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Disruptive behavior in the Compact Toroidal Hybrid torsatron-tokamak

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Understanding the control and avoidance of major disruptions in current carrying toroidal plasmas is important in mitigating the effects of such loss of confinement. Helical configurations with low toroidal currents are largely free of disruptions, and it has long been known that a low level of vacuum transform, $\iota_{VAC}(a) \approx 0.1$, confers some disruption immunity to current-driven toroidal discharges [1, 2]. Experiments on the Compact Toroidal Hybrid (CTH) torsatron are investigating avoidance of disruptions in Ohmically-driven, ECRH-generated plasmas in which the ratio of vacuum or external to total (external + Ohmic) transform can be lower than 10%. The minimum vacuum rotational transform in which helical discharges can be obtained in CTH to date is $\iota_{VAC}(a) \approx 0.04$. At or near these values, disruptions may take place when $\iota_{TOTAL}(a) \approx 0.5$ and strong MHD activity is typically observed. Disruptivity is noticeably reduced when the vertical position of the plasma is controlled to prevent or delay vertical displacement events. Interpretation of these results makes use of three-dimensional equilibrium reconstruction from magnetic diagnostics using the V3FIT code [3].

Introduction

Early stellarator experiments with toroidal current flowing in the plasma demonstrated that the occurrence of current-driven disruptions was eliminated if the vacuum rotational transform $\iota_{VAC}(a)$ at the plasma surface, i.e. the transform produced by the external currents of the stellarator coils at the plasma minor radius a, was greater than a threshold value of $\iota_{VAC}(a) \cong 0.14$ [1, 2]. These current-driven stellarator discharges were operated with a net transform of $\iota_{TOTAL}(a) \geq 0.5$ and could be generated without exciting an unstable external kink mode. Because of the need to reduce the consequences of major disruptions in ITER and future burning plasma

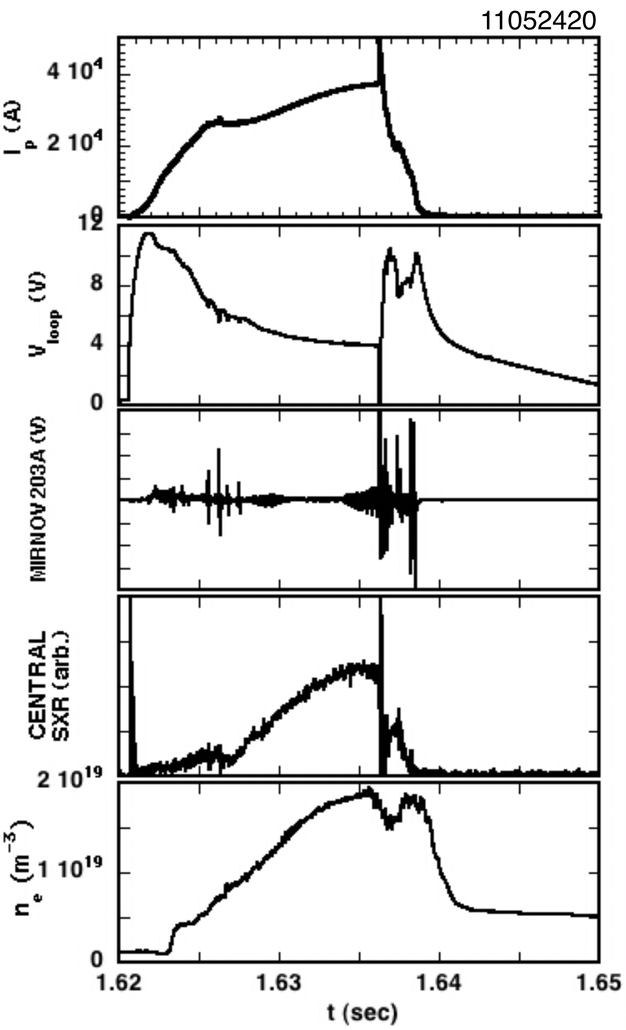

Figure 1. Evolution of plasma parameters for a low external transform plasma that disrupts. The disruption is preceded by growing m=2 and m=3 MHD oscillations as the edge transform approaches one half.

devices, this robust disruption resistance exhibited by the hybrid stellarator-tokamak configuration could have significant benefits in regard to disruption suppression for future experiments that employ such levels of 3D shaped magnetic fields.

Disruption avoidance experiments

Experiments are underway on the CTH device to investigate the causes and limits of disruption avoidance in hybrid stellarator-tokamak plasmas. The CTH experiment at Auburn University is a low aspect ratio ($R/a_p \le 4$) l = 2 torsatron with a vacuum rotational transform capable of being varied in the range $0.02 \le \iota_{VAC}(a) \le 0.4$ with auxiliary toroidal field coils. The shear of the vacuum transform (and the average vertical plasma elongation) is also variable with the use of quadrupole field shaping coils. Ohmic plasma currents up to I_p = 75 kA are induced in ECRH-generated stellarator target discharges using recently upgraded Ohmic heating circuitry. Disruptions can be generated in current-driven CTH discharges by exceeding a safety factor limit or an electron density limit, as in tokamaks. An example of a low external transform disrupting plasma is shown in figure 1. Furthermore, Ohmic plasmas in CTH have also been observed to be subject to vertical displacement events (VDE), as are also observed in elongated tokamak experiments. VDEs in CTH can lead to a disruption late in the discharge as the plasma minor radius shrinks due to contact with the upper limiter. However, disruptions of any kind are not observed if the vacuum transform

