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Hybrid scenario at high beta with mild MHD activity on MAST-U

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The possibility to develop a hybrid scenario at relatively high-beta values (β_N ~ 2.5-3.0) with mild MHD activity has been recently demonstrated at JET and proposed for the first operations of JT-60SA [1]. This contribution reports on preliminary investigation conducted on MAST-U, within the remit of the EURO fusion Tokamak Exploitation Package, to develop a high-beta hybrid scenario, optimizing the plasma current (I_p) ramp-up phase for q-profile tailoring and studying the effect of NBI timing and power on the evolution of the current profile and on MHD stability properties.

In the first part of experiments, dedicated ohmic test pulses have been performed to optimize the plasma current ramp-up phase to avoid Internal Reconnection Events (IRE), which cause drops in temperature and density [2], and to obtain a wide region of low magnetic shear in the plasma core, with a safety factor value $q > 1$ near the magnetic axis before the beginning of the I_p flat-top phase. To this purpose, a systematic approach has been followed, with a series of pulses with different dI_p/dt values (between 2 and 8 MA/s) during the ramp-up phase, up to reaching a plasma current flat-top of 750 kA, with a toroidal magnetic field $B_T = 0.6$ T (q_{95} ~ 5.6). The experiments confirmed the presence of IRE in pulses with higher I_p ramp-up rate (5-8 MA/s), as clearly visible in the temperature and electron density signals and in the SXR measurements. No IRE were observed in pulses with lower I_p ramp-up rate (2-3 MA/s), which are characterized by long-lived "snake" instabilities [3], clearly visible in the innermost lines of sight of the SXR and absent in the immediately outermost ones. This confirms the "internal" nature of the mode and provides a first estimation of $q = 1$ location. Saw-teeth are observed after the “snake” instabilities. A preliminary study on the effect of a current "overshoot" on the q-profile shape has also started, by means of lightly perturbative MSE measurements, although shape control issues led to the decision to postpone further studies.

The information about the highest I_p ramp-up rate not leading to any IRE (~ 3 MA/s), and the $q = 1$ arrival time in the ohmic test pulses have been utilized in subsequent experiments, aimed at optimizing the timing and the power of the NB injection to obtain relatively high-beta plasmas with mild MHD. As a first step, a systematic approach has been followed to determine the best timing for the beam with on-axis deposition, with a series of pulses with $I_p = 600$ kA, $B_T = 0.6$ T (q_{95} ~ 7.0), $P_{NBI} = 1.6$ MW and different NBI start-times in the I_p flat-top phase, to slow down the current diffusion starting from different q on-axis values and possibly avoid sawtooth activity. 2/1 NTM have been observed in case of early NB injection, whilst good confinement properties have been obtained by injecting the NB power slightly before the expected $q = 1$ arrival time in corresponding ohmic test pulses, with sawtooth activity occurring during the heated phase and a mild 3/2 NTM destabilized at β_N ~ 2.6 with moderate effect on confinement (see Figure 1), in agreement with previous observations on other devices, such as TFTR [4], DIII-D [5], and JET [6]. The destabilization of a 2/1 NTM, with a strong effect on confinement, is observed in the second half of the pulse, probably associated with the residual plasma current diffusion [7].

A further scenario optimization, possibly avoiding sawtooth activity during the pulse, has been proposed, by injecting more power by means of a second beam (with off-axis deposition) to further slow down the current diffusion or by modifying the density in the initial phase of the pulse to allow an early power injection without destabilizing a 2/1 NTM.

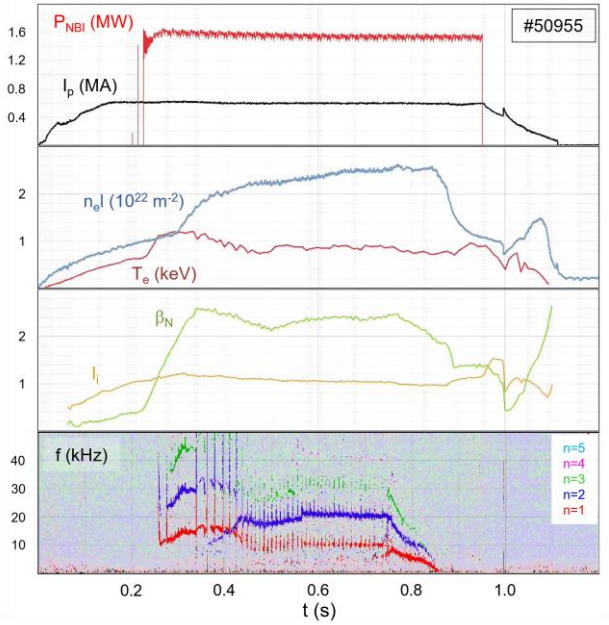

Figure 1. From top to bottom: plasma current and NBI power, line-average density and core electron temperature, normalized beta and internal inductance, spectrogram from magnetic pick-up coil array.

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