Disruption trajectory studies on TCV: experiments and modelling

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1. Introduction

The sudden release of energy to surrounding structures makes disruptions [1] a threat for the integrity of present-day and future tokamaks. As a consequence, great attention is devoted to the experimental and numerical studies of such events, especially in terms of their possible consequences [2].

One of the strategies currently investigated for disruption mitigation in DEMO is the set-up of sacrificial limiters that can be possibly replaced in case of damage [3]. The effectiveness of this solution relies on the possibility of constraining the plasma-wall interaction at specific locations inside the vacuum chamber. This means, first of all, being able to forecast the plasma movement during a disruption and possibly to design configurations that drive the plasma evolution along prescribed trajectories.

Based on this motivation, during the recent experimental campaign carried out on TCV in the frame of the EUROfusion Medium Size Tokamak Task Force, dedicated experiments have been carried out, aimed at extensively studying the plasma trajectory during a disruption. The present paper reports the main results and is organized as follows: Section 2 illustrates the experimental strategy and the main experimental results, while Section 3 reports simulations and draws the conclusions.

2. Experimental strategy and results

The experimental strategy is based on three pillars. 1) Trigger the disruption starting from five different MHD equilibrium configurations: negative triangularity, “drop-like”, positive triangularity, Single Null, Double Null, see the examples in Figure 1. 2) For a given shape, trigger the disruption starting from configurations with different growth rates. 3) For a given configuration, try three different disruption triggering mechanisms: density limit, low boundary

q limit, loss of vertical stability. Specifically, the loss of vertical stability is induced by giving a kick with the in-vessel coils and then switching off the vertical controller, hence giving rise to a Vertical Displacement Event (VDE). The density limit disruption is triggered
by increasing the plasma density, via gas fuelling, intentionally above the Greenwald limit, while the low boundary q disruption is obtained by deliberately increasing the plasma current. Some snapshots during the events are reported in Figure 1, as reconstructed by LIUQE.
The disruption triggering mechanism does not seem to influence significantly the disruption trajectory, as shown in Figures 2a and 2b, displaying the position of the magnetic axis in the poloidal plane. Similarly, Figure 2c clearly shows that the growth rate does not affect the trajectory; the two configurations have also similar elongations (1.57 and 1.60 respectively) and the different growth rates have been obtained by suitably shrinking the plasma cross-section. Conversely, the starting equilibrium configuration – and triangularity in particular, intended as an average between upper and lower triangularity – has a strong influence on the trajectory (Figure 3a): positive triangularity configurations (including Single Null and Double Null) move towards the inboard side, while negative triangularity configuration consistently move outwards; drop-like configurations, with almost vanishing triangularity, tend to stay centred in the vacuum chamber.

3. Simulations

Simulations have been carried out with the CarMa0NL code [4]. First of all, we reproduce qualitatively the trajectory of the disruptive plasma during a loss of vertical stability, feeding the vertical control circuit with an arbitrary voltage kick.

