

Stability of Beam Driven Equilibria with a Closed Stabilization Wall

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Considering a current profile driven by a neutral beam having a beam energy up to 2.5 MeV, attainable normalized beta β_N with and without a stabilization wall are investigated for next step reactors with $R_0 = 7.25$ m and $R/a = 3.4$. Because of restrictions in the attainable current profile, β_N is restricted up to 2.5 without a wall, while $\beta_N = 3.4$ is possible with a wall, because broader current profiles are allowable in the wall stabilized equilibria. This result suggests that wall stabilization is necessary even in the conservative design with $\beta_N < 3$.

Keywords:

tokamak fusion reactor, wall stabilization, resistive wall mode, beta limit

Considering conventional tokamaks with a moderate aspect ratio $A (= R/a)$, the normalized beta β_N in MHD equilibria without a closed conductive wall is restricted up to 3 to 3.5. In order to achieve a higher β_N , a closed conductive wall is necessary to stabilize ideal MHD modes. It is also known that control of resistive wall modes (RWM) which are caused by the finite resistivity of the wall is an important issue to maintain such wall-stabilized high beta plasma [1]. The RWM may be stabilized by external coils with feedback control but such a technique is still under development. The range of β_N where the wall-stabilization and RWM control are required is an important issue in the design and development strategy of tokamak reactors.

Without the wall, a peaked current profile results in a higher β_N limit [2]. On the other hand, the current profile tends to broaden because of the bootstrap current (BSC), which will carry a larger part of the plasma current with higher beta. This fact runs counter to the current profile aligned for high beta without the wall. In this paper, it is shown that, considering the current profile driven by the beam and BSC in a reactor-size tokamak, the stabilization wall will be necessary even at $\beta_N < 3.0$.

The result of an ideal MHD analysis for various current profile is summarized in Fig. 1, where $A = 3.4$,

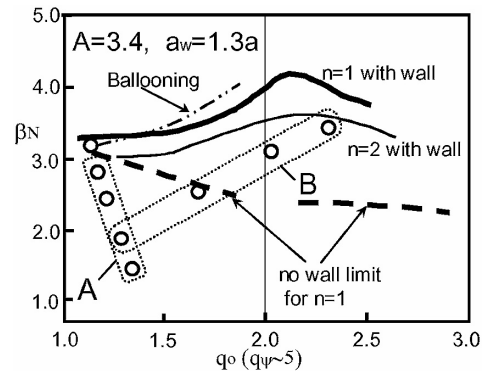


Fig. 1 Beta limit vs q_0 values

elongation $\kappa = 1.85$, triangularity $\delta = 0.35$ and $q_\psi \approx 5$ are assumed. A broadening current profile corresponds to an increase in q value on axis ($= q_0$). In the analysis for Fig. 1, the current profiles are given without regard to the current drive method.

Without the wall, the β_N limit against $n = 1$ kink and high n ballooning modes is maximized with q_0 close to unity, and a larger q_0 (i.e. broader current profile) results in a lower beta limit. On the other hand, with the wall, the β_N limit increases with q_0 in the range of $q_0 < 2.1$, where a wall radius of $a_w = 1.3a$ is assumed.

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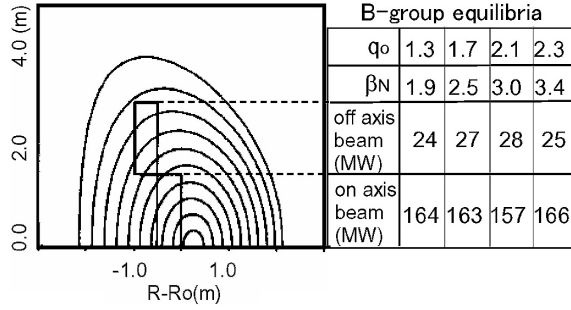


Fig. 2 Beam powers for B-group equilibria shown in Fig. 1, where $E_b = 1.5$ MeV. Note that, with A-group equilibria, $\beta_N \geq 2.5$ is not attainable with an 1.5 MeV beam.

