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Progress in integrated modeling of JT-60SA plasma operation scenarios with model validation and verification

モデル妥当性確認と検証を伴ったJT-60SAプラズマ運転シナリオの統合モデリングの進展

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Development of plasma operation scenarios in JT-60SA has been progressing by using integrated modeling codes. Anomalous heat transport model, which are one of major uncertainties in the prediction, have been validated for ITB plasmas with full current drive (CD) condition in JT-60U and JET, and integrated codes TOPICS and CRONOS equipped with the models are used for the model verification. It is found that CDBM model predicts temperatures close to those in experiments or underestimates them, and thus can be used for the conservative prediction. By using TOPICS with CDBM model, JT-60SA ITB plasmas with high β_N and full CD condition have been predicted consistently with Ar seeding to reduce the heat load on divertor plates below 10 MW/m^2. In the prediction, TOPICS is coupled with impurity transport code IMPACT to examine the Ar core accumulation for the influx to the core and the separatrix density evaluated by integrated divertor code SONIC. The Ar accumulation is found to be so mild that the performance can be recovered by additional heating. Due to the strong dependence of accumulation on the pedestal density gradient, the high separatrix density is important for low accumulation as well as low divertor heat load.

1. Introduction

Validation of main models for plasma simulation is required for extrapolation to future devices (JT-60SA[1], ITER, DEMO). Such validation activities are being carried out through a JA-EU cooperation, especially for development of JT-60SA operation scenarios. JT-60SA scenarios should be based on experimental results of two machines that are the most similar for size & configuration: JT-60U & JET. JA and EU codes are used and thus models are verified between the codes. The best recipe to predict JT-60SA plasmas needs to be obtained. By using the recipe, plasma performance at I_p flattop phase is studied at first, and then operation scenarios with I_p ramp up/down are examined. The validation and verification (V&V) for H-mode and hybrid plasmas, and the prediction of these plasmas at I_p flattop phase have been done [2]. In this paper, we perform V&V and prediction for ITB plasmas with the full current drive (CD) condition at I_p flattop phase.

2. Validation and verification of heat transport models for ITB plasmas with full CD in JT-60U and JET

Anomalous heat transport model is one of major uncertainties in the prediction. Integrated codes TOPICS and CRONOS are used for the model verification and equipped with typical three anomalous transport models, CDBM (Current Diffusive Ballooning Mode, without ExB shear effect), BgB (Bohm / gyro-Bohm, CRONOS version, with ExB shear effect) and GLF23 (with α stabilization and internally calculated E_r). For the model validation, 3 shots in JT-60U and 1 shot in JET are chosen. Electron and ion temperature profiles are solved inside the pedestal (ρ<0.85) starting from experimental profiles and then a stationary state is obtained.

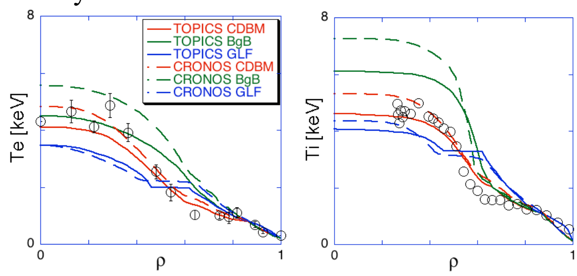

Fig.1. Comparison of electron (left) and ion (right) temperatures of simulations (lines) to experimental ones (symbols) for a JT-60U shot (48246)

Figure 1 shows an example of result. The CDBM results agree with experiments, but the BgB results are higher and the GLF ones are lower than the experiment. From all results including other shots, it is summarized that the CDBM results are close to or lower than experiments and thus CDBM can be used for the conservative prediction.

