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Optimization of density and temperature profiles with internal transport barrier for tokamak DEMO reactor including ion diamagnetic drift effects

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Japan Atomic Energy Agency proposed a JA DEMO reactor aiming for fusion power achieving 1.5 GW in 2014 [1]. When a perfectly conducting wall is placed at 1.35 times the minor radius of the plasma, the normalized beta $\beta_{\mathrm{N}} = 3.5$ is achieved. However, this plasma is close to the ideal magnetohydrodynamics (MHD) stability limit. It is desirable to design a plasma less closer to the ideal MHD stability limit.

In the present study, we explore optimized temperature and density profiles with internal transport barriers (ITBs) taking into account ion diamagnetic effects in the MHD stability analyses. We also study differences in the optimization strategies with/without the stabilization effects by the perfectly conducting wall. MHD equilibria were calculated by the ACCOME code [2] that solves the Glad-Shafranov equation for pressure and current-density profiles self-consistently determined from specified temperature and density profiles. Ideal MHD stability analyses were carried out by the MARG2D code [3]. Note that MEUDAS code [4] was used to improve accuracy of the MHD equilibria for the stability analyses.

Our previous study [5] found an optimized plasma that achieves a fusion power 1.8 GW, a bootstrap current fraction 55%, and that are stable against ideal MHD modes with toroidal mode numbers $n = 1, \cdots, 5, 10, 15,$ 20 and 30 with the perfectly conducting wall at $r_{\mathrm{w}}/a = 1.3$, where r_{w} is the wall position, and a is the plasma minor radius. However, a $n = 50$ mode was unstable.

In the present study, we included ion diamagnetic drift effect, expecting stabilization of higher-n modes. Indeed, we found the $n = 50$ mode, which was unstable in [5], is stabilized by the ion diamagnetic drift effects.

The optimized plasma mentioned above utilizes the stabilization effect by the perfectly conducting wall, where we may need feedback stabilization of resistive wall modes in reality. It must be nice if we could design a plasma with reasonably good performance without the wall stabilization. Although the achievable beta value decreases, such a lower-beta plasma has been targeted for a pulse operation in the DEMO reactor development.

When the wall stabilization exists, the optimization strategy is to make the ITBs closer to the plasma edge; the beta value increases. However, kink-ballooning modes become unstable in such a high beta plasma without the wall stabilization. Thus it is necessary to decouple the ballooning modes excited at the ITB from the external kink mode. Let us assume that the external kink mode can be stabilized by controlling the plasma current and the resultant safety factor at the plasma edge. The remaining higher-n modes around the ITB is likely to be stabilized by the ion diamagnetic drift. Therefore, the optimization strategy without the wall stabilization is to make the ITBs of the density and temperature profiles at a smaller minor radius with less steep gradients to decouple the ballooning mode from the kink mode, while at a larger minor radius with steep gradients as much as possible to maximize the beta value.

We have optimized the profiles with $r_{\mathrm{w}}/a = 2.5$; the wall stabilization is negligible. We have found a stable equilibrium achieving $\beta_{\mathrm{N}} = 2.6$. Figure 1 shows a comparison of the optimized pressure profiles under $r_{\mathrm{w}}/a = 1.3$ and $r_{\mathrm{w}}/a = 2.5$. When $r_{\mathrm{w}}/a = 2.5$, a ballooning mode with $n = 50$ is excited around the ITB, and the ion diamagnetic drift stabilizes it as expected.

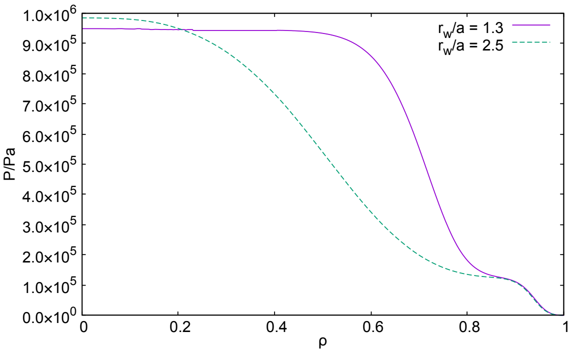

Figure 1: Optimized pressure profiles with/without the wall stabilization. In the case without the wall stabilization ($r_{\mathrm{w}}/a = 2.5$), the ITB was placed at a smaller minor radius with less steep gradient than in the case with the wall stabilization ($r_{\mathrm{w}}/a = 1.3$).

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