S4-2

First observation of plasma healing via helical equilibrium in tokamak disruptions

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Control of chaotic states is of broad interest across the interdisciplinary areas of nonlinear sciences. It is also important for the safety of future nuclear fusion reactors, which are threatened by plasma disruptions. A changeover from intact flux surfaces to chaotic magnetic field lines, typically referred to as stochastic fields in tokamaks, plays a leading role in triggering disruptions. A novel dual tangentially-viewing soft x-ray imaging system (dual-SXI) was developed in the DIII-D tokamak to diagnose the magnetic topology evolution across plasma disruption. The dual-SXI consists of duplicate tangentially viewing camera systems with identical views but toroidally 120° apart. Each visible camera observes the phosphor, which monitors filtered SX radiation via pinhole optics [1], as shown in Fig. 1. It allows differential imaging from two systems to extract nonaxisymmetric, nonrotating perturbations.

Mode locking, i.e., non-rotating magnetic islands, precedes the plasma disruption, where measurements show edge-locked island chains with multiple helicity with narrow widths appear between the outer separatrix of a large $m=2/n=1$ island (m and n: poloidal and toroidal numbers) and the last closed flux surface [2], as seen from Fig. 2(a). It shows good agreement with the synthetic images in Fig. 3(a1) and (a2). These narrow island chains govern the cooling process in the plasma peripheral region, which are initially well separated from the 2/1 island, leading to a quasi-stationary phase. After hundreds of *ms*, the island chains trigger thermal quench immediately after they start to overlap with the large 2/1 island, producing a broad stochastic layer deep into the plasma midradius. Plasma cooling, caused by the co-existence of multiple edge-locked island chains and the overlap, is successfully reproduced by the non-linear reduced Magnetohydrodynamic model TM1 [3].

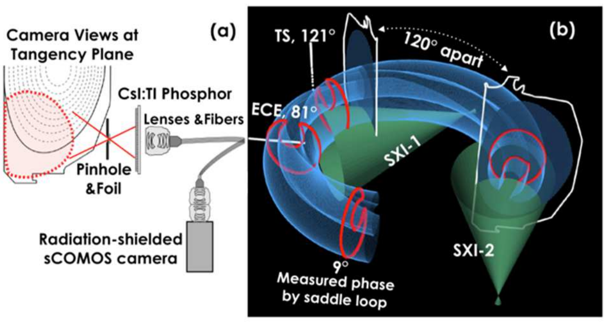

Figure 1 (a) Diagnostic principle of the dual soft X-ray imaging system. The soft X-ray is monitored by the CsI:TI phosphor, and the visible light is further collected through the fiber optics by the camera. (b) The identical cone-shaped views of the dual-SXI system in the DIII-D tokamak.

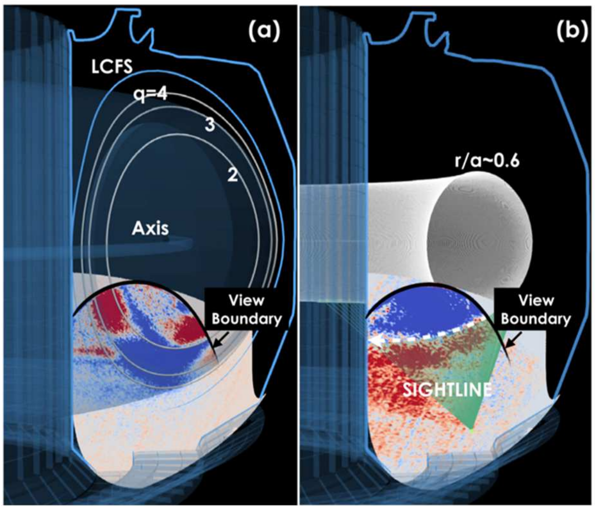

Figure 2 Differential images obtained by dual-SXI system at the tangent plane in R-Z coordinate (a) before the onset of the CQ and (b) at the initial phase of the CQ in shot 172102. The red/blue perturbation bands align with flux surfaces poloidally in (a) and toroidally in (b).

In the early period of current quench, a prompt transition from a dominantly stochastic field line state occurs and the plasma heals into a 3D helical equilibrium [4]. The dual-SXI system identifies it as a single helicity magnetic island of m=1/n=1 in the plasma core, as shown in Fig. 2(b), consistent with the synthetic image in Fig. 3(b1) and (b2) The electron cyclotron emission and Thomson scattering systems measure different helical phases of 1/1 islands, which agree with the measured 3D magnetic topology. A rapid increase of electron temperature is observed only inside the 1/1 island, indicating the presence of good flux surfaces inside island, but stochastic fields outside.

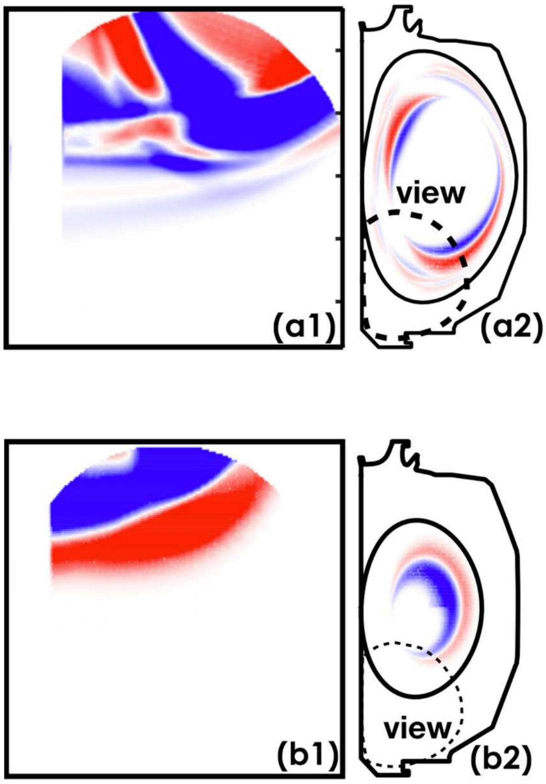

Figure 3 Synthetic images in (a1) using 2/1, 3/1 and 4/1 island chains given by (a2). The synthetic image in (b1) using the 1/1 island chain given by (b2). The color is linearly scaled. The last closed flux surfaces predicted by equilibrium code (EFIT) are depicted in (a2) and (b2) and the camera views at the tangency plane is represented by dashed curves

As a result, the plasma current termination or current quench process ceases [4], i.e. from a completed quench accompanied by a vertically unstable disruption to a rapid termination of current decay followed by a full recovery to its pre-disruption value. Runaway electrons are not generated, owing to the slow current quench and limited loop voltage increases. This observation implies prompt stochastic fields healing through the rapid non-linear growth of a magnetic island in the plasma core may provide a plausible path for a soft-landing scenario of tokamak disruption.

Based on these results, a novel emergency shut down method has been developed and tested in recent DIII-D experiments. MHD instabilities are excited to form a warm, helical core in post-thermal quench plasma using neutral beam heating and 3D fields [5]. It is observed that this soft-landing technique is particularly robust in the plasma with higher current and small inner gap to the wall. Development of a soft-landing scenario to achieve simultaneous mitigation of thermal quench and current quench is left as an important and urgent future work for the safety operation of the future fusion power plants.

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