LIBRA: A New Free-Boundary MHD Equilibrium Code for the Analysis of PROTO-SPHERA Plasma Configurations

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PROTO-SPHERA [1,2] is an innovative magnetic confinement experiment developed at ENEA C.R. Frascati, capable of generating high-density plasmas in a spherical configuration through helicity injection [3] from a central screw-pinch discharge. Unlike conventional spherical tokamaks, PROTO-SPHERA does not require a metallic centerpost and relies on the interplay between plasma currents, external poloidal magnetic fields, and magnetic reconnection processes to generate closed magnetic flux surfaces.

To investigate the properties of this complex magnetic configuration, a new free-boundary ideal magnetohydrodynamic (MHD) equilibrium code, named **LIBRA**, has been developed. The code solves the Grad–Shafranov equation [4] using a finite-element formulation on unstructured triangular meshes and computes self-consistently both the plasma boundary and the associated magnetic configuration for both the screw pinch and the plasma torus. The machine geometry and the currents flowing in the screw pinch discharge and in the external poloidal field coils are provided as input parameters, while the plasma separatrix is determined as part of the solution.

Following validation against some analytical benchmark equilibria, LIBRA has been applied to the study of PROTO-SPHERA configurations characterized by the coexistence of a central screw pinch and a toroidal plasma generated through magnetic reconnection. Particular attention is devoted to the scaling of the equilibrium solutions with machine size and external coil currents. The analysis focuses on the dependence of the toroidal plasma current on the current flowing in the central pinch, with the aim of identifying the operating conditions that enable the sustainment of configurations with toroidal current amplification. In addition, an extension of the model including plasma rotation [5] is presented, providing a first assessment of the influence of rotational effects on the stability of PROTO-SPHERA MHD equilibria.

The results demonstrate the capability of LIBRA to reproduce the main features of PROTO-SPHERA plasmas and provide a versatile numerical framework for the design and optimization of helicity-injection-based magnetic confinement configurations. The code represents a valuable tool for future investigations of PROTO-SPHERA and other free-boundary plasma systems.

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