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Plasma Breakdown Studies on COMPASS

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The COMPASS tokamak (R = 0.56 m, a = 0.26 m) was transferred from Culham, UK in 2007 to the Institute of Plasma Physics, Prague [1]. For its re-installation, a new experimental hall, new power supplies and a new control and data acquisition system had to be designed and manufactured. In addition, computer controlled vacuum and gas - handling system were designed and put into operation and a proper vacuum (~ several times 10^{-8} mbar) was achieved. The tokamak vessel is conditioned by inductive heating and glow discharges in He are used to clean the first wall elements. The maximum available toroidal magnetic field is currently 0.9 T. The first plasma in COMPASS was observed in December 2008, the routine operation started in February 2009.

Basic diagnostics are available at the moment: selected magnetic sensors are used to measure the loop voltage, the plasma current and the plasma position. Furthermore, we use the 2 mm microwave interferometer, several detectors for monitoring of the plasma radiation (H_α and CIII lines, the impurity survey spectrometer, HXR) and selected Langmuir probes mounted in divertor plates. A fast camera, designed and manufactured by the Association EURATOM/HAS is installed to observe nearly the whole poloidal cross-section of the torus in visible range with submillisecond temporal resolution.

In this contribution we report results of initial studies of the start-up phase of the discharge. The following steps are taken before discharges:

- The vacuum vessel is pumped down to a pressure < 10^{-7} mbar, and baked up to ~ 120^{o} C.
- Glow Discharge Cleaning in Helium is applied for several hours (U_{GD} = 500 V, I= 0.5 A, p= 10^{-2} mbar).
- Pre-ionization of the working gas (Hydrogen) is performed by a UV lamp.
- Waveforms for working gas puffing are pre-programmed.
- Temporal evolutions of the toroidal, magnetizing and equilibrium fields are pre-programmed. Typical waveforms of the magnetizing (MFPS) and equilibrium (EFPS)

currents are shown in Fig 1. The shaping field is not currently used and the fast feedback system to control the plasma position is not yet operational.

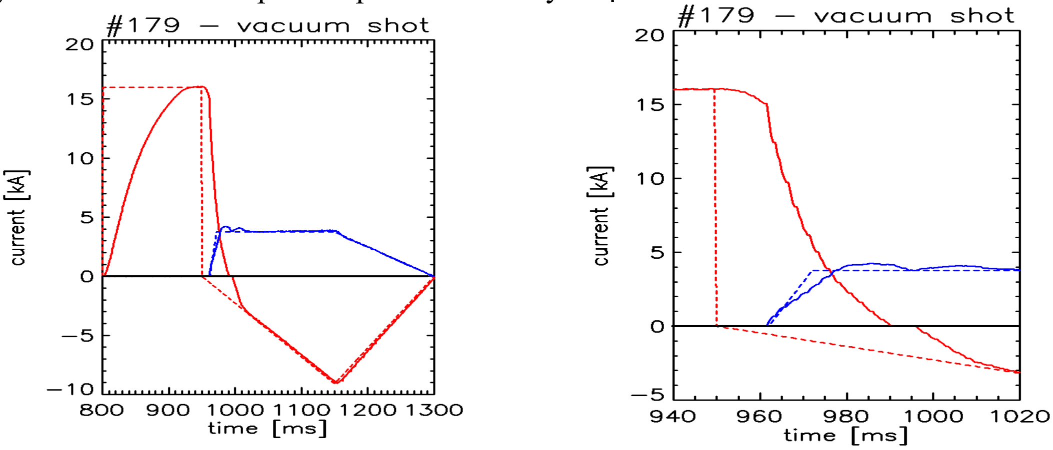

Fig 1: Left panel: *Temporal evolution of the MFPS (red) and EFPS (blue) currents in poloidal field coils. Dotted lines show the requested waveform, the full lines are the result of measurements. Right panel is a zoom of the time interval corresponding to the start up phase of the discharge. The loop voltage required for breakdown is generated during the fast ramp-down of I_{MFPS} current at t ~ 963 ms.*

It is seen from the Fig. 1 that the currents in the poloidal field coils follow the requested waveforms.

