Reconstruction of Magnetic Field Surfaces of the NOVILLO Tokamak by means of the 3D-MAPTOR Code

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Abstract. A 3-D code has been developed in order to simulate the magnetic field lines in circular cross-section tokamaks. The toroidal magnetic field can be obtained from the individual fields of circular coils arranged around the torus, or alternatively, as a ripple-less field, as well as the vertical field coils, and divertor-like coils. The poloidal field is provided by a given toroidal current density profile. Proposing initial conditions for a magnetic filed line, it is integrated along the toroidal angle coordinate, and the Poincaré maps can be obtained at any desired cross section plane along the torus. Following this procedure, the code allows to explore the necessary current values for the existence of magnetic field surfaces, allowing for deviations from axial symmetry, such as ripple effects. Therefore it is a good design instrument, in which different parameters and arrangements of coils can be tested. On the other hand, the current signals from experimental devices can be used in order to reconstruct the behaviour of the magnetic field surfaces, including the $q(r)$ profiles. The reconstruction properties of the code are shown in this work.

Keywords: Tokamak, Magnetic confinement and equilibrium, Nonlinear Dynamics.
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INTRODUCTION

Tokamaks and stellerators have become good toroidal confinement devices, thanks to the success in designing them with the necessary symmetry properties to allow the existence of robust closed magnetic field surfaces. By knowing the currents in the confinement device, as well as the plasma current density, it is possible to integrate the magnetic field lines in the three dimensional space, starting from a given initial condition, just as trajectories of particles in Hamiltonian systems are integrated in phase-space [1]. In the case of tokamaks, the toroidal angle plays the role of time in the case of the particle. Therefore, if one knows the evolution of the current signals involved in a discharge, it is in principle possible to reconstruct the behavior of the magnetic field surfaces, and know when they may cease to exist due to lack of axisymmetry. The main source for this, could be the ripple due to the finite number of toroidal field coils, for instance.

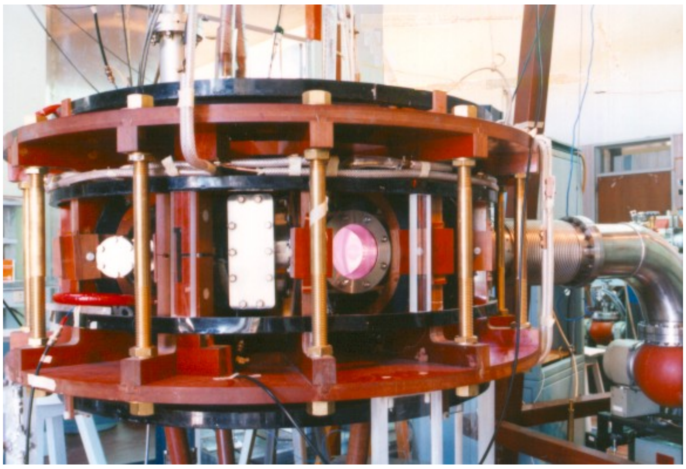

FIGURE 1. The Novillo Tokamak at the Instituto Nacional de Investigaciones Nucleares

In order to study the existence of magnetic field surfaces, we have developed a three dimensional 3D-MAPTOR code [2, 3], in which the external coil currents can be included, and a plasma current profile is assumed, so the behavior of the field surfaces can be studied for a given design. It is based on the superposition of magnetic fields produced by circular loops, given in terms of elliptic integrals [4], so at present, it is limited by such a geometry. The code allows the study of magnetic fields even when there is no equilibrium, and conditions for the existence of surfaces are not met. In a former work it was applied to the study of an ergodic divertor, when the axisymmetry is broken by a slanted internal coil [2].

In this work, we have used the code to reconstruct the behavior of the plasma column in the NOVILLO tokamak (Figure 1), which operated throughout the 1990s at the Instituto Nacional de Investigaciones Nucleares, in Salazar, Mexico, and was decommissioned in 1999. The major radius was $R = 0.23$ m, the minor radius $a = 0.06$ m, and it had 12 toroidal field coils. The four sectors of the device are insulated, in order to prevent image currents. The evolution of the current signals of the toroidal field coils, the ohmic heating coil, the vertical field coils and the plasma is shown in Fig. 2 for a typical discharge, lasting around 1500 μs. Since there is no diagnostic for the current density profile, it was chosen to be of the form $j(r) = 4j_o(1-r^2/a^2)^3$, although it could be adjusted. The arrangement of coils and plasma current density profile is shown in Fig. 3 (a).

