Towards the integrated analysis of tokamak plasma equilibria: PLEQUE

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Introduction

Dealing with a tokamak plasma equilibrium is a common task form the most of the tokamak plasma scientist. It serves as a mandatory input into a majority of simulation codes, and plasma reconstruction from measured data is essential for the interpretation of experiments. Knowledge of the plasma equilibrium topology is also necessary for the design of whole machines and their subsystems, e.g. of plasma facing components or diagnostic systems. In this paper, we present innovative open-source python package PLEQUE (PLasma EQUilibrium Enjoyment) [1, 2], which aims to simplify work with the plasma equilibrium and to open it up to a broader number of scientists. This package was created as a site product of the COMPASS-U design the driving momentum was the need for cooperation between multiple work groups using various simulation codes.

The code is initialised by imposing poloidal flux ψ on R and Z grid with a profile of pressure $p(\psi)$ and toroidal field flux function $F(\psi)$. This information may be complement

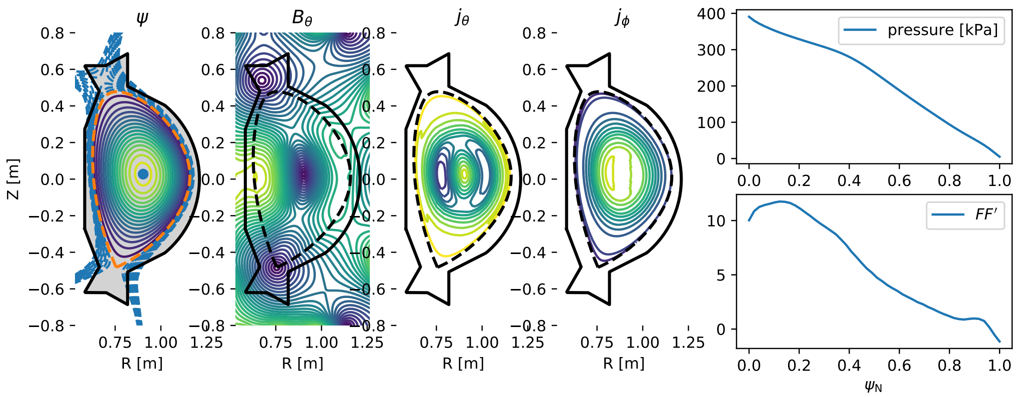


Fig. 1 COMPASS-U baseline scenario with Fiesta profiles. The poloidal magnetic field, toroidal current denisty and poloidal current denisity are calculated by PLEQUE.

with the information about the first wall structure and used the tokamak coordinate convention (COCOS [3]). Provided input profiles are interpolated using univariate spline and bivariate rectangular spline. Based on the input data, the critical points, plasma type and last closed flux surface are identified. Providing additional information about the plasma on input may be necessary for the code to identify all of its parts, for example, contact-points and strike-points. All consequential plasma equilibrium quantities like a poloidal (B_θ) and toroidal (B_ϕ) magnetic field or poloidal and toroidal current are calculated from ψ, $p(\psi)$ and $F(\psi)$. The additional flux functions are interpolated onto ψ using univariate spline and mapped to the equilibrium. The example of a calculated B_θ, poloidal current density and toroidal current density can be seen in Fig. 1.

PLEQUE benefits from its easy coordinate syntax. It allows users easily create `Coordinates` object in any supported coordinates[1]. Through the created object, users gain access to other various coordinates, mappings and transformations. All the required calculations are done automatically. Supported coordinates types are listed in [2]. The usage of this approach can be particularly helpful in combination with flux functions mapping where the flux function can be evaluated at any point.

Developed code utilities

The minimum requirements of input data for PLEQUE object construction make it suitable to be integrated with various equilibrium formats and databases. The complete, up-to-date PLEQUE input/output schema can be seen in Fig. 2. Due to implemented conversion to Interface Data Structure (IDS) [4], PLEQUE can be used as a bridge to calculations under Integrated Modelling Analysis Suite (IMAS) [5,6]. The workflow using ASCOT [7] code within IMAS framework can be seen in

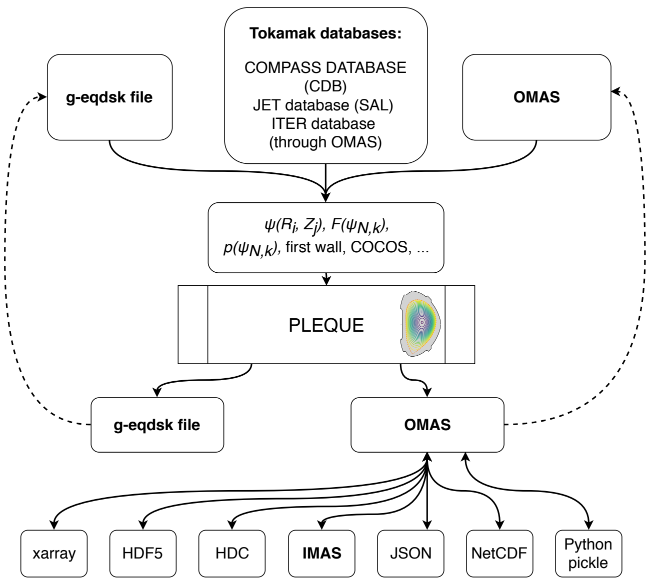


Fig. 2 INPUT/OUTPUT diagram of PLEQUE.

