Verification of the equilibrium and MHD stability codes within the Integrated Tokamak Modeling Task Force framework.

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**See the Appendix of F. Romanelli et al., Proceedings of the 24th IAEA Fusion Energy Conference 2012, San Diego, US*

Validation of the numerical tools used for modeling of the fusion plasma is an important step in the interpretation of experimental results. As several codes are usually used in the fusion community to model the same plasma processes, prior verification of the codes should be done in order to avoid discrepancies in the results treatment. Often numerical codes use different post- and pre-processing routines, coordinate system conventions, etc. These make such comparison complicated.

One of the main efforts within the Integrated Tokamak Modeling Task Force (ITM TF) is the verification and validation of the existing numerical tools on the existing tokamak experiments. The framework developed in ITM provides common standard interfaces for accessing, storing and exchanging data. All codes integrated in the ITM framework use this common interface which makes the verification process straightforward. Analysis of the plasma equilibrium and MHD stability is one of the topics covered by the ITM. Several equilibrium and MHD stability codes presently integrated in the ITM framework are verified in this work including fixed boundary equilibrium codes CHEASE[1], HELENA[2], SPIDER[3], CAXE[4] and linear MHD stability codes MARS[5], MARS-F[6] and KINX[4]. Reconstruction of the equilibrium for the JET the pulse #74221 using EQUAL[7] or EFIT[8] codes is used as starting point of these studies. The steady state experimental scenario was studied in the chosen pulse with high values of normalized beta observed (β_N up to 2.4 see fig. 1c). The pulse was terminated by a disruption at $t \approx 9.24$ *sec* due to a loss of vertical control. The studied operational scenario with such high values of β_N could be unstable to the ideal kink modes allowing verification of both equilibrium and linear stability codes using one set of experimental conditions.

Verification of the fixed boundary equilibrium codes.

Verification of the CHEASE, HELENA, SPIDER and CAXE fixed boundary equilibrium codes is presented in this section. All codes are solving Grad-Shafranov equation i.e. finding the poloidal magnetic flux Ψ using the plasma boundary shape, current density and pressure profiles obtained from the equilibrium reconstruction code EQUAL or EFIT for these studies). The poloidal flux profile mapped on the flux coordinate system (straight field line coordinates) is compared here together with the profiles of the safety factor and pressure. A quantitative measure of the accuracy of the results is used $\Delta b(s) = \sqrt{\frac{|b(s)-b_0(s)|^2}{|b_0^2(s)|}}$ where $b(s)$ is the profile obtained from the fixed boundary equilibrium code, $b_0(s)$ – profile obtained from the equilibrium reconstruction code (EQUAL) and s is the square root of normalized poloidal flux $s = \sqrt{\frac{|\Psi-\Psi_0|}{|\Psi_a-\Psi_0|}}$ where Ψ_a, Ψ_0 are the poloidal flux values at the plasma boundary and at the plasma center respectively. JET pulse #74221 is used for the verification. One time point $t=9.199$ *sec* is chosen prior to the disruption. The profiles of the safety factor, pressure and poloidal flux as a functions of s obtained from the EQUAL reconstruction for the chosen equilibrium are shown on fig. 2a,b,c together with the same profiles obtained from the different fixed boundary equilibrium codes. Although profiles look the same qualitatively, quantitative comparison using the measure introduced above shows different accuracy for the different fixed boundary equilibrium codes (fig. 2d,e,f). The observed differences in profiles could be caused by several factors including prescription of the plasma boundary in the particular code (affecting the determination of the last close flux surface) or (and) different numerical methods used (for example for numerical integration).

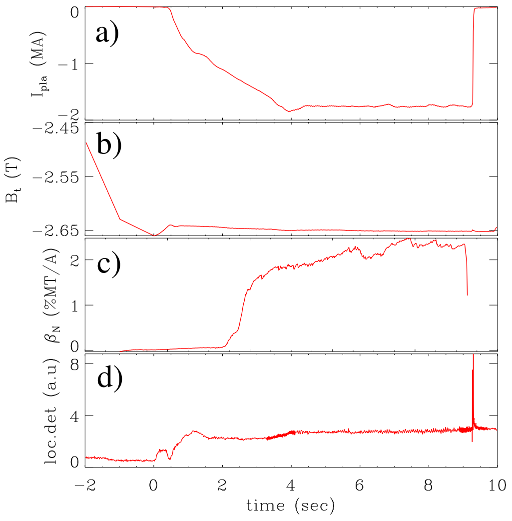

Fig. 1. Time traces of plasma parameters for the JET pulse #74221. a) plasma current; b) toroidal magnetic field; c) normalized beta; d) locked mode amplitude