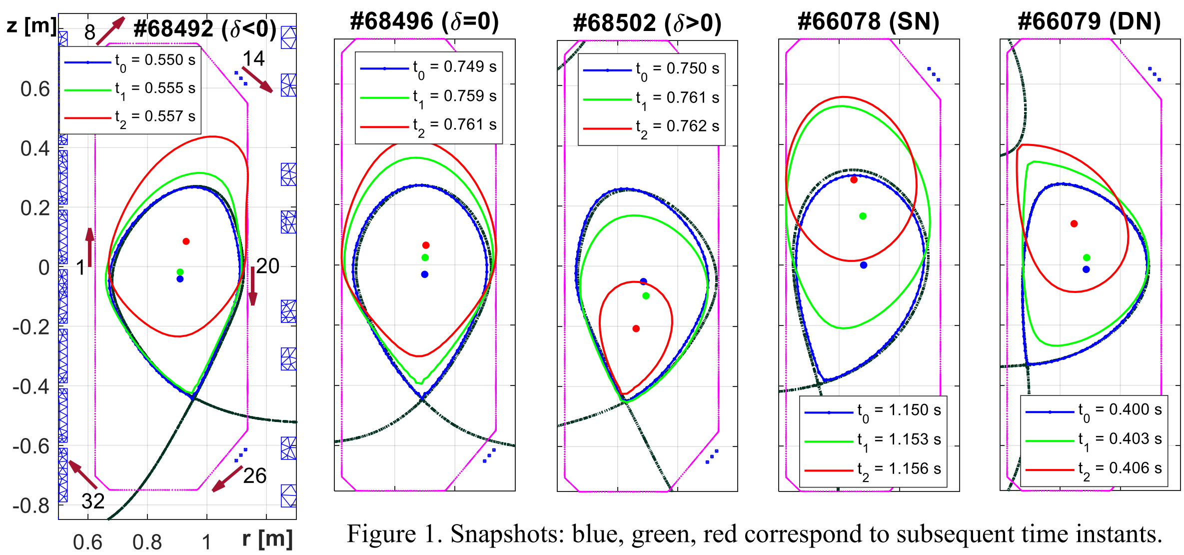
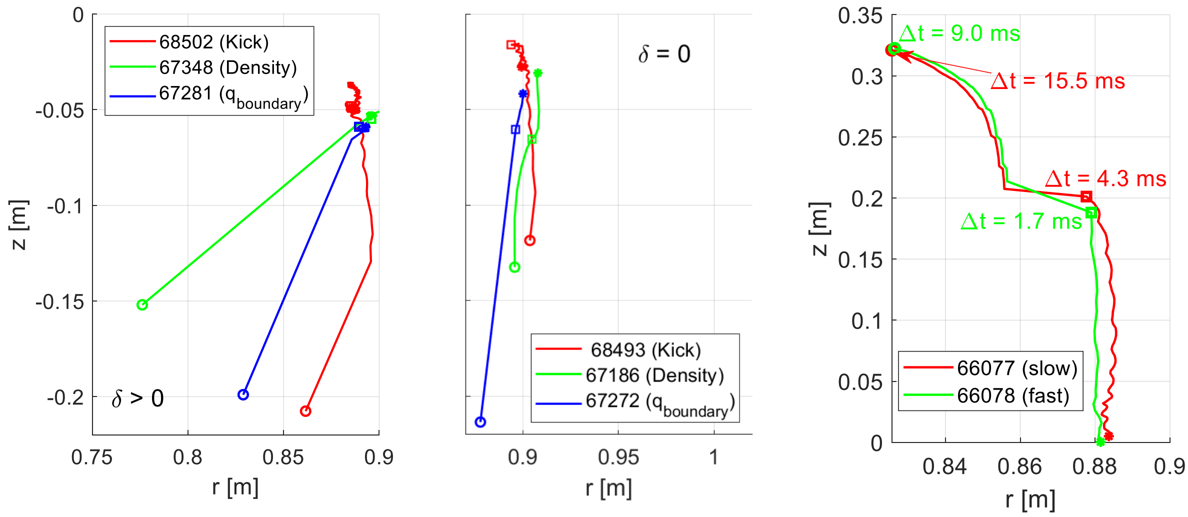


Figure 1. Snapshots: blue, green, red correspond to subsequent time instants.



(a) Positive Triangularity	(b) Drop-like	(c) Single Null
68502: $\delta = 0.25$	68493: $\delta = -0.01$	66077: $\delta = 0.31$
67348: $\delta = 0.25$	67186: $\delta = +0.01$	66078: $\delta = 0.32$
67281: $\delta = 0.23$	67272: $\delta = +0.00$	

Figure 2. Trajectory weak dependence on the disrutpion trigger (a) (b) and on growth rate (c).

The results (Figure 3) confirm the experimental dependence on triangularity, also in line with recent simulations carried out on COMPASS-U geometry [2, 5]. Moreover, a quantitative simulation of shot #66078 has been carried out, using as input the measured experimental plasma current and active coil currents and solving evolutionary equilibrium equations to get the simulated magnetic field measurements and plasma trajectory reported in Fig. 4. The position and of the orientation of the sensors are reported in Fig. 1. The LIUQE reconstructed time traces tend to deviate from experimental data when the effect of induced currents in the vessel becomes significant.

To sum up, disruption trajectory experiments have been successfully carried out on TCV for different configurations, demonstrating that trajectories do not depend on growth rate and show a rather weak dependence on the disruption trigger. Conversely, triangularity has a strong influence in determining the disruptive trajectory. Experimental findings have been confirmed by simulations, which hence provide a useful tool for the prediction of plasma trajectories in future devices.

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[3] F. Maviglia et al., *Fus. Eng. Des.* **158** (2020) 111713