3. Prediction of JT-60SA ITB plasmas with high β_N and full CD, consistent with impurity seeding to reduce divertor heat load

TOPICS with the CDBM model is used for the prediction of JT-60SA plasma. Pedestal profiles are determined on the basis of a pedestal width scaling and a stability check by a linear MHD code MARG2D [3]. Various states with high-β_N (>3.5) and nearly full CD condition can be obtained by using various sets of actuators (nearly-on or off-axis negative-ion-based NB (NNB), positive-ion-based NB (PNB), ECH/CD) in JT-60SA. Figure 2 shows an example of profiles with assumed Z_{eff}=2 with full-striped carbon. By using $P_{NNB,off\text{-}axis}$=5MW, P_{PNB}=12MW, P_{EC}=7MW (110GHz for heating), a plasma with H_H=1.68, β_N=3.90, f_{BS}=0.72, f_{NB}=0.22, f_{OH}=0.04 (V_{loop}~3mV) is obtained. The full CD scenario requires low separatrix density n_{esep} for high CD efficiency and low peak heat load q_{peak} on divertor plates. Analysis by integrated divertor code SONIC showed, for the total input power P_{in}=37MW in initial and integrated research phases, the conditions can be satisfied by Ar seeding of 0.86 Pa m^3/s resulting in low n_{esep} (~1.46×10^{19} m^{-3}) and low q_{peak} (~10 MW/m^2) [4]. The Ar accumulation in the core may reduce the performance and should be studied. From the SONIC result, the Ar influx to the core is about 5×10^{20} s^{-1}, which is the maximum because the value is not net flux and P_{in}<37 MW in the TOPICS simulation. To study the Ar core accumulation, TOPICS is coupled with impurity transport code IMPACT for multi impurity species and charge states where n_{esep} is set to the SONIC value (already in Fig.1), and neoclassical impurity diffusivities and convective velocities are calculated by NCLASS. Anomalous impurity diffusivities are set to 0.2 m^2/s, which is neoclassical level (larger value reduces the accumulation), and convective velocities are zero. The intrinsic impurity carbon content is conserved from making initial Z_{eff}=2 and the effect of carbon transport only slightly reduces the performance. Figures 3 and 4 show profiles with the Ar influx to the core, which is assumed to be injected as neutrals in IMPACT. An inward pinch due to bulk density gradient exists in the core and a outward convection due to temperature gradient in the pedestal, resulting in $Ar^{16\text{-}18+}$ accumulation in the core and the increase in the radiation power from 2.8 MW to 4.3 MW. The performance decreases, but can be recovered by adding the PNB power to supplement the radiation increase. Half reduction of n_{esep} keeping the pressure results in the inward pinch in all region and further decrease in the performance. The high n_{esep} is important for low accumulation.

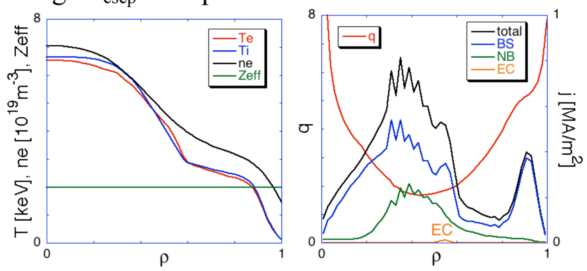

Fig.2. Profiles of temperatures, electron density, Z_{eff} (left) and safety factor, current densities (right) in a JT-60SA plasma with given Z_{eff}=2

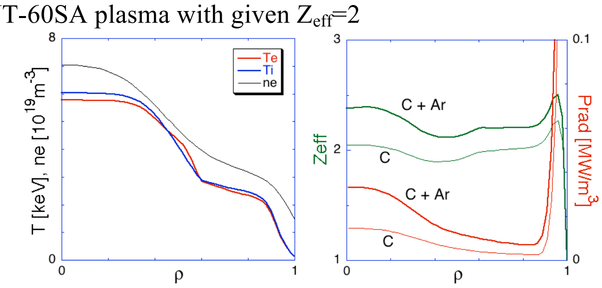

Fig.3. Profiles temperatures (left) and Z_{eff} and radiation powers (left) with C and Ar transport solved

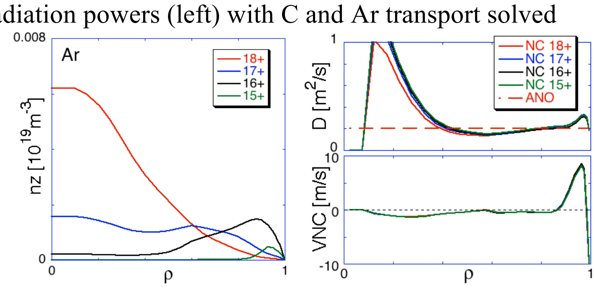

Fig.4. Profiles of Ar density, diffusivity and convective velocity for each charge state

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