Modelling of FAST equilibrium configurations by a Toroidal Multipolar Expansion code using Kepler workflows

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Abstract. In this paper we present the fusion advanced studies torus (FAST) equilibrium configurations, designed by means of the ITM FIXFREE code version for reproducing those of ITER (with scaled plasma current) and suitable to fulfil plasma conditions for integrated studies of plasma–wall interaction, burning plasma physics, ITER relevant operation problems and steady state scenarios. FIXFREE is a toroidal multipolar expansions equilibrium code, recently ported to the Integrated Tokamak Modelling (ITM) Gateway platform. The European ITM Task Force opted for the open source workflow system Kepler to link various codes and coordinate the data flow among them. A description of the development of the FIXFREE code under the Kepler environment will be given in this paper.

1. Introduction

Fusion Advanced Studies Torus (FAST) [1] has been proposed as a possible option for a European ITER Satellite facility [2], aimed at supporting the preparation of ITER operation scenarios and the exploration of technologies relevant to DEMO physics and technology issues in a wider (dimensionless) parameter space than JT-60SA and with characteristic values closer to ITER. FAST equilibrium configurations were designed in order to reproduce those of ITER with scaled plasma current. These equilibria, suitable to fulfil plasma conditions of relevance for studying integrated burning plasma physics, have been calculated using FIXFREE [3], a toroidal multipolar expansions equilibrium code, developed in Frascati and recently ported to the Integrated Tokamak Modelling (ITM) Gateway platform. The European ITM Task Force opted for the open source workflow system Kepler to link various codes (actors in a workflow) and coordinate the data flow among them. These actors are independent of a particular device and interact with each other via consistent physical objects (CPOs), i.e. a data structure containing all relevant information on machine description and plasma parameters [4]. In order to design the FAST equilibria, the FIXFREE code has been run as a Kepler actor. A description of the FIXFREE code development under the Kepler environment will be given in this paper. Two different equilibrium configurations, corresponding to the FAST reference H-mode and Advanced Tokamak (AT) scenarios, will be presented.

2. The FIXFREE code within theKepler workflow system

The FIXFREE equilibrium code solves the Grad-Shafranov equation [5] by using the semi-analytical expansion of the scalar flux function ψ in terms of toroidal multipoles [6] based on the full toroidal co-ordinates [7]. The equilibrium is solved iteratively, using an integration mesh with a circular cross section, both for free and fixed conditions. The results - i.e. currents in the external poloidal circuit, toroidal plasma current I_P, the poloidal β_P and functional form of the kinetic plasma pressure $P(\psi)$ and the diamagnetic total plasma current $I^2(\psi)$ are easily interpreted in terms of toroidal multipoles. The semi-analytical method makes the code extremely flexible in modifying the coil positions for a given tokamak, because the dependence on the integration mesh is extremely reduced with respect to other fully numerical solution methods that require sophisticated mesh generators. Therefore, this methodology is particularly suited to the design of new tokamak devices. FIXFREE code is written in FORTRAN®. Some of the input parameters could be passed directly to FIXFREE through CPOs (basically the coil geometries and currents, magnetic field and plasma current), while others must be imported by XML files in the code-parameters section of the equilibrium CPO. A FORTRAN library that parses and interprets XML files, based on the open source XML2LIB library, has been developed for this purpose. In order to adapt FIXFREE to the ITM requirements, some quantities have been added to the output variables that were not present in the original FIXFREE code, while the description of the poloidal field coils (PFC), which was originally specified together with all the other code parameters, is now read from the PFSSYSTEM CPO. The structure of FIXFREE has also been slightly modified in order to always run as a batch job, for it was originally a mostly interactive program, even though a batch modality was allowed. A program that populates MDSPLUS trees with the FAST data has also been written and finally all has been assembled within a Kepler actor. A Kepler workflow of a FAST equilibrium is shown in Fig. 1. Blue boxes represent actors that carry out complex tasks and can even be a complete analysis code, while the rectangles represent Kepler variables or simple actions. The actor "ualinit" initializes the Universal Access Layer (UAL) that acts as the communication layer of the ITM infrastructure, retrieves the engineering machine description for the chosen device (in this case FAST) from the ITM database and populates it with experimental (or simulated) “shot” data. As no experimental data exist, the input FAST CPOs have been populated with "design" data from FAST configuration. The top box "Display" is a general purpose output display actor native of Kepler.

