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# FreeGSNKE: an open source pure-Python predictive evolutive equilibrium code for control design and validation

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FreeGSNKE [1,2] is an open source, pure-Python, finite difference solver of the 2D dynamic plasma equilibrium problem. It couples the plasma equilibrium with the currents in the poloidal field (PF) coils and passive vessel [3, 1]. FreeGSNKE can run predictive simulations of the plasma response to the voltages applied to the PF coils by the power supplies, thereby supporting shape control and control design studies.

One of FreeGSNKE's aims is to lower the entry barrier to studies seeking to adopt ML approaches to plasma control. FreeGSNKE is fully open source and seamlessly integrates with Python ML libraries and algorithms, overcoming the need for cross-language binders or socket interfaces for multi-language interaction. A set of examples and dedicated documentation are provided to facilitate adoption by new users [2].

FreeGSNKE builds on FreeGS [3], introducing i) a static Grad-Shafranov (GS) solver based on the Newton-Krylov (NK) method; ii) linear and non-linear solvers for the evolutive equilibrium problem, also based on the NK method. We validate FreeGSNKE's static GS solver on a selection of MAST-Upgrade (MAST-U) discharges with EFIT++ reconstructed equilibria [5]. To validate the evolutive solver we simulate the 'flat-top phase' of MAST-U shots, using the recorded voltages applied to the PF coils and an EFIT++ reconstructed equilibrium as initial conditions. Fig.1 illustrates one such FreeGSNKE simulation by displaying the evolution of a set of standard plasma shape targets. These are compared with the corresponding reconstructed quantities.

Several concurrent development tracks are presently underway. I) A Pulse Design tool is being built to allow for in-silico development of new plasma shapes and controllers to support MAST-U operations. II) An auto-differentiable and GPU-compatible version of FreeGSNKE is being developed using the JAX library. III) We are integrating FreeGSNKE with a transport module, to enable integrated modelling with time evolving free boundary equilibria. Using the IMAS data formats, we are coupling FreeGSNKE with JETTO. The coupling with TORAX [6] will leverage the JAX implementation. IV) FreeGSNKE is being used to support vertical stability studies of STEP plasmas [7]. The evolutive capabilities will be used to support the estimation of EM loads during VDEs.

References

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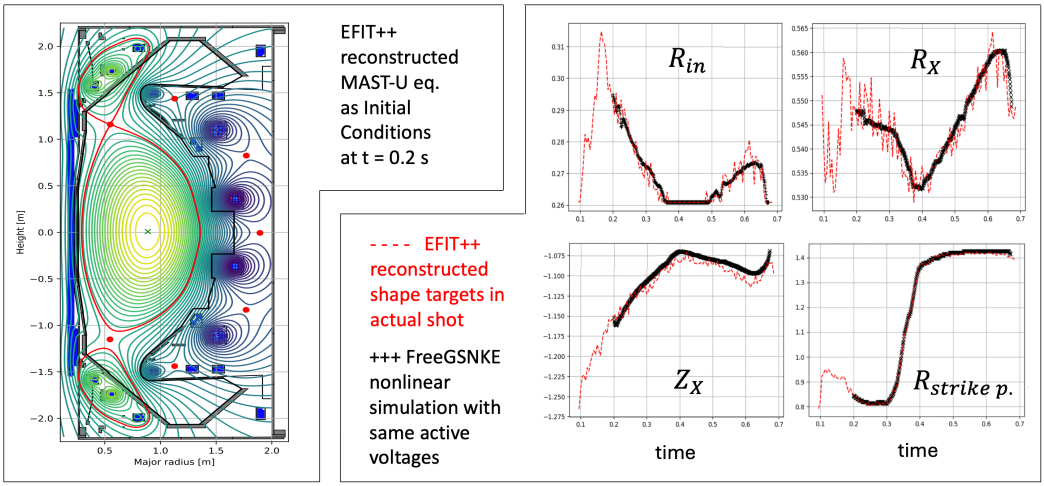


Figure 1. Example FreeGSNKE simulation of a MAST-Upgrade shot. The left panel displays the plasma equilibrium used as initial conditions. The right panels show a comparison between the observed shape targets (from EFIT++ reconstructions) and the shape targets obtained in the simulation.