[1]The list of supported coordinates is not final and will be extended in the future.

Fig. 3. The OMAS python package [8] is used as an interface for data saving/loading to/from IMAS database.

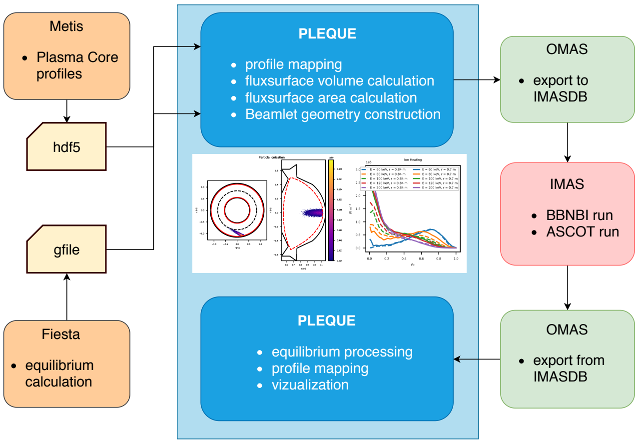


Fig. 3 ASCOT and BBNBI IMAS simulation setup and analysis workflow.

PLEQUE implements a simple interface for the field line tracing which can be used, for example for calculation of connection lengths. In some particular cases one may need to do integration along the field line traced in the vicinity of the x-point[2] (e.g. calculation of Melnikov integral [9]). This may be difficult due to the singularity in the x-point where the $B_\theta = 0$. The presence of the singularity is demonstrated in Fig. 4 (a). In order to trace the field line in the vicinity of the x-point, the PLEQUE package provides tools for the following technique.

The field line tracing equation in the vicinity of x-point expanded to the first nonzero term has the form of

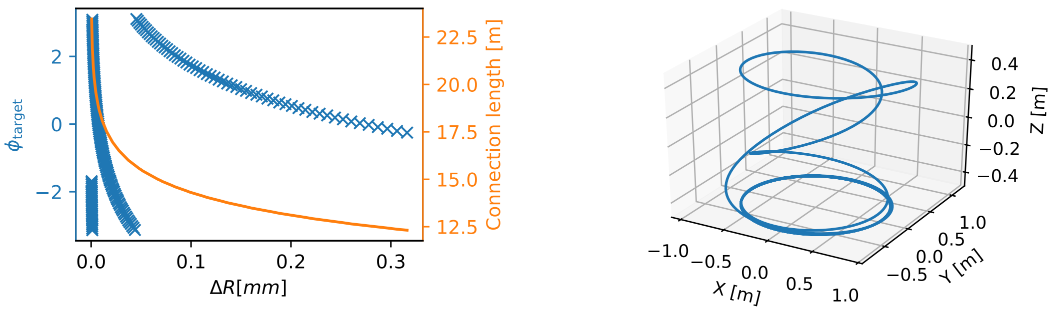
$$\frac{\mathrm{d}\vec{r}(s)}{\mathrm{d}s} = \frac{1}{R}\begin{pmatrix} -\frac{\partial^2\psi}{\partial R\partial Z} & -\frac{\partial^2\psi}{\partial Z^2} \\ \frac{\partial^2\psi}{\partial R^2} & \frac{\partial^2\psi}{\partial R\partial Z} \end{pmatrix}(\vec{r}(s) - \vec{r}(0)). \tag{1}$$

The matrix eigen vectors point in the direction of both wings of separatrix. This allows numerical integration by making finite step along the separatrix into a region with nonzero B_θ. Example of field line trace in the vicinity of x-point can be seen in Fig. 4 (b).

Conclusion

The PLEQUE package aims to simplify work with plasma equilibrium and to open it up to a wider scientific community. User is provided with a simple set of tools which offers efficient processing and utilisation of equilibria without the need of any deep knowledge of programming or the equilibrium physics in general. PLEQUE in its core concentrates on the proper numerical treatment of the data to minimise errors and to supply the user with possibly any required transformations, coordinates, tracings, mappings, etc. This allows the user to concentrate its efforts in other areas and on physics research. PLEQUE usage also allows unifying procedures

[2]In this type of integral it is required that the integrated quantity goes to the zero in the vicinity of x-point and that the integral is finite.



(a) (b)

Fig. 4 (a) Connection lengths of field line traced from the position of x-point $+\Delta R$ and the toroidal angle of the field lines on the target. (b) Magnetic field line traced from the x-point along the separatrix and ending in x-point. COMPASS-U baseline scenario was used.

within or between work groups, which can sometimes lead to unnecessary errors or time consumption. The support of various export and import formats makes it also a good candidate for a bridge between experimental and modelling results as well as in between different work frames.

Acknowledgement

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission and within the framework of the project COMPASS-U: Tokamak for cutting-edge fusion research (No. CZ.02.1.01/0.0/0.0/16_019/0000768) and co-funded from European structural and investment funds.

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