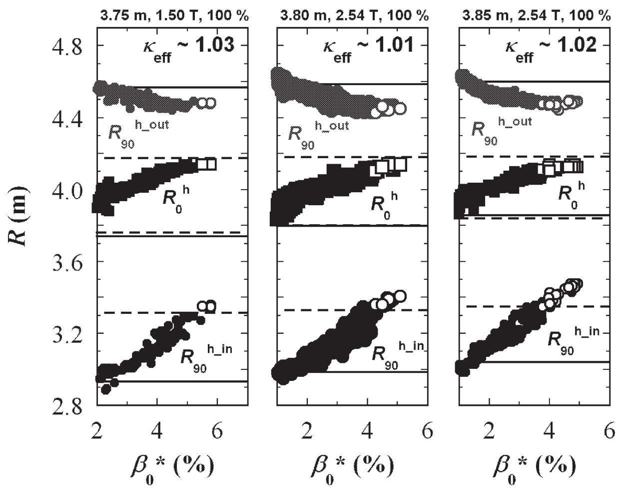

Fig. 2. β_0* dependence of R_0^{h}, $R_{90}^{h\_in}$, and $R_{90}^{h\_out}$ in the outward-shifted plasmas of R_{ax} = 3.75 – 3.85 m. Three horizontal straight (broken) lines denote $R_1^{h\_out}$, R_0^{h}, and $R_1^{h\_in}$ ($R_1^{v\_out}$, R_0^{v}, and $R_1^{v\_in}$) in the vacuum configuration, from top to bottom.

Reference
[1] N. Ohyabu *et al*., Phys. Rev. Lett **97**, 055002 (2006).

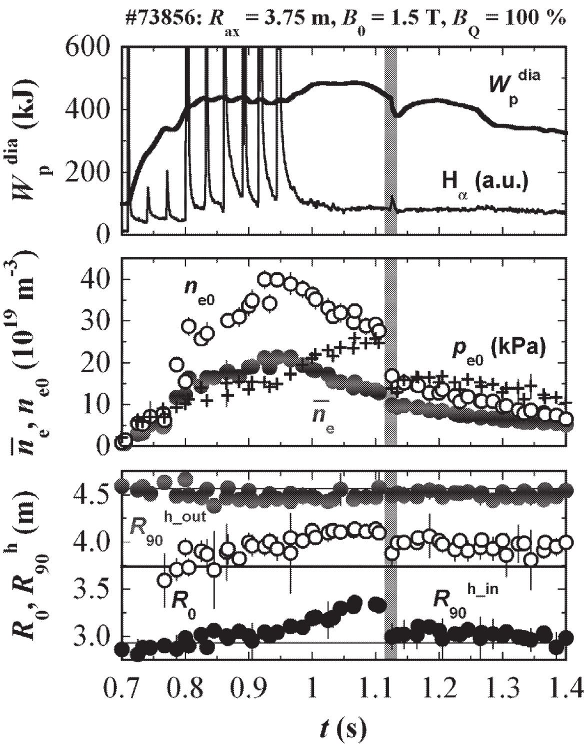

Fig. 1. Typical waveforms of IDB discharge. CDC takes place at ~ 1.13 s.

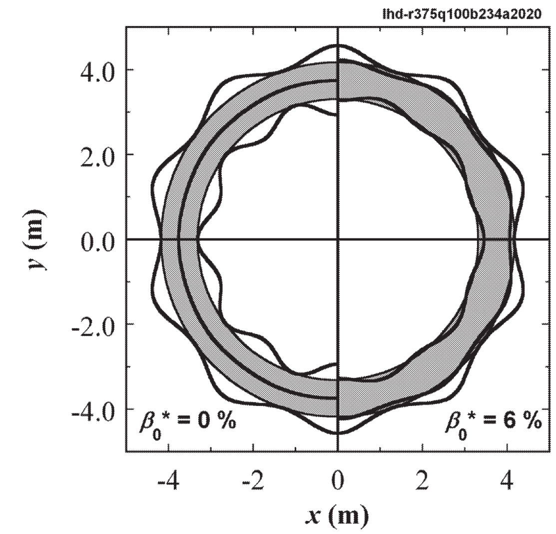

Fig. 3. Toroidal shapes of the LCFS and the plasma center on the equatorial plane calculated by the VMEC code. β_0* = 0 % and β_0* = 6 % are assumed in the left half (x < 0 m) and the right half (x > 0 m), respectively.