Comparison of Toroidal Velocity Models Using Integrated Predictive Modeling Code in ITB *H*-Mode Plasma

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Introduction

The improved performance of *H*-mode plasmas in tokamaks is a result of the formation of an edge transport barrier (ETB). Additional formation of an internal transport barrier (ITB) can also further improve the performance of *H*-mode discharge. Formation of both transport barriers together has improved a tokamak's performance significantly. It is widely considered that the ω_{ExB} flow shear is the main mechanism used in describing the formation of ITBs in a magnetic confinement device. Toroidal velocity is one of the terms used in calculation of the ω_{ExB} flow shear. There have been much study of momentum and velocity transport in poloidal direction but not much has been done in the toroidal direction. Recently, the pinch velocity is being investigated because it is believed to affect toroidal rotation. In general, the toroidal velocity can be expected to be a function of plasma parameters including plasma density, current and/or torque. The exact calculation could be complicated because it requires detailed information. A simple toroidal velocity model based on empirical approach was developed in Ref. [1]. This work aims to develop a theory-based approach relating toroidal velocity to current density flow, and to compare the results of both models.

Both toroidal velocity models are implemented in the BALDUR integrated predictive modeling code [2] to carry out the time evolution of plasma profiles of 10 optimized shear JET discharges. The anomalous transport model used in this work is called Mixed Bohm/gyro-Bohm (Mixed B/gB) [3]. The boundary conditions are taken to be at the top of the pedestal, where the pedestal values are described using a theory-based pedestal model based on a combination of magnetic and flow shear stabilization pedestal width scaling and an infinite-n ballooning pressure gradient model [4].

The empirical-based model was derived from experimental observation that the toroidal velocity is directly proportional to a local ion temperature with the form

$$v_{tor} = 1.43 \times 10^4 T_i \,. \tag{1}$$

In the theory-based model, it is assumed that the toroidal velocity can be viewed as a current density flow of positive ions as follows:

$$v_{tor} = \frac{J_{tor}}{e n_i Z_{eff}} \,, \tag{2}$$

where J_{tor} is the current density in toroidal direction, n_i is ion density, and Z_{eff} is effective charge of ion species.

Simulation Results

First of all, the profiles of the toroidal velocity from the simulations are compared with experimental data. The diagnostic time of each JET discharge is chosen with selection criteria based on ITB and *H*-mode considerations. The velocity profile plots are shown in figure 1. Each graph demonstrates the toroidal velocity as a function of normalized minor radius, where the closed circles represent experimental data; the line with triangle marker represents simulation result of empirical-based model; and the red line represents simulation result of theory-based model. It can be seen that in most of the discharges, the results from empirical-based model are closer to experimental data than that of theory-based model. In particular, in discharges 46664 and 51599, the theory-based model overpredicts the experimental values by up to factors of 5 and 3, respectively. Moreover, the general profile shape of theory-based model is inconsistent, especially near the plasma edge where the toroidal velocity abruptly spikes and then decreases to zero at the edge. The strange behavior is a result of numerical calculation of how BALDUR computes the current density. Essentially, the edge current density is assumed to be zero at the edge, the next value is dramatically increased because it tries to conserve overall current flow. Quantitatively, the average RMSE of the empirical-based model is 37.09% with its offset value of -0.27. The average RMSE of the theory-based model is 73.02% with its offset value of -0.64, which is consistent with qualitative interpretations.

Figure 2 illustrates ion temperature time-evolution profiles of JET discharge 40542. The temperature gradient can be implied from the separation between each line which represents different position inside tokamak, ITB formation is the region of large separation. It can be concluded that when using experimental data of flow shear as an input, ITB formations can be successfully simulated for both position and time of the occurrences.

However, when using experimental toroidal velocity as input only the occurrence's time is retained correctly. The empirical-based theory yields similar profile, while ITB formations in the profile of theory-based model are relatively less pronounced.

