Development of a Novel Integrated Model GOTRESS+ for Predictions and Assessment of JT-60SA Operation Scenarios Including the Pedestal

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Abstract

• GOTRESS can find out an exact steady-state solution using global optimization techniques and robustly deal with stiff transport models.
• A novel integrated model GOTRESS+ with GOTRESS at its core has been developed in collaboration with equilibrium and heating codes.
• GOTRESS+ has been extended to incorporate the in-house EPED1 model exploiting the MHD stability code MARG2D and is now able to predict the plasma profiles over the entire region.
• The ITER-like inductive scenario and the fully current drive high β scenario for JT-60SA have been assessed by GOTRESS+ with CDBM and were found to be feasible with most of the target dimensionless parameters met.

Background

• Operation scenarios are often stipulated by various target parameters such as β_p, the H_n factor and the bootstrap current fraction f_{bs}.
• Self-consistent predictive simulations using an integrated transport model are essential to investigate whether these parameters simultaneously satisfy the specified target values.
• The pedestal governs the plasma performance to a large extent.
• The EPED1 model is considered to be the most successful semi-empirical model in predicting pedestal height and width.

GOTRESS / Original GOTRESS+ / EPED1

GOTRESS (Global Optimization version of Transport Equation Stable Solver)

• is an MPI-parallelized novel transport code that finds solutions of the steady-state transport equations using global optimization techniques such as genetic algorithms (GAs) (consult details in [Honda CPC18, PoP19]).
• directly finds out a set of \((T, 1/L)\) to satisfy the governing equations.
• does not require numerical differentiation of \(T\) to obtain \(1/L\).
• has an affinity with Deep Learning because GAs produce many data.

GOTRESS+

• originally consists of GOTRESS, the equilibrium and current profile solver ACCOME, the orbit-following Monte Carlo code OFMC and the ECH code.
• provides us with the consistent steady-state solution of the plasma profiles, the equilibrium and the heating and current drive profiles.
• has given the results same as TOPICS’s almost 6 times faster.
• so far has been able to calculate \(7\) and \(1/L\) only inside the pedestal.

We develop our in-house EPED1 model based on the EPED1 model [Snyder, PoP09] and incorporate it into GOTRESS+ to calculate profiles over the entire plasma with the pedestal.

Our EPED1 model

• uses the original scaling formula \(\Delta = 0.076\beta_{p,\text{eff}}^{1/2}\) with MARG2D that can evaluate low to high \(n\) MHD stability.
• successively increases the pedestal pressure and examines the stability until the plasma becomes unstable.
• gives the final pedestal height at a marginally stable point.

GOTRESS+ incorporating EPED1

Overall

The workflow of GOTRESS+ w/ EPED1, shown in right figure, is regulated by Python scripts and the job scheduler, providing the machine independent execution environment. The converged result will go through MHD stability check by MINERVA-0 or MARG2D.

EPED1 and interface programs in GOTRESS+

• Our EPED1 consists of the EPED1 scaling program, ACCOME and MARG2D.
• EPED1 assumes that profiles are described in tanh function form.
• The “map_to_eped” program works out the coefficients of tanh func. by fitting the discrete profile data from GOTRESS.
• It solves this nonlinear least-squares problem using GAs.

JT-60SA operation scenario development

ITER-like inductive scenario

• Single-nl equ. with \(\omega=1.81, \delta=0.41, f_{/B} = 4.6MA/2.28T, R/\rho=2.93m/1.14m\)
• Target values: \(\beta_{p}=2.8, H_{n}=1.1, f_{\text{bs}}=0.3, f_{\text{GW}}=0.8\) (\(f_{\text{GW}}\) is given and fixed)

\[ P_{NB}=34\text{ MW} (E_{NB}/E_{GW} \approx 800keV/500keV): \beta_{p}=2.674, H_{n}=1.072, f_{\text{bs}}=0.23 \]

\[ P_{NB}=34\text{ MW} w/ P_{EC}=2\text{ MW} (138GHz): \beta_{p}=2.929, H_{n}=1.154, f_{\text{bs}}=0.25 \]

High β_p fully current drive scenario

• Single-nl equ. with \(\omega=1.90, \delta=0.47, f_{/B}=2.3MA/1.72T, R/\rho=2.97m/1.11m\)
• Target values: \(\beta_{p}=4.3, H_{n}=1.3, f_{\text{bs}}=0.68, f_{\text{GW}}=0.85\) (\(f_{\text{GW}}\) is given and fixed)
• Difficult to balance b/w MHD stability and large fraction of BS current.

\[ P_{NB}=16\text{ MW} w/ P_{EC}=7\text{ MW} (110GHz): \beta_{p}=4.33, H_{n}=1.68, f_{\text{bs}}=0.676 \]

Point: \(E_{NB}=480\text{ keV}\) and the density pedestal being slightly outward

Summary and perspectives

• The integrated model GOTRESS+ has been extended to use the in-house EPED1 model implementing MARG2D that can apply to low to high-\(n\) modes.
• GOTRESS+ successfully validated the JT-60SA scenarios w/ CDBM almost satisfying the pre-defined target values for dimensionless parameters of \(\beta_{p}, H_{n}\) and \(f_{\text{bs}}\).
• Use of TGLF for scenario development; Coupling with edge models for B.C.

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