The feasibility of a current profile driven by a neutral beam (NB) and BSC is investigated for the stable MHD equilibria shown in Fig.1. This current drive analysis has been done consistently with the MHD analysis [3]. The current profile driven by NB is adjusted to the stable profile by changing each power of on- and off-axis beam (shown in Fig. 2). Through the iterative calculation, the beam and alpha pressures are taken into account and the density profile is determined consistently with a specified temperature profile. In this study, $T = T_0(1-x^2)^{1.3}$ is assumed, where $x^2 = \phi/\phi_0$. When the consistent profiles can not be attained, the code shows the profile as close as possible.

The A-group in Fig. 1 shows a set of MHD equilibria where $1.5 \leq \beta_N \leq 2.9$ with $q_0 \approx 1$. Using this A-group equilibrium profiles and assuming $R = 7.25$ m, $\langle T_e \rangle = 18$ keV and B_{10} (on axis) = 8T, attainable equilibria with the beam energy $E_b = 1.5$ MeV are restricted up to $\beta_N = 1.9$. With a higher β_N , the total driven current including BSC results in a higher q_0 than the required value even with no power from the off-axis beam. From an engineering point of view, 1.5 to 2.0 MeV will be a threshold in the use of a conventional accelerator with static electric field [4]. Therefore $E_b \approx 1.5$ MeV seems a feasible range as the beam energy for next step devices succeeding the ITER.

If $E_b = 2.5$ MeV, which reduces the power deposition near the periphery, is available, $\beta_N = 2.5$ is possible, but a higher β_N is still not attainable.

In the actual design of a reactor, the beam capacity is determined by the maximum power requirement. Therefore it is desirable to minimize the change in power as much as possible throughout the operating range. The equilibria of B-group in Fig. 1 is a result of a

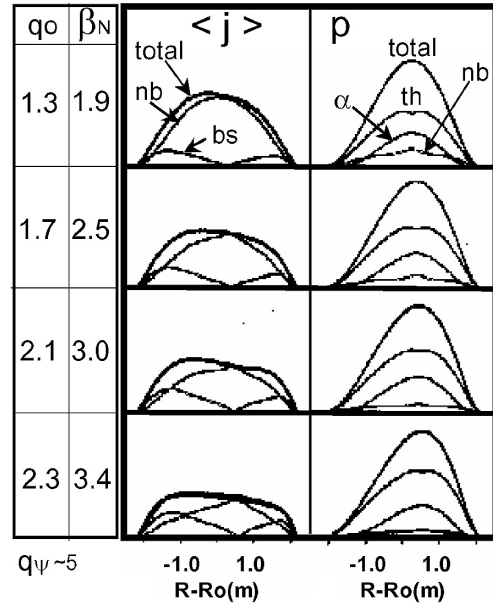


Fig. 3 Current and pressure profiles (in arb. unit) of the B-group equilibria. $R = 7.25$ m, $B_{10} = 8$ T. The letters th, α , nb and bs indicate the components of thermal, alpha, beam, and BSC respectively.

survey in which the powers of the on- and off-axis beams have been kept nearly constant. The beam powers are shown in Fig. 2, where $R = 7.25$ m and $E_b = 1.5$ MeV have been used again. In this case, the equilibria up to $\beta_N = 3.4$ can be sustained with an 1.5 MeV beam by increasing q_0 according to the increment of β_N . The changes of on- and off-axis beam powers are kept in the range of ± 5 MW and ± 2 MW, respectively. The profiles of currents and pressures are shown in Fig. 3. The BSC is effectively utilized for achieving stable profiles without changing the beam powers. But we have to note that the equilibria with $\beta_N > 2.5$ in the B-group exceeds the no-wall limit, i.e., the control of RWM will be necessary.

In conclusion, if a beam energy of 1.5 MeV or so is used for next step reactors with $R_0 \sim 7$ m and a moderate aspect ratio, a closed conductive wall will be required for plasma stability even at $\beta_N < 3$. This means that the conductive wall and RWM control will be necessary even for a demo-plant based on conservative design parameters [5]. Therefore, study of wall-stabilized plasma is a critical issue for the next step of fusion research and it is essential to design a blanket system consistent with the closed wall, the RWM control coils, and other engineering aspects. Some parameters, e.g., the aspect ratio, the temperature profile, etc., have been

fixed in this study. Further investigation regarding these issues is underway.

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