Figure 2 displays the evolution of a discharge with the best performance achieved up to now. This 70 ms discharge, stopped by a disruption, was stable with a flat top phase at Ip ~ 120 kA and the line average density ~10^{19} m^{-3}.

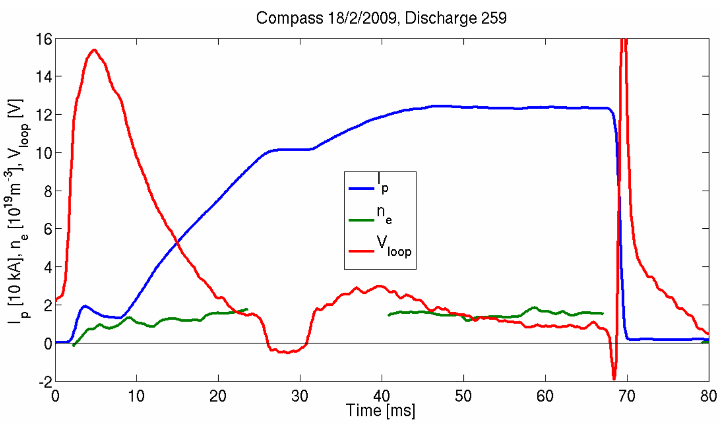

Fig. 2: *Temporal evolution of the loop voltage, plasma current and the line average density in the shot #259 of duration ~70 ms. B_T = 0.9 T.*

However, it has to be emphasized that discharges are not yet reproducible. Next figure shows a typical evolution of "bad" shots.

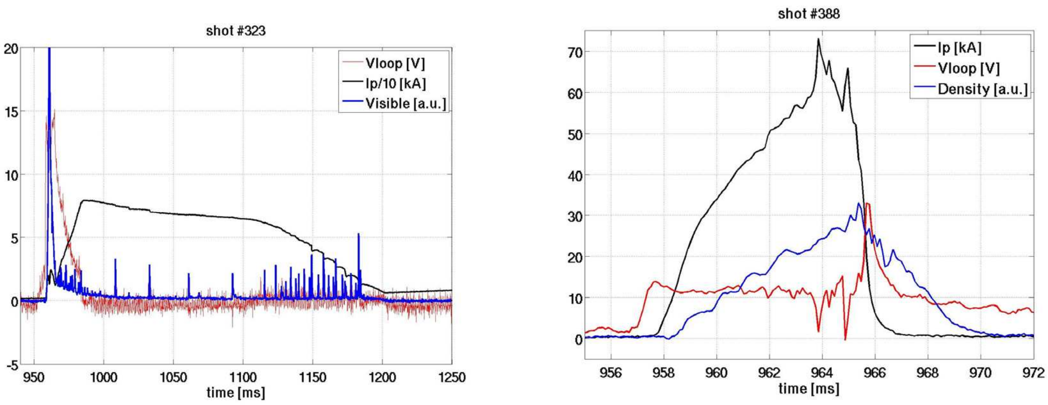

Fig 3. Left panel - *A low-density discharge with a significant fraction of runaway electrons. Right panel - A short discharge with an uncontrolled increase of plasma density.*

The left panel of Fig 3 shows the evolution of a "long" discharge (~240 ms). However, the toroidal current is mainly composed of a well-confined beam of runaway electrons. The spikes on the signal of the visible radiation indicate appearance of the anomalous Doppler instability followed by interaction of the runaway electrons with first wall elements and consequent enhancement of recycling. The right panel in Fig. 3 displays a discharge with a short ramp-up phase of the plasma current, possibly because of a wrongly pre-programmed equilibrium magnetic field and consequent enhanced recycling and uncontrolled increase of the plasma density.

It is evident that an efficient breakdown and a reproducible ramp-up of plasma current require an optimization. An example of such attempt is shown in Fig. 4, where the filling pressure of working gas is changing on a shot-to-shot basis changing the maximum magnetizing current I^{max}_{MFPS} in the range 8-14 kA**.** The aim of this scan is to find an optimum pressure window where the loop voltage is low but still sufficient for breakdown (to save voltseconds and reduce the production of runaway electrons during the breakdown phase). Simultaneously, we look for conditions at which the discharge is sufficiently long and the plasma current high enough (> 30-50 kA)**.** It has to be noted again that any feedback of the plasma position is not yet operational on COMPASS. The equilibrium current is just pre-programmed to start at t_{EFPS} = *961 ms* and ramps up with dI_{EFPS}/dt = *310 A/ms* to its maximum value I_{EFPS} = *4.8 kA*.