NUMERICAL RESULTS

The reconstruction of the plasma column was made using the signals shown in Fig. 2, and their Poincaré maps at the 0^o toroidal angle plane were plotted in such a way that its evolution could be seen as a movie. The maps for 50, 150, 400, 700 and 1450 μs are shown in Figs 3(b-f). Four constant circles can be appreciated in them. The outer two are the toroidal field coil at 0^o. The inner two represent the vacuum chamber and the limiter. The outer magnetic field surface is defined as the one which touches the limiter. It can be clearly seen how the column is centered at 50 μs, then it moves towards the outer board by 150 μs, when the plasma current reaches its maximum, but the vertical field is too strong, and by 400 μs it has been thrown inward. The column contracts as time increases, and extinguishes by 1450 μs when the plasma current falls. This result is consistent with qualitative observations of the plasma column position made with magnetic probes.

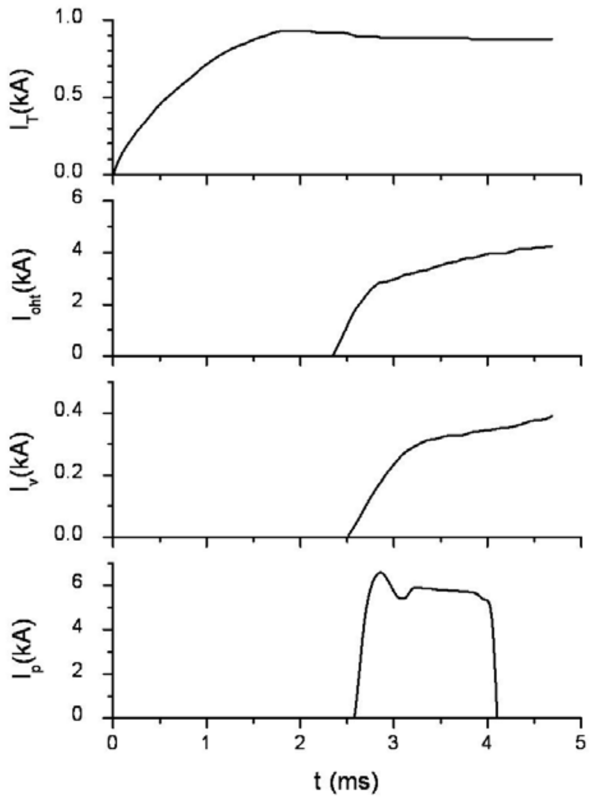

FIGURE 2. Set of signals used for the reconstruction of the magnetic field surfaces in a plasma discharge lasting approximately 1500 μs. These are, from top to bottom, the toroidal field coils current, the ohmic heating coil current, the vertical field coils current, and the plasma current.

Further information can be obtained from the magnetic field surfaces, such as the evolution of the profiles of the poloidal flux $\psi_p(r)$, which can be readily integrated and the safety factor $q(r)$. Figure 4 shows the evolution in time of the poloidal flux and the safety factor at the outer surface, the average pressure $\langle p \rangle$, and beta poloidal β_p.

CONCLUSIONS

The capabilities of the 3D-MAPTOR code to reconstruct the evolution of the magnetic field surfaces in a circular section tokamak discharge have been tested, taking the signals from a typical discharge of the NOVILLO tokamak. However, its flexibility allows its use for other circular section tokamaks. It would be particularly useful as a complement in experiments for which other diagnostics are used for the determination of the plasma column position. On the other hand the code can also be used as an aid for the design of new devices, easily varying the number and position of coils, as well as the current values.

