Imaging of a Double Helical Structure in the Reversed Field Pinch

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***Abstract*—X-ray tomography and Poincaré reconstructions with the ORBIT code allow imaging of coherent structures emerging in a magnetized fusion plasma when chaos in the magnetic field is reduced.**

***Index Terms*—Magnetohydrodynamic (MHD), Monte Carlo methods, reversed field pinch, soft X-ray tomography.**

THE reversed field pinch (RFP) is a current-carrying configuration for the magnetic confinement of a toroidal plasma [1]. It is characterized by a magnetic field with toroidal and poloidal components of comparable magnitude, mainly generated by currents within the plasma. This makes the plasma prone to magnetohydrodynamic (MHD) instabilities, which can be characterized by poloidal and toroidal mode numbers m and n, respectively. These instabilities break the toroidal symmetry of the magnetic field and are the driver of the self-generated toroidal magnetic field. In standard RFP plasmas, there is a wideband, temporally fluctuating spectrum of $m = 0$ and $m = 1$ modes which nonlinearly interact and produce a stochastic magnetic field.

A strong transient reduction of magnetic turbulence has been obtained by applying a parallel electric field to the plasma edge, the so-called pulse parallel current drive (PPCD) technique [2]–[4]. A population of very energetic electrons has recently been measured in the plasma core during PPCD and has been interpreted as a result of the substantial decrease of magnetic stochasticity in that region [5]. This interpretation is consistent with measurements [6] performed with a soft X-ray (SXR) tomographic diagnostic installed on the Madison Symmetric Torus (MST) RFP device [7]. This diagnostic is composed of two arrays of solid-state silicon detectors, which collect SXR radiation along 24 lines of sight. Tomographic algorithms [8], [9] applied to these line-integrated measurements provide the two-dimensional (2-D) emissivity profile in a poloidal cross section, as depicted in the inset in Fig. 1. For the first time in a RFP, two distinct SXR structures are observed [6]. In the MHD framework, the kinetic pressure is constant on magnetic flux surfaces and SXR iso-emissivity surfaces are representative of them; based on the analysis of correlation between magnetic and SXR fluctuations, we conclude that these structures are magnetic islands. In standard plasmas, SXR structures are not observed because of the large mode amplitudes, corresponding to a condition with strong overlap of magnetic islands and a highly stochastic field structure without helical flux surfaces.

This is confirmed by the analysis of the magnetic field lines topology, as reconstructed by the ORBIT code [10], [6], recently adapted to the RFP configuration. ORBIT is a Monte Carlo code, in which test particle guiding center equations are cast in hamiltonian form and can, therefore, be integrated for long distances in order to reconstruct the magnetic flux surfaces. Guiding center trajectories of particles of vanishingly small energy coincide with magnetic field lines. By using experimental boundary conditions (magnetic fluctuations and equilibrium measurements), constrained by SXR tomographic reconstructions, the helical coherent structures have been reconstructed [11]. The results of the ORBIT simulations confirm the presence of two SXR structures: their radial positions and dimensions are in good agreement with ORBIT field map. Thus, in addition to the 2-D reconstruction of the SXR tomography, magnetic flux surfaces computed by ORBIT give a three-dimensional (3-D) representation of the magnetic flux surfaces, as shown in Fig. 1. The image represents two particular magnetic surfaces of the two magnetic islands. In the case considered here, the islands correspond to the two innermost resonant modes $(m = 1, n = 6)$ and $(m = 1, n = 7)$. The 2-D reconstruction of the SXR emissivity in the poloidal section of the tomography is highlighted. The two innermost resonant magnetic islands, though existing in close proximity to one another, are spatially well resolved.

To summarize, our SXR data reveals a significant change in magnetic topology, which is represented in 3-D by magnetic field line tracing, confirming the conclusion that, during PPCD, a substantial reduction of magnetic chaos occurs in the plasma core.