It is seen that, the loop voltage at the breakdown (the top panel) is predominantly determined by the maximum value I_{MFPS}, and its consequent fast ramp-down. The V_{loop} versus pressure dependence for each value of I^{MAX}_{MFPS} resembles the Paschen curve. It is seen that the V_{loop} can be reduced down to 10 V at I^{max}_{MFPS} = 8 kA, which is noticeably lower than the breakdown voltage achieved routinely on COMPASS-D at Culham (~15-18 V). However, the discharge duration is less than 10 ms and the maximum plasma current I_p <30 kA at these conditions.

The optimum pressure window (40-90*10^{-6} mbar of H_2) is marked in the figure by yellow shadowing. We see that the discharge duration is long enough (> 30 ms) to ramp-up the plasma current up to ~90 kA in this range of filling pressures.

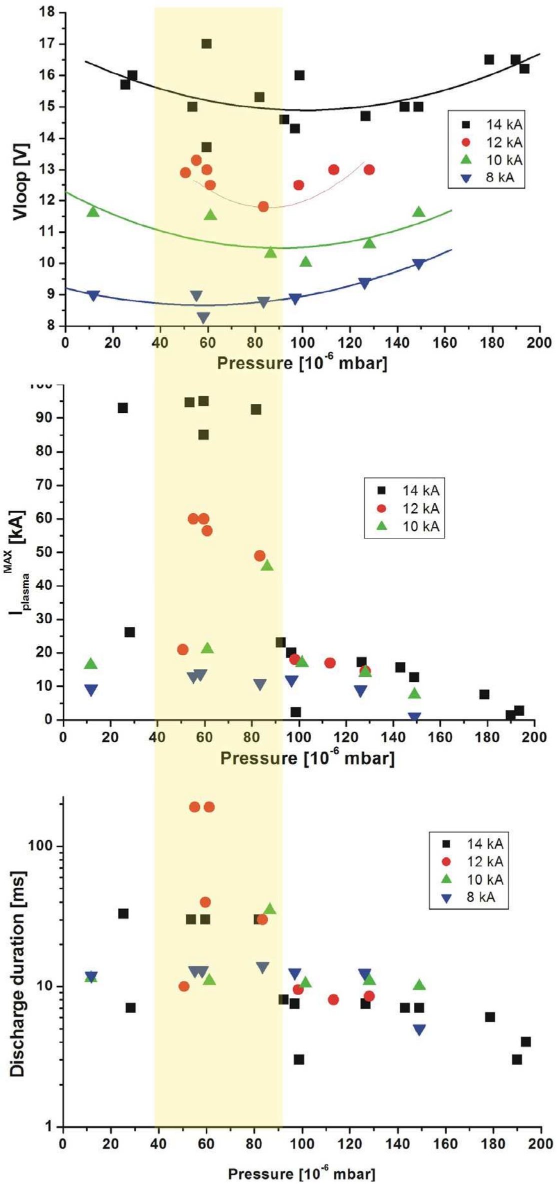

Fig. 4: *Dependence of the loop voltage at the breakdown, the duration of the discharge and the maximum plasma current on the filling pressure at different values of* I^{max}_{MFPS} *(# 473-515).*

Conclusions

To optimize the breakdown and the subsequent I_p ramp-up, we still have to:

- Operate at full values of the toroidal magnetic field B_T < 2.1 T with a feedback system for plasma position;
- Optimize the ramp-up of the vertical magnetic field during the start-up phase of the discharge;
- Modify the forming circuit for ramping down the magnetizing current to reduce rise time of the plasma current after breakdown.

In addition, improvement of reproducibility of the start-up phase of a discharge would require improved conditioning of the vacuum vessel and consequent reduction of recycling during the breakdown and the ramp-up phase. Baking and GDC should be operational for a longer time. It is also suggested to perform discharges in Helium.

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References:

[1] R Panek et al: Czechoslovak Journal of Physics, Vol. 56 (2006), Suppl. B, B125