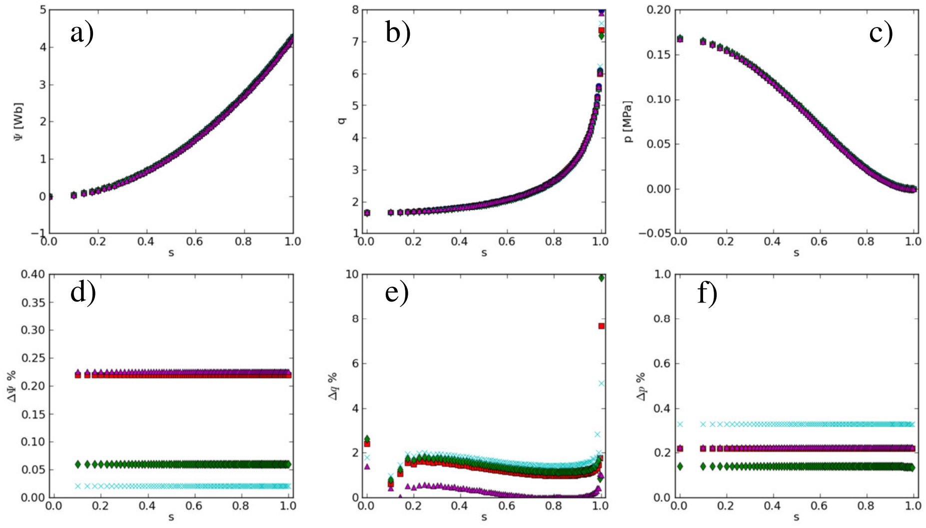

Fig. 2. Comparison of the profiles and correspondent accuracies of the poloidal flux(a,d), safety factor (b,e), pressure(c,f). Blue(circles)-EQUAL, red(squares)-CHEASE, green(diamonds)-SPIDER, cyan(×)-HELENA, magenta(triangles)-CAXE.

Verification of the linear stability codes.

Equilibrium refined by the fixed boundary equilibrium codes is used for the verification of the linear stability codes MARS, MARS-F and KINX. Equilibrium obtained by CHEASE is used as input (in case of KINX further processed by CAXE). The linear stability of the n=1 mode is calculated and eigenvalues and eigenfunction profiles are compared. Convergence of the results with respect to the number of grid points and to the number of poloidal harmonics is examined prior to the comparison in order to exclude non-physical discrepancies. It is found that the studied equilibrium is unstable for the ideal external kink. The eigenvalue obtained depends on the initial equilibrium reconstruction used; the mode growth rate is higher for the equilibrium reconstructed using EFIT code with kinetic constraints than that for the equilibrium reconstructed with EQUAL code using only magnetic measurements.

	MARS	MARS-F	KINX
EFIT+kinetic	2.22e-02	2.23e-02	2.23e-02
EQUAL	2.78e-03	3.54e-03	2.10e-03

Table 1. Eigenvalues of the external kink mode obtained by the different stability codes for the two equilibrium reconstructions of JET pulse #74221, t=9.199 sec.

The external kink mode eigenvalues obtained by the different stability codes for two equilibrium reconstructions (marked EFIT+kinetic and EQUAL) are presented in the Table. 1. Eigenvalues are normalized to Alfvén time in the plasma center. It is seen that the results depend on the equilibrium used (results are more robust for more unstable case

EFIT+kinetic). It is found that the stability calculations are sensitive to the equilibrium details near the stability boundary (EQUAL case).

The profiles of the first ten positive poloidal Fourier harmonics (dominating the spectrum) of the normal displacement $\xi_n=\xi\bullet\nabla\psi$ are shown on fig. 3 for the case EFIT+kinetic. Profiles are scaled using the maximum value of the dominant harmonic (m=2) for one stability code (KINX) as scaling parameter. Such scaling allows the comparison of relative amplitudes of the poloidal harmonics for different stability codes. It is seen that the shapes of the poloidal harmonics and relative amplitudes are in agreement for all codes.

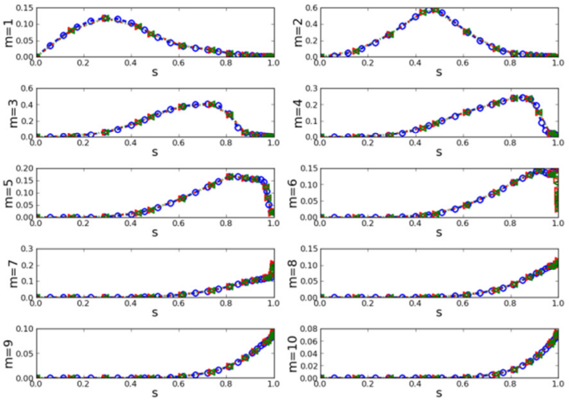

Fig. 3. Poloidal Fourier components (m=1-10) of the normal displacement ξ_n. Blue – KINX, red – MARS-F, green – MARS.

In conclusion, verification of fixed boundary equilibrium codes and linear stability codes was performed for a JET pulse within ITM framework. The verification procedure becomes straightforward using the standard format for data flow and storage implemented in the ITM. Different accuracy of the equilibrium solution for different equilibrium codes is observed quantitatively. It is found that the equilibrium details are important for the stability calculations near the stability boundary.

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