EVALUATION OF FINITE ORBIT WIDTH EFFECT ON ALPHA AND NBI IONS HEATING IN CFETR SCENARIOS

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1. INTRODUCTION

When the FOW effect is considered, fast ions are no longer treated as confined to a single magnetic surface; instead, they move cross multiple magnetic surfaces through drift motion and neoclassical transport, broadening the slowing-down deposition profiles (e.g., ion/electron heating density and driven current density), thus affecting fusion performance. Our focus is on two main aspects: (i) We assess the FOW effects on alpha particle slowing-down deposition under CFETR parameters by comparing the test particle code PTC [1] with the simple delay model (the alpha heating model used in CFETR integrated simulations [2]). The PTC code is also used to evaluate the FOW effect on NBI particle deposition. (ii) PTC code is coupled into workflow in OMFIT integrated simulation platform for prediction [3]. This workflow is employed to refine the hybrid and steady-state scenario for CFETR with fusion power near 1 GW, by replacing the simple delay model for alpha heating, which did not account for the FOW effect.

2. KEY SIMULATION RESULTS

Three types of safety factor profiles used in this study are shown in Figure 1(a). As the *q* profile increases, the ion heating density, electron heating density, and pressure profiles of alpha ions calculated by the PTC code exhibit a broader distribution compared to the ONETWO simulations, which do not account for FOW effects, as shown in Figure 1(b). As the magnetic field decreases, or the initial fraction of trapped particles increases, the slowing-down profile of fast particles also becomes increasingly broadened. These phenomena are primarily due to the increase in orbit width, which enables fast ions to traverse more magnetic surfaces by drift motion and neoclassical transport. Moreover, the slowing-down deposition profile of alpha ions exhibits a more pronounced broadening in deep core and ITB regions, while for NBI particles, the broadening is more evident near the magnetic axis and inflection point. This characteristic is mainly due to the steeper gradients of fast ions source in these regions. In addition to the broadening effect, the deposition profile of NBI particles also shows a tendency to shift inward toward the core region, and the current drive is significantly reduced due to the conservation of magnetic moment.

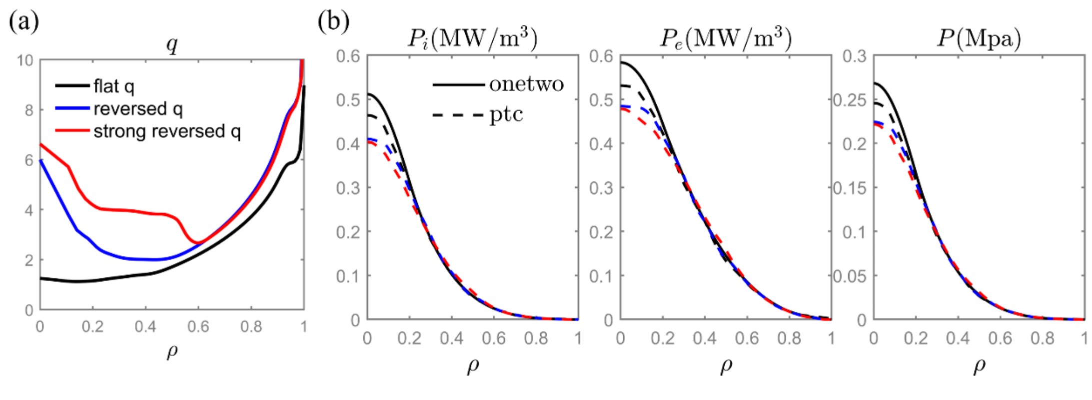

FIG. 1. (a) Three types of safety factor q profiles; (b) The alpha ions slowing-down deposition profile with different q profile.

In the CFETR hybrid scenario, when the alpha heating model considers the FOW effect, a significant reduction in both electron density and temperature is observed within the deep core, while ion temperature remains relatively unchanged. The decrease in density within the deep core is primarily due to the drop in electron temperature, as the TEM drive inward electron flux under the CFETR parameters. As a result, the Q value decreases by 6.4%, and the Ohmic flux surpasses engineering limits.

In the CFETR steady-state scenario, when the alpha heating profile is modified from ONETWO to PTC results in transport code TGRYO, excluding "integrated simulation effects", a reduction in both the strength of density, electron and ion temperature ITB and within the region inside ITB ($\rho < 0.42$), as shown by the black solid and blue dashed lines in Figure 2(a)-(c). The reduction is primarily attributed to the significant broadening of the heating profile at the ITB and deep core region.

The decrease in density within inside ITB region is primarily due to the inward transport driven by TEM being greater than the outward flux driven by ITG. However, when "integrated simulations effect" are included, density partially recovers, while ion and electron temperatures further decline within the region inside the ITB. A significant reduction in total pressure within the region inside the ITB (see Figure 2(f)) and a decrease in β_P from 2.48 to 2.36 lead to a reduction in the Shafranov shift and the α stabilization effect, both of which further degrade confinement performance inside the ITB. The fusion power decreases by 68 MW, slightly less than the 70 MW reduction in the hybrid scenario. However, the Q value drops by 17%, more than twice the decrease observed in the hybrid scenario. This is due to the weakening of the temperature ITB strength leads to an increase in auxiliary heating power (11.4MW) to offset the decline in bootstrap current.

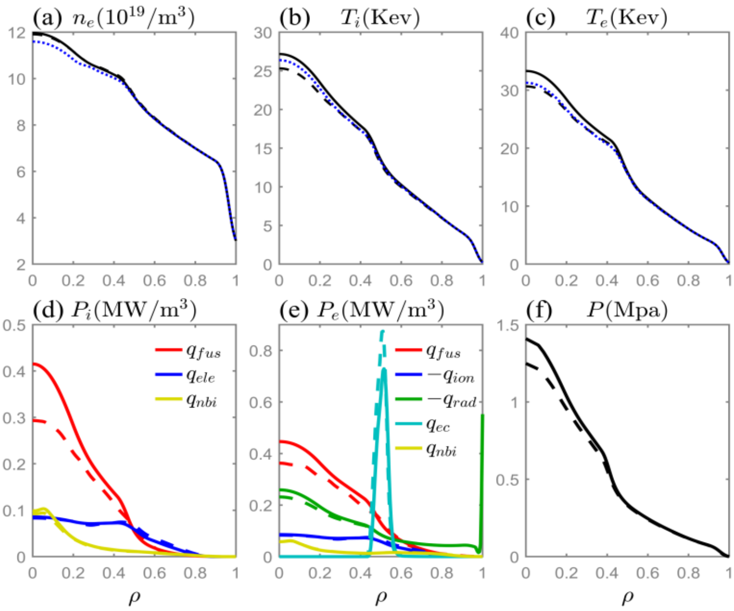

FIG. 2. The predicted profiles by IM simulation in CFETR steady-state scenario. The solid and dashed lines represent the converged solutions from integrated simulations with ONETWO and PTC alpha heating model, respectively. The dotted line in (a)-(c) represents the profiles obtained from TGRYO, with the input parameters consistent with solid line, except for the alpha heating, which is recalculated using the PTC model.

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