§9. Advances in High-Beta Experiments

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In order to realize economical fusion reactor, high–beta operation is required. The potential of Heliotron type configuration as a reactor can be demonstrated if we can form a high–beta plasma free from deteriorating effects of the MHD activities with reactor–relevant beta values.

High–beta plasma has been realized by the increase in the heating power and also by the optimization of the magnetic configuration in order that the neutral beam (NB) heating is effective. In LHD, inward–shifted plasmas are characterized by favorable orbits of the charged particles; we expect a good confinement of high–energetic particles. Therefore, we adjust the aspect ratio of the plasma ($A_p \sim 6.6$) so that the Shafranov–shift of the magnetic axis is minimized.

Volume averaged beta $< \beta > \sim 4.5\%$ has been achieved in 2006 in this way and improved to 4.9% (Fig. 1) and to 5.1% transiently by ice-pellet injection in 2008. The magnetohydrodynamics (MHD) instabilities in the core region vanish from the formation of the magnetic well, whereas the edge MHD instabilities remain (See, Fig. 1). Stationary high–beta plasma ($\beta > 4.5$ %) is obtained; plasma can be sustained for more that 100 times of the energy confinement time of the plasma.

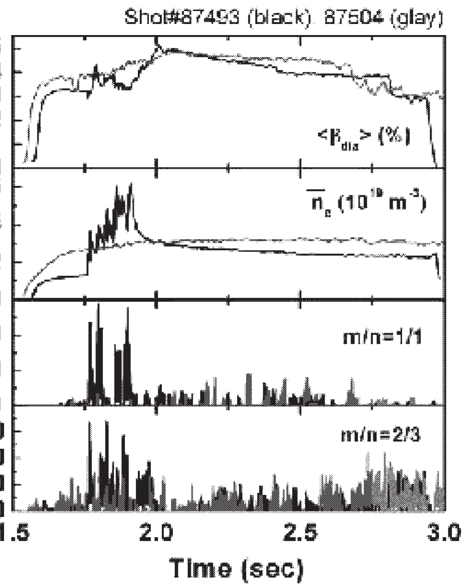

Fig. 1: Time evolution of of the plasma parameters at a highest beta discharges.

Another possible high–beta configuration is pellet–induced discharges with peaked pressure profiles[1]. While the electron density decreases after the pellets, the electron temperature recovers quickly. In this recovery phase, the pressure profile becomes fairly peaked; "high–central–beta plasma" is thus formed. From an MHD point of view, there are many advantages; the magnetic well is deeper in the core region from the larger Shafranov–shift and the pressure gradient in the edge region is smaller. The central–beta β_0 exceeds 10% with the toroidal magnetic field $B_t = 0.65$T in 2008.

Operational regime of two kinds of discharge is summarized in Fig. 2.

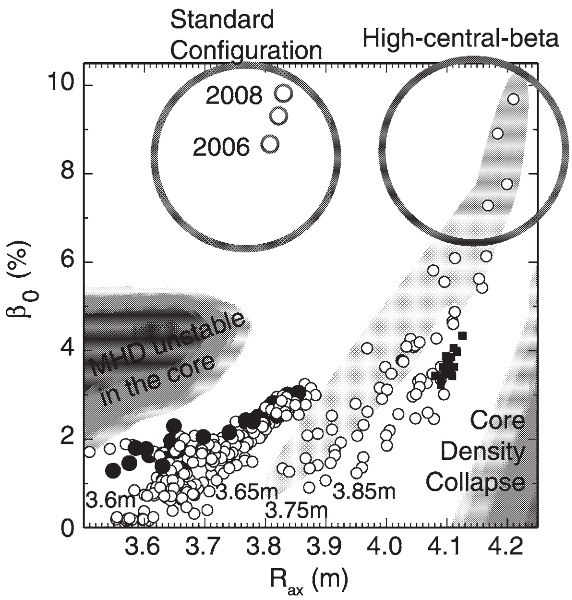

Fig. 2: *Operational regime of high–beta experiments is shown. Red triangles and blue squares represent sawtooth–like activity and m=3 MHD activity, respectively.*

Two MHD unstable regions can be seen in the diagram. In inward–shifted plasmas, core–localized modes are activated and the peaking of the plasma is disturbed by them. In outward-shifted plasmas, the increase of β_0 is limited by the so-called core density collapse (CDC) events. Experimentally, CDCs appear when the magnetic axis position exceeds $\sim$ 4.1m (in a horizontally elongated section). Therefore, the best way to achieve the high central–beta plasma is to keep the magnetic axis between 3.7m and 4.1m in the formation phase of the peaked profile, avoiding these two unstable regions.

The importance of the magnetic axis control is recognized more than before. Using a newly introduced poloidal–coil power–supply which can control the magnetic axis position in real–time, we investigate the effect of the magnetic axis position further. Study about core instabilities and about the CDC will be discussed in other articles in detail.

1) S. Ohdachi, et. al, in Proc. 22th IAEA FEC Conference, Geneve, 2009, EX/8-1Rb