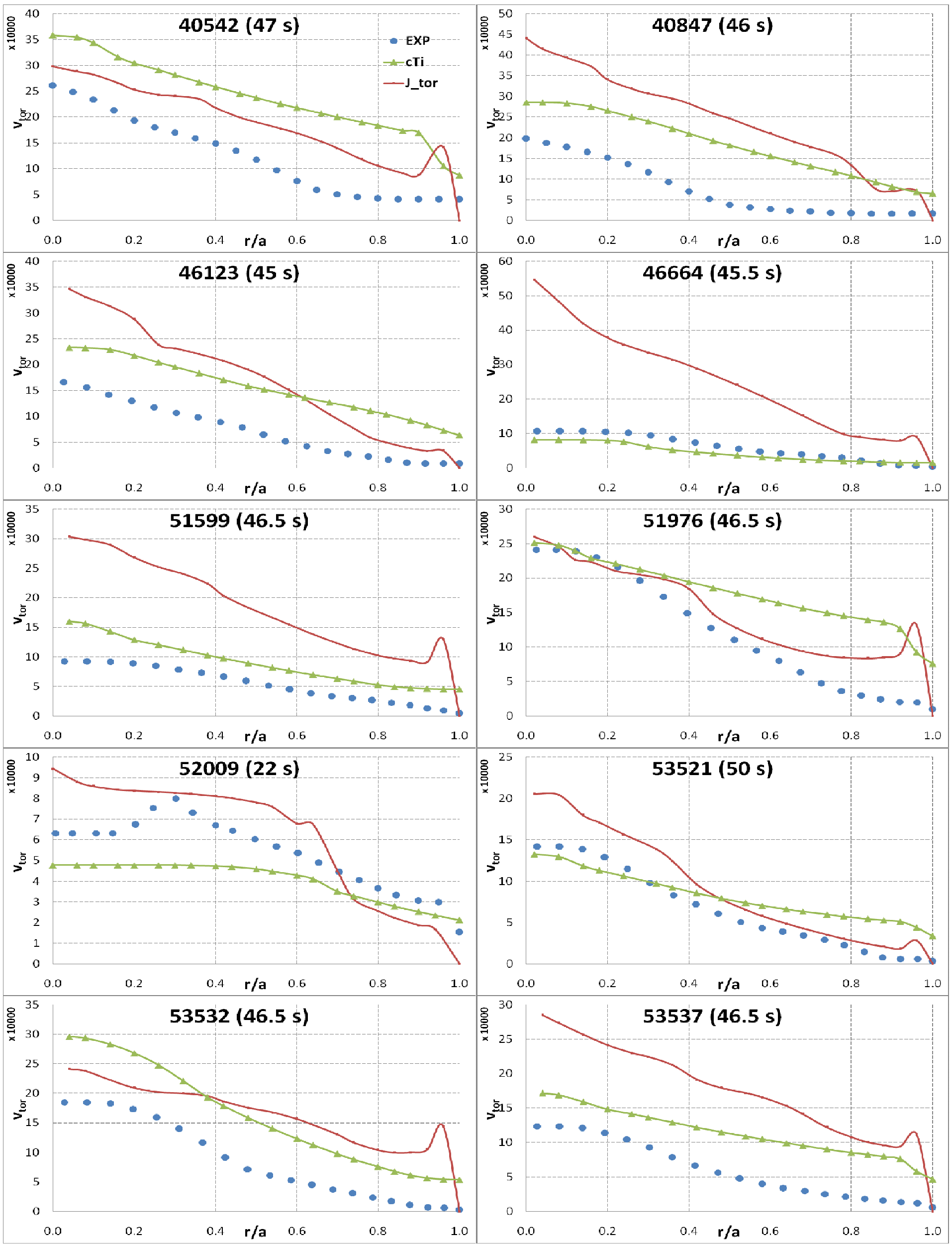

Figure 1: Comparison of toroidal velocity between experimental values and simulation results using empirical-based and theory-based models.

Conclusions

Two models for predicting toroidal velocity in ITB *H*-mode plasma is developed and implemented in BALDUR integrated predictive modeling code. The toroidal velocity is used by transport code in BALDUR to calculate the shearing rate which is believed to be the cause of turbulence suppression. It is found that the empirical-based toroidal velocity model results in a better agreement to experimental data than that using the theory-based toroidal velocity model.

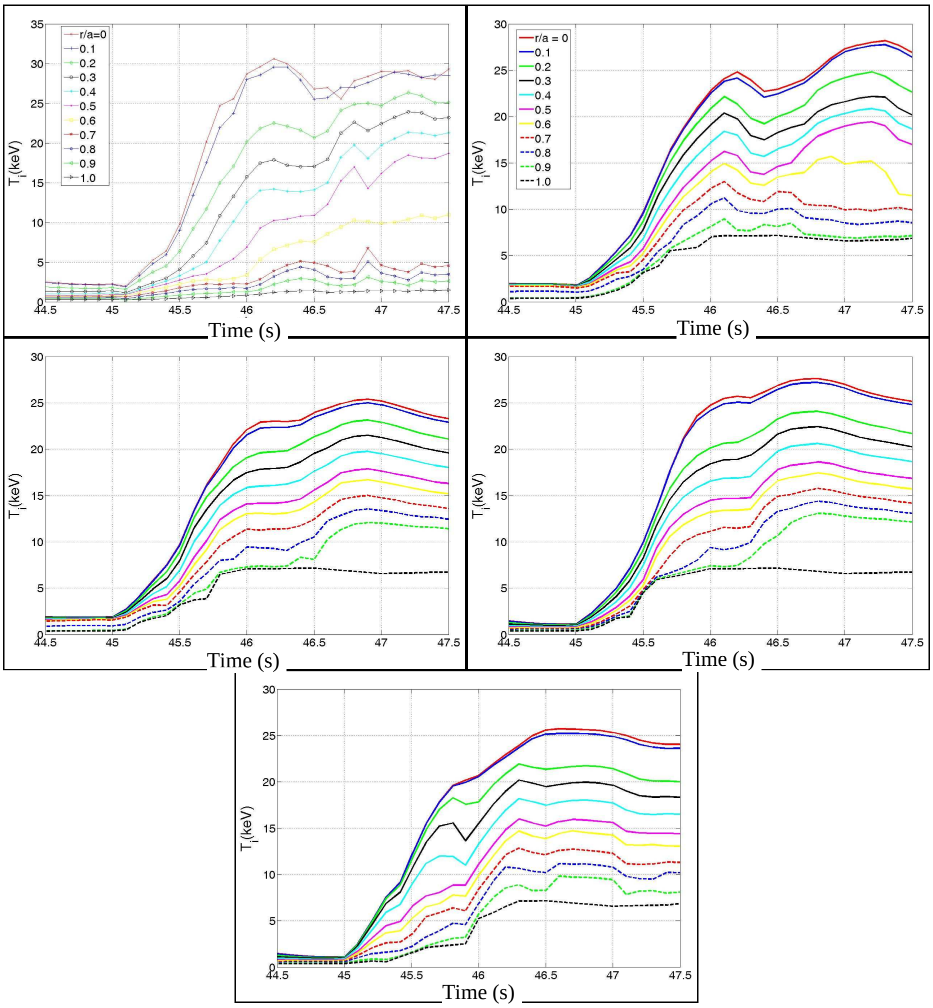

Figure 2: JET 40542 Time-evolution profiles of T_i: experimental data (top left) and simulation results using experimental ω_{ExB} (top right), experimental v_{tor} (middle left), CT_i model (middle right), and J_{tor} model (bottom).

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Reference

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