INVESTIGATION OF THE MAGNETIC FLUX PUMPING EFFECT IN MAST UPGRADE

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Development of high-performance plasma scenarios that can achieve steady state operation at high plasma beta, and therefore high fusion power, is of great importance to the success of future power plants. Spherical, low aspect ratio tokamaks naturally operate at high plasma beta and so are an attractive concept to pursue. A new 'flux pumping' plasma scenario has emerged, whereby specific MHD modes can anomalously re-distribute current away from the plasma centre, leading to a sawtooth-free, stationary plasma scenario [1-5]. This could be a potential candidate scenario for future devices such as ITER or DEMO, however access to this regime requires a high plasma beta. Investigations on the MAST Upgrade (MAST-U) tokamak attempt to establish a flux pumping scenario. Combining both on and off-axis neutral beam injection (NBI) in H mode plasmas often leads to a sawtooth-free, high beta plasma scenario that maintains a stationary q profile and qmin~1, hallmarks of the 'flux pumping' regime.

MHD such as fishbones [2] or the helical core mode [3] induced either by external field coils [4] or m/n = 2/1 tearing modes [5] have been shown to drive this flux re-distribution. In almost all instances where magnetic flux pumping is observed on MAST-U, a low frequency m/n = 2/1 tearing mode is sustained, as shown in Fig. 1, and at the q = 1 arrival time a stationary q profile is measured using a motional Stark effect constrained equilibrium reconstruction as seen in Fig 4 [6, 7]. Ideal MHD modelling in the no wall limit using MISHKA [8] indicates an increase in the n = 1 growth rate just prior to the start of flux pumping, which provides evidence that a helical core mode is also present. These findings are consistent with the tearing mode induced helical core observations as described in [5]. One key distinction is that there is no stationary 'flux pumping' phase, as shown in Fig 3, when using solely on axis NBI injection, and when chirped modes or a helical core mode is present without a tearing mode. Comparison of the magnetic shear s = r/q dq/dr shows that in the flux pumping case, a q profile with zero central and positive off-axis magnetic shear is maintained, compared to sustained negative magnetic shear (q0 > qmin) in the non-flux pumping case. Further experiments look to quantify the critical amplitude of the helical core mode necessary to drive the 'MHD dynamo' effect [2].

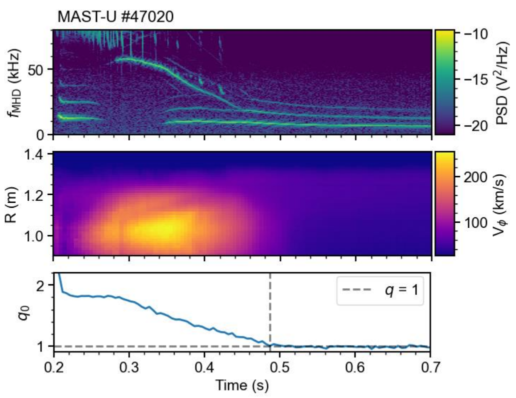

Fig 1. a) Magnetic Omaha probe spectrum for MAST-U pulse #47020. b) Plasma rotation velocity measured by the charge exchange recombination spectroscopy (CXRS) diagnostic [10]. A decrease in the rotation is measured at the q = 1 arrival time, co-inciding with the onset of stationary q. c) q0 derived from equilibrium reconstruction constrained by magnetics and MSE measurements.

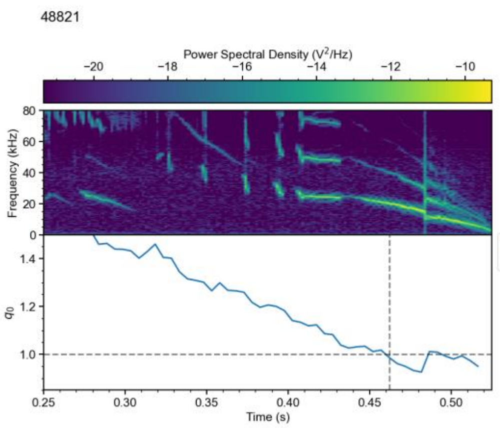

Fig 2. a) MHD spectrogram of MAST-U pulse #48821, showing the presence of chirped modes, then a helical core mode prior to a large sawtooth. In this instance, the q profile continues to evolve during the helical core phase, indicating that flux pumping does not occur.

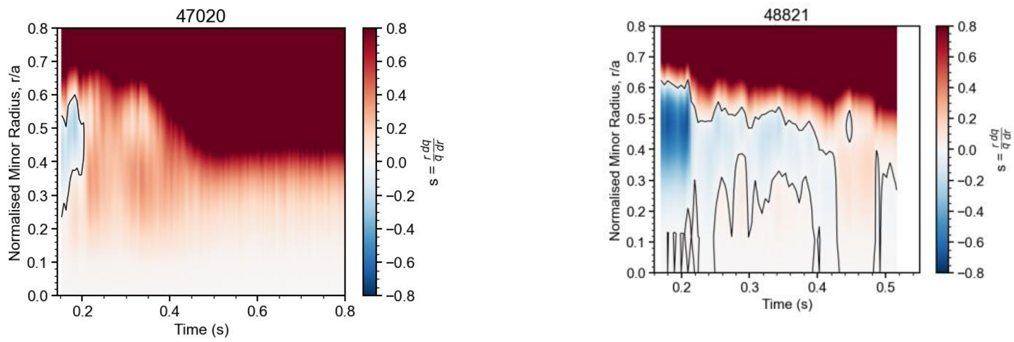

Fig 3. Evolution of the magnetic shear s = r/q dq/dr in MAST-U pulse #47020 (left) and #48821 (right). Black contours indicate regions of s < 0. In MAST-U, a stationary q profile and no sawteeth are observed when s >= 0 .

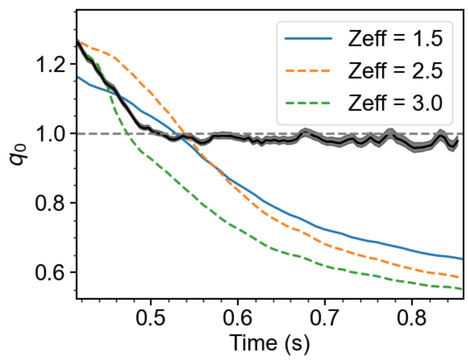

Fig 4. Evolution of q0 from a magnetics and MSE constrained equilibrium reconstruction, compared to predictive TRANSP [9] runs, scanning in flat Z effective values.

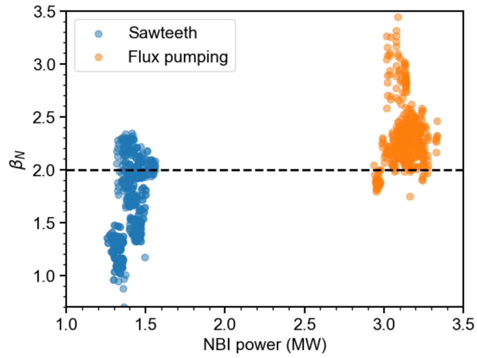

Fig 5. Normalised beta vs NBI injected power for 44 MAST-U pulses. Pulses which contain saw teeth use only on axis NBI at lower power levels (blue circles), and flux pumping is observed at high injected power with both on and off axis NBI (orange circles).

Analysis across multiple discharges with and without magnetic flux pumping is performed to identify an experimental beta threshold associated with flux pumping. Results thus far indicate that MAST-U plasmas readily access the flux pumping regime at lower normalised beta $\beta_N \sim 2$ compared to conventional aspect ratio machines.

ACKNOWLEDGEMENTS

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