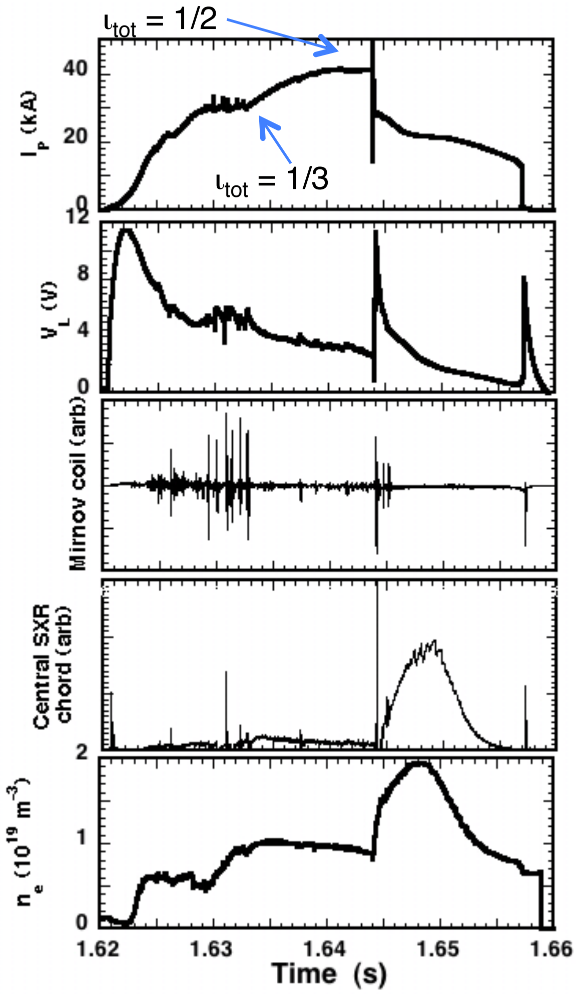

Figure 2. Evolution of plasma parameters for a low external transform plasma that disrupts. The disruption is preceded by growing m=2 and m=3 MHD oscillations as the edge transform approaches one half.

of the configuration exceeds a value $\iota_{VAC}(a) \approx 0.11$, more or less in agreement with earlier results from W7-A [1] and JIPPT-2 [2].

Depending on the magnitude of the applied vacuum transform, high-current discharges undergo an *n*=0 rigid, vertical drift (VDE). Higher elongation, lower vacuum transform plasmas are observed to have lower vertical stability in accord with theoretical predictions [4]. Recently, the *n*=0 vertical drift motion has been compensated for by energizing a set of radial field coils using a pre-programed current waveform. An example of the disruption of a well-centered discharge throughout its lifetime is shown in figure 2. As is seen disruptions still occur, in this case at $\iota_{VAC}(a) = 0.04$, but without complete collapse of the current channel. In some cases the plasma core is even observed to reheat and re-establish sawtooth activity after the partial collapse seen in figure 2 as the edge transform reaches $\iota_{TOTAL}(a) = 0.5$. An important point is that vertical displacement of the stellarator discharge complicates the understanding of the elimination of density and current-driven disruptions at low vacuum transform, particularly since a non-vertically symmetric 3D reconstruction procedure is not yet available to model these discharges properly.

MHD mode activity

An important measurement to aid in the understanding of the disruptive process and how it changes with the addition of vacuum transform is the structure of the MHD

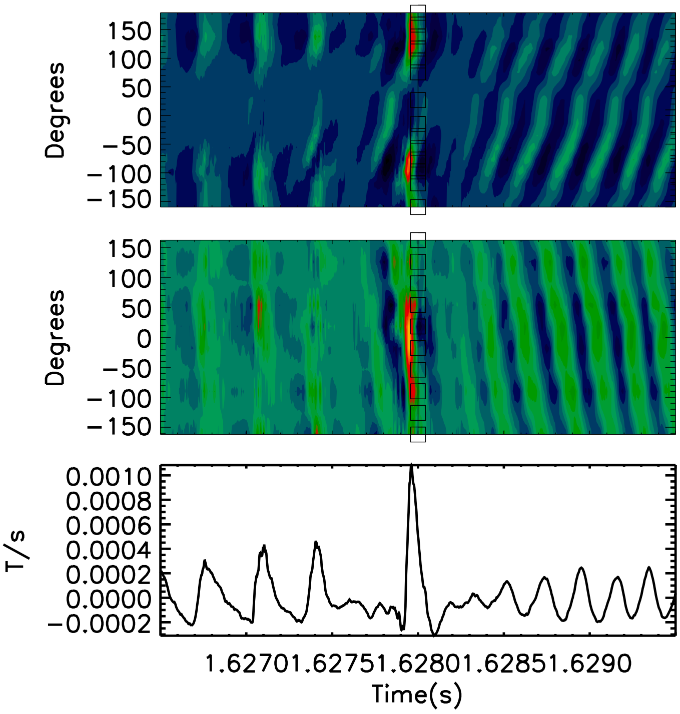

Figure 3. MHD fluctuations observed during the plasma current rise. An n=0 oscillating mode is seen that is poloidally localized to the inboard side of the plasma. After a minor internal disruption a rotating m=2, n=1 mode is then observed.

activity associated with the disrupting plasma. Also, it is of intrinsic interest to understand the MHD mode physics of 3D plasma configurations like CTH. Figure 3 shows the observed MHD activity during the current rise phase of a discharge. As low order rational surfaces reach the edge of the plasma, they typically clamp the plasma current to a fixed value for a brief period of time. Equilibrium reconstructions indicate that the current profile contracts during these episodes leading to peaked profiles later in the discharge.

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