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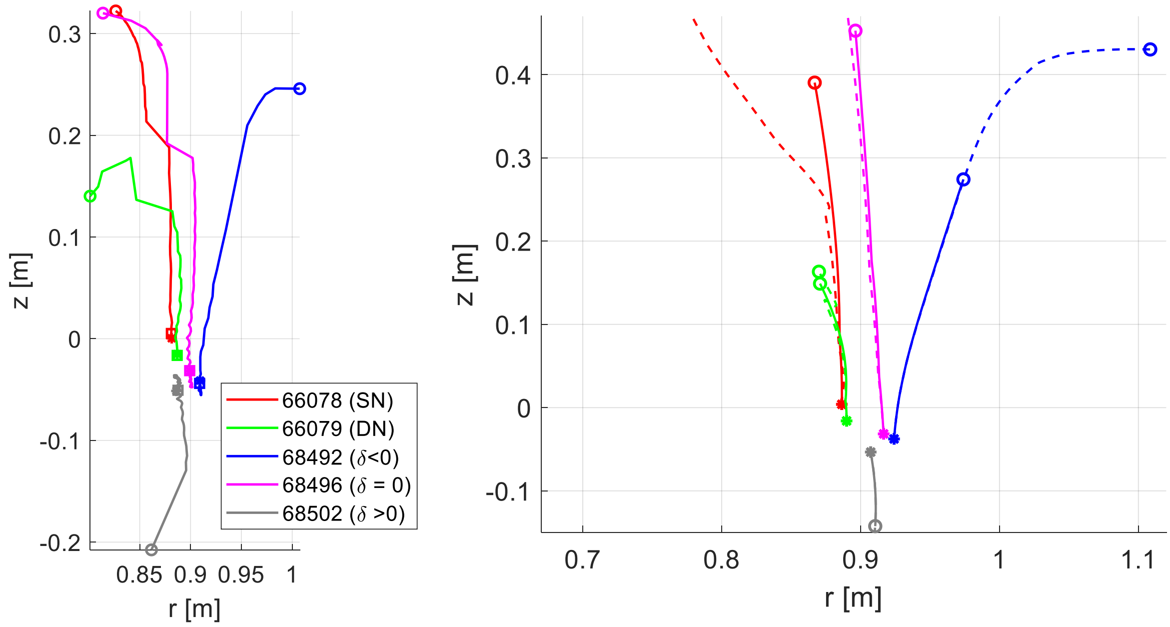

Figure 3. Effect of triangularity on plasma trajectory. On the left panel the LIUQE reconstruction is displayed. On the right panel we show qualitative results in CarMa0NL: solid lines are obtained keeping constant the total plasma current and CarMa0NL shape parameters; dashed lines correspond to the imposition of the plasma current quench.

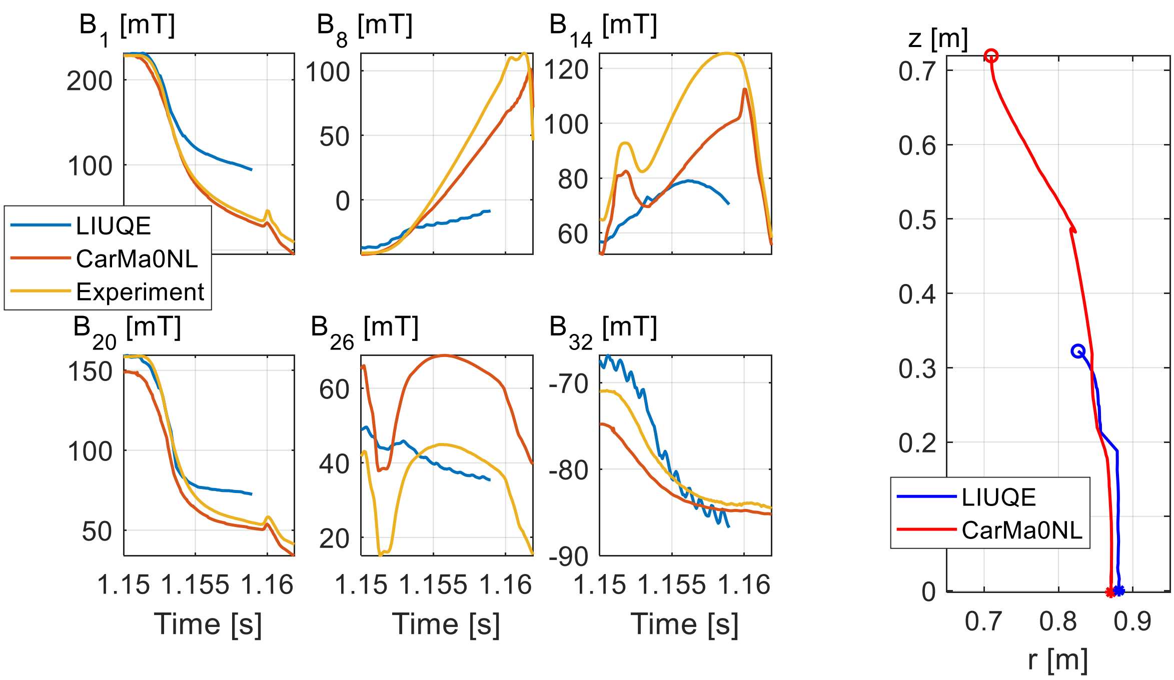

Figure 4. Comparison of #66078 simulation with experimental data. Left: experimental and simulated magnetic field measurements provided by sensors portrayed in Figure 1. Right: trajectory of the magnetic axis in the poloidal plane.