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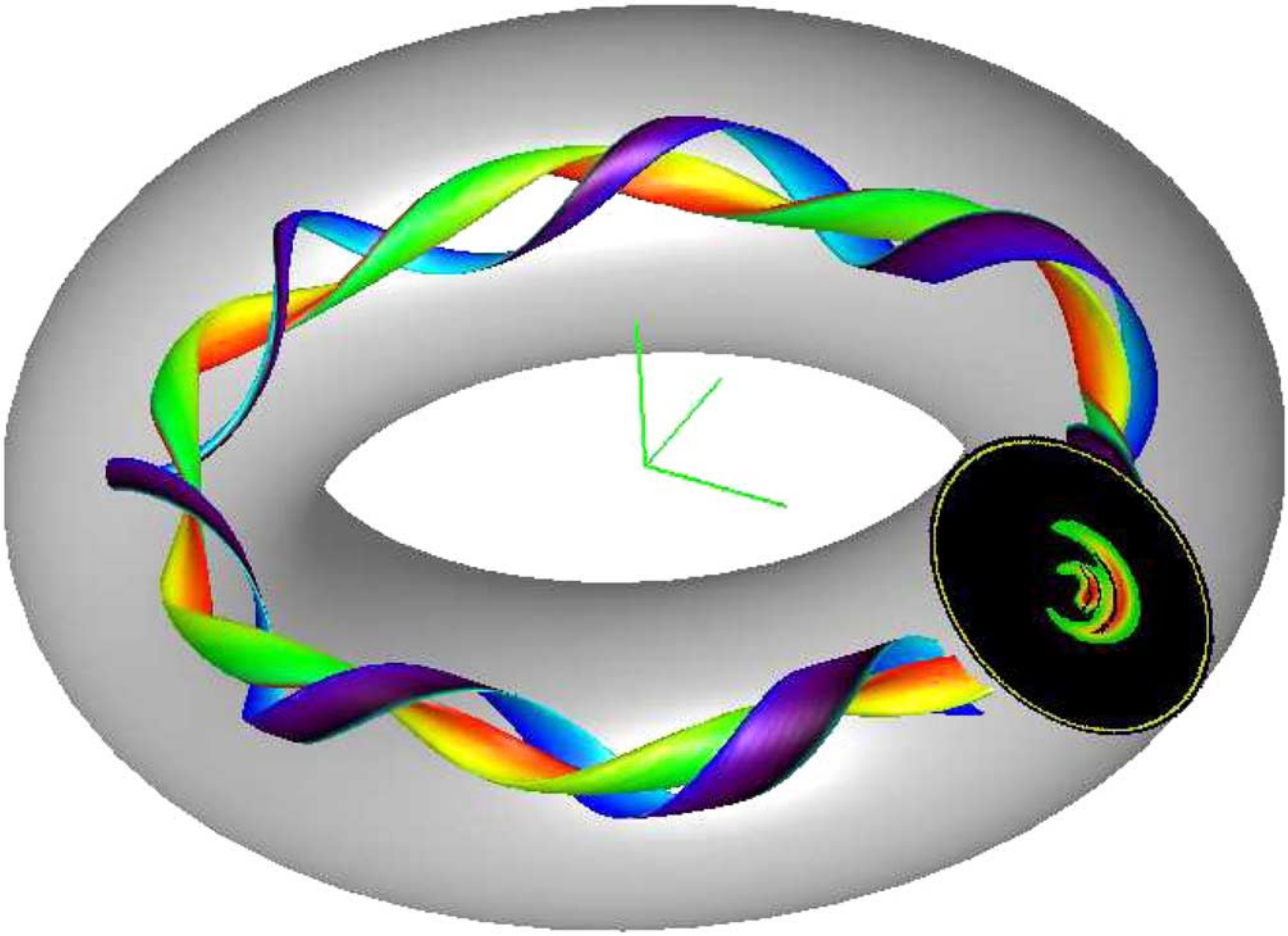

Fig. 1. 2-D tomographic reconstruction of SXR emissivity (red: high emissivity, green: low emissivity), together with a 3-D representation of two helical magnetic surfaces. 3-D color coding is only to aid visualization of the helical structures: green-yellow-red refer to (1, 6) and cyan-blue-violet to (1, 7).

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