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Statistical approach for predicting energy transport in LHD plasmas based on the TASK3D-a analyses database

TASK3D-a解析データベースに基づく LHDプラズマにおけるエネルギー輸送予測の統計的手法

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The integrated transport analysis suite, TASK3D-a [1], has enhanced energy transport analyses in LHD. It has provided the possibility for trying to obtain regression expressions for the ion and electron heat diffusivities (χ_i and χ_e), separately, taking also those radial-profile information into account. In this proceeding, TASK3D-a analysis database for high ion-temperature (high-T_i) plasmas [2] in LHD (Large Helical Device) [3] are exemplified. This approach should be applicable to any other combinations of integrated transport analysis suites and fusion experiments.

1. Introduction

Conventionally, scaling laws for the global energy confinement time (τ_E) have been one of the approaches to systematically grasp the energy confinement of fusion plasmas [4,5], and are also considered as one of the guidelines to design/predict future devices, such as ITER [6].

On the other hand, physics-based transport models have been employed to predict the plasma performance, such as expected temperature profiles for certain operation scenarios. In such predictions, it has been always problematic whether employed model(s) are actually governing energy transport in plasmas to be forecasted.

In this proceeding, we will propose an innovative consideration to overcome such difficulties based on statistical approach utilizing analysis database created by the extensive application of TASK3D-a to LHD plasmas.

2. TASK3D-a

Recent development of the integrated transport analysis suite, TASK3D-a, and its extensive application to a wide-ranging LHD plasmas have created the analysis database which includes profile information such as ion and electron temperatures (T_i and T_e), electron density (n_e), NBI heating deposition, and ion and electron heat diffusivities (χ_i and χ_e), and others.

TASK3D-a consists of modules for profile fittings, equilibrium specification, NBI deposition calculations [7] and energy transport calculations, so that they are sequentially executed in an automated manner [1].

3. Description of regression analysis based on TASK3D-a database

The number of high-T_i discharges considered here is 31. Multiple timings are analyzed in each discharge (corresponding to the timing of T_i-profile measurement, leading to a total of about 200 timings), so that the evolution of T_i at the core region from low-T_i to high-T_i phase can be tracked. The T_e profile is rather stiff compared to that of T_i in this database. The n_e profiles are flat to hollow. Figure 1 shows profiles of χ_i obtained from the dynamic transport analysis [8]. The total number of data points is around 3,000.

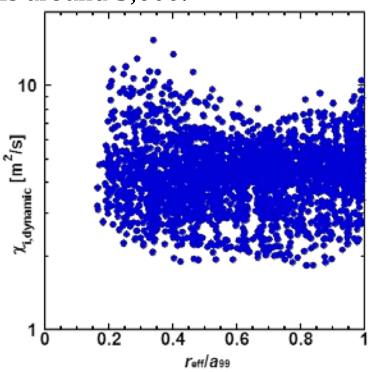

Fig.1. Radial profiles of χ_i of TASK3D-a database

The accumulation of TASK3D-a analyses results has led to the attempt at deducing regression analysis for χ_i with certain parameters based on a statistical approach. Since χ_i has radial dependence, the variables which are appropriate for describing radial position should also be implemented into the database. The effective helicity, ε_{eff} [9], has been implemented as such an example.

On performing statistical analysis, χ_i is dimensionally normalized by Bohm diffusion coefficients, $T_i/(eB)$. Candidate predictive variables are also made into dimensionless variables, such as, for ions, the collision frequency normalized by that of the plateau_Pfirsch-Schlüter boundary (ν_i*), the normalized Larmor radius (ρ_i*), and the temperature ratio (T_e/T_i).

There are wide freedoms for the fitting model selection, including choices and combinations of predictor variables. Let us limit ourselves in this proceeding to proposing an approach that employs the available four variables.

Here, as a standard exercise in scaling studies, the assumed simple power-law scaling model has been transformed to the log-linear form. Multiple ordinary least squares (OLS) regression analysis has resulted in the regression expression for $\chi_i/[T_i/(eB)]$, by employing data shown in Figure 1.

$$\chi_{i,fit}/(T_i/eB) = 2.9\times10^{-10}\,\nu_i^{*-0.182}\,\rho_i^{*-2.72}\,(T_e/T_i)^{0.77}\,\varepsilon_{eff}^{-0.136}\,. \quad (1)$$

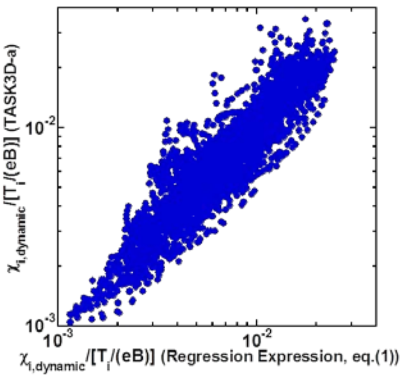

Fig.2. The comparison of $\chi_i/[T_i/(eB)]$ values between TASK3D-a analysis database and the regression results

Figure 2 shows comparison of $\chi_i/[T_i/(eB)]$ values between TASK3D-a analysis database and the predicted values, eq.(1). Around 3,000 data points are reasonably aligned on the diagonal line in Figure 2. An important statistical measure of the quality of the model is the ratio R^2 of the variation explained by the model to the total variation. The obtained value is R^2=0.84, which is a relatively high value, indicating that eq.(1) reasonably reproduces the response variable, that is, $\chi_i/[T_i/(eB)]$. The root-mean-square-error (RMSE) value is 0.27.

As for electrons, $\chi_e/[T_e/(eB)]$, the same set of predictor variables as ions, (ν_e*, ρ_e*, T_e/T_i and ε_{eff}), gives a fitting expression with only R^2=0.29. This poor confidence level of statistics may be attributed to the small range of T_e in the database causing a smaller range of predictor variables. Recently, trials have been conducted in the LHD for increasing T_e in high-T_i plasmas (from $T_i > T_e$ towards $T_i \sim T_e$) [10]. A corresponding increase of TASK3D-a analysis database (inclusion of higher T_e cases in high-T_i plasmas) is foreseen, when it is anticipated to increase the confidence level for electrons, as well.

4. Concluding remarks

In this proceeding, a statistical approach is proposed as an energy transport "modelling" in fusion plasmas. The extensive application of the integrated transport analysis suite TASK3D-a to the LHD experiment has made this approach possible. Statistically-confident regression expression for the ion heat diffusivity for LHD high-T_i plasmas has been obtained, which can be directly implemented into the predictive simulation as a transport "model." It should be emphasized that this approach is comprehensive for other combinations of integrated transport analysis suits and fusion experiments.

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