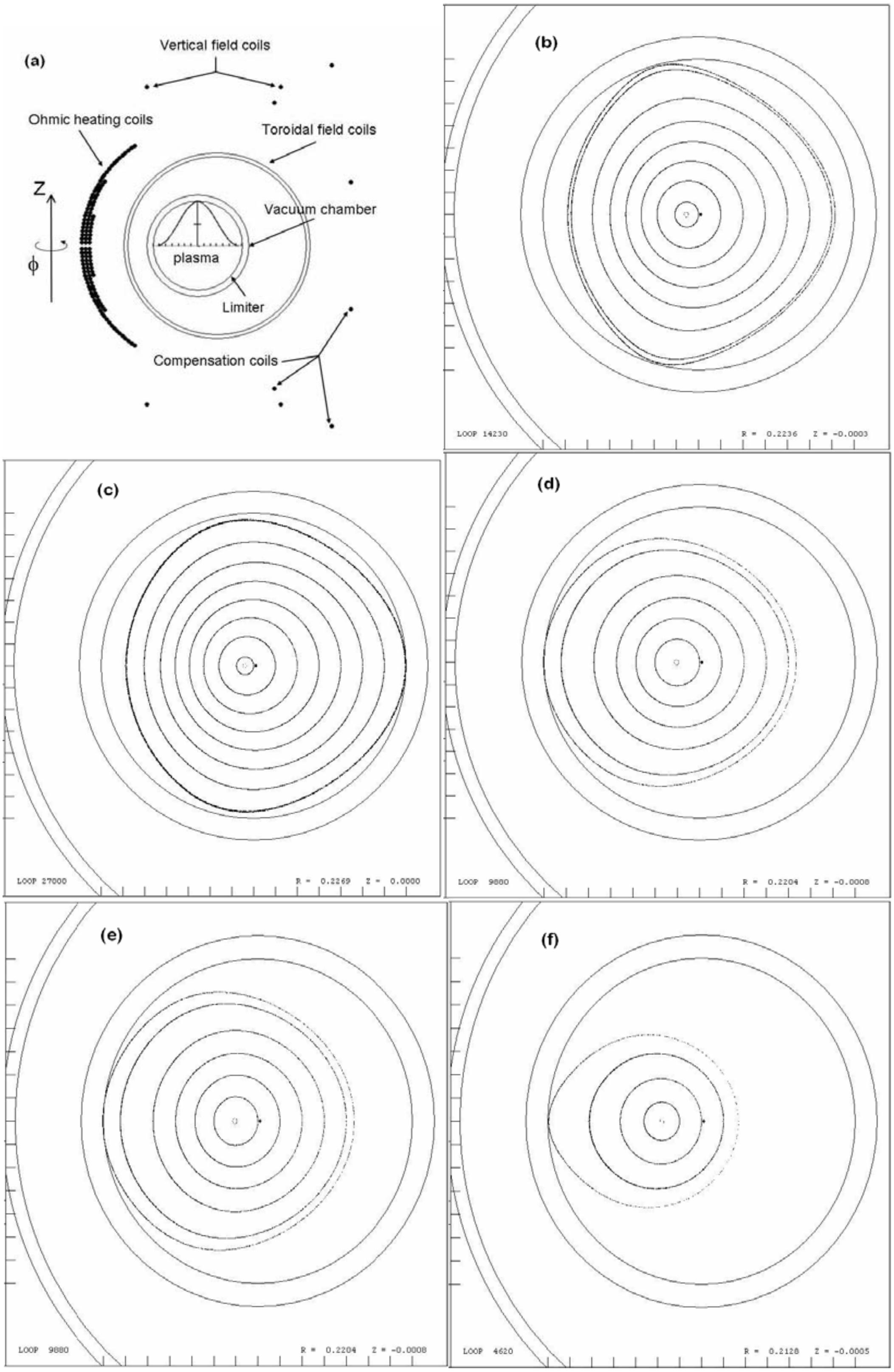

FIGURE 3. (a) Coil arrangement for the NOVILLO tokamak (b-f) Reconstruction for surfaces at 50, 150, 400, 700 and 1450 μs, for the discharge shown in Fig. 1.

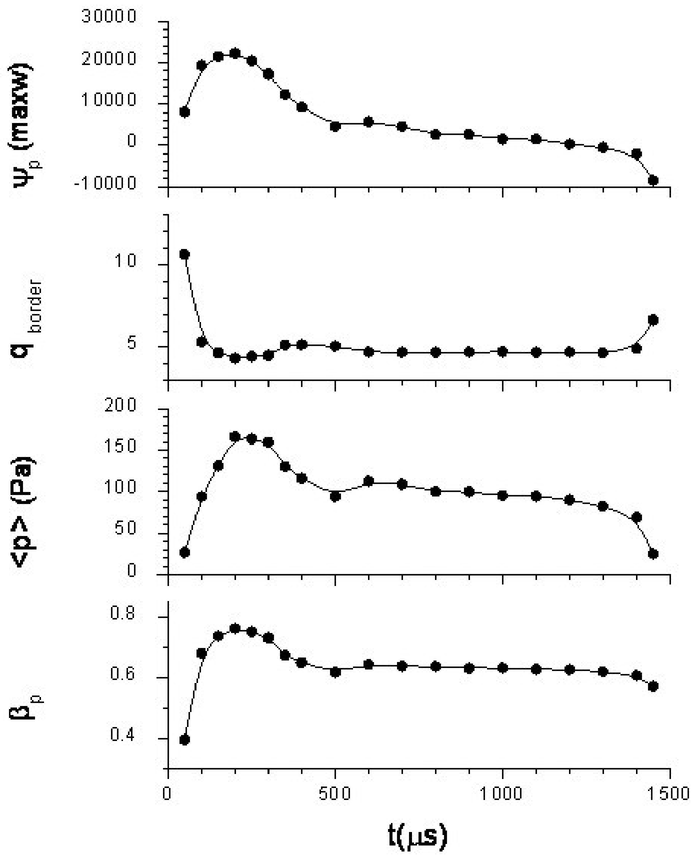

FIGURE 4. Temporal evolution of the poloidal flux ψ_p and the safety factor *q*, both at the outer surface, the average pressure, and beta poloidal β_p.

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