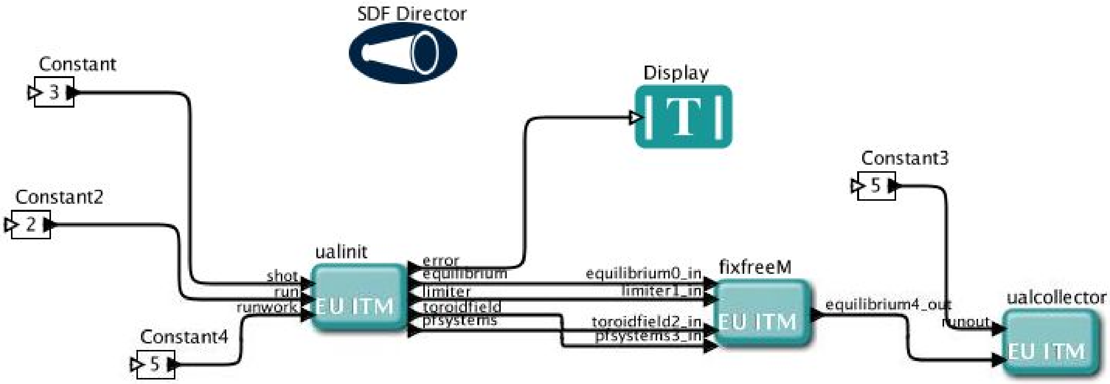

Figure 1: . Kepler workflow of a FAST equilibrium

3. FAST equilibrium configurations

FAST equilibrium configurations have been designed in order to reproduce those of ITER with scaled plasma current, but still suitable to fulfil plasma conditions for studying operation problems, Plasma Wall Interactions (PWI) and burning plasma physics issues in an integrated framework [8]. The prerequisites to be satisfied, in order to reproduce the physics of ITER relevant plasmas, yield the following set of FAST parameters: (1) plasma current, I_P, from 2MA (corresponding to full NICD) up to 8MA (corresponding to maximum performance); (2) auxiliary heating systems able to accelerate plasma ions to energies in the 0.5–1 MeV range; (3) major radius of about 1.8m and minor radius ~0.65 m; (4) pulse duration from 20 s, for the reference H-mode scenario, up to 170 s (~40 resistive times τ_{res}) at 3 MA/3.5 T in the AT scenarios. All the studied equilibria have been designed to have the same geometrical plasma features dictated by ITER similarity: R=1.82 m, a=0.64 m, k=1.7, $<\delta>=0.4$.. In addition, these plasma equilibria satisfy the following constraints: (a) minimum distance of 0.03 m between the plasma last closed magnetic surface and the first wall, in order to minimize the interaction between the plasma and the main vacuum chamber; this value results from assuming a distance ~6λ_p, with λ_p (the power flux e-folding length) considered to be 0.005 m on the outer equatorial plane [9]; here, a furtherfactor 2 has been used to take into account the uncertainties in the λ_p estimation; (b) maximum transient current density in the poloidal field coils ~32 MAm^{-2}. The main parameters of the reference H-mode equilibrium obtained by the ITM FIXFREE code are reported in table 1. A good agreement has been found [12] between the FIXFREE equilibrium and those obtained by means of CREATE-NL [10] and MAXFEA [11] . The time evolution of equilibrium configurations is shown in Fig. 2. For AT scenarios, the plasma boundary shape is essentially the same as that shown in Fig. 1 for the reference H-mode scenario, whereas the q profile is assumed to be slightly reversed, with $q_{axis} > 2$ and $q_{min} < 2$ (at around half radius), as expected in such scenarios [8].

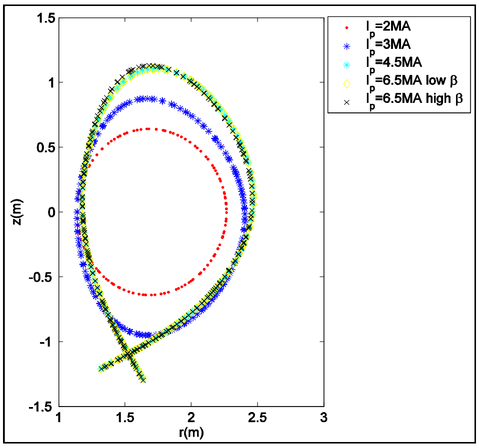

Figure 2: Time evolution of FAST H-mode equilibrium configurations obtained by ITM FIXFREE

I_P (MA)	6.5
β_N	1.3
P_0/<P>	2.35
q_{95}	3
q_{axis}	1.09
Volume (m^3)	22.8

Table 1: Main parameters of the reference FAST H-mode equilibrium

The FIXFREE equilibrium configurations have been used to carry out transport simulations by means of JETTO [13] and CRONOS [14] codes. The next stage of ITM FIXFREE further development studies will be the coupling of the code to the European Transport Solver (ETS) within the Kepler workflow system. From these premises, we may conclude that FIXFREE may be come one of the reference free-boundary equilibrium codes for the ITM environment.

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