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First results from MAST

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The MAST device now operational at Culham is essentially a scaled-up version of the successful START experiment but with good vacuum conditions, feed-back controlled power supplies, and having a plasma cross-section comparable to ASDEX-U and DIII-D. A schematic of MAST is shown in Fig 1.

The plasma physics programme commenced in December 1999 with tests of the novel merging-compression technique pioneered on START, which utilises a special feature of the START and MAST designs, namely that the PF coils are inside the vacuum vessel as shown in Fig 1. The process involves the use of flux from the large-radius P3 coils, rather than the central solenoid, to initiate the plasma. Spherical Tokamak plasmas at currents of ~ 400kA are routinely obtained by this merging-compression technique. The central solenoid can then be used (as on START) to maintain or increase this initial plasma current, and plasma ramp rates of up to 13MA/s at a loop voltage of 7V can be sustained. Double null divertor (DND) plasmas of up to 1MA have been obtained using approximately one-half of the available solenoid flux swing.

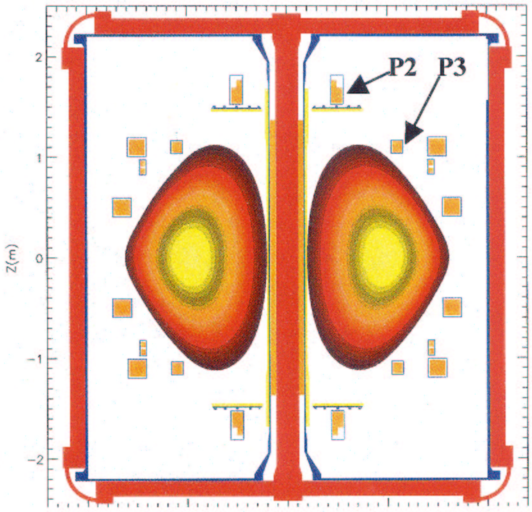


Fig 1 Cross-section of MAST, showing the (internal) PF coils

Operating Parameters	Design Range	Shot 2482
Major radius, R (m)	0.7 – 0.85	0.77
Minor radius, a (m)	0.5 – 0.65	0.53
Plasma current, I_p (MA)	≤ 2	1.05
Aspect ratio, A	≥ 1.3	1.45
B-field , B_0 (T)	≤ 0.6	0.44
P_{AUX} (MW)	≤ 6.5	0.7
Pulse length (s)	≤ 5	0.12
n_e (× 10^{19} m^{-3})	1 – 18	2.6

Table 1. Main operating parameters of MAST. Parameters for shot 2482 at time 100 ms are given in the right hand column

Parameters of a 1MA discharge shown in Figs 2,3 are listed in Table 1. This discharge used ~700kW of NBI (H→D) using one of the two beamlines on loan from ORNL (eventual injection power is 5MW for deuterium injection).

Central electron temperatures in Ohmic plasmas (measured with the 30-point Thomson scattering diagnostic) are typically ~800eV and ion temperatures (measured by a Neutral Particle Analyser and Doppler spectroscopy) ~400eV but both can exceed 1keV under NBI, as for example in #2482 (Fig 3).

Boronisation, via addition of trimethylated boron to a helium glow discharge, is very successful, reducing both high and low Z impurities by typically a factor 10.

A feature of START was the high neutral density in the vacuum vessel and in the plasma edge. This caused high NBI losses and enhanced charge exchange losses. H mode was achieved on START [1] but at power levels an order of magnitude higher than predicted by the usual threshold scalings. Measurements of the neutral density on MAST

[2] indicate a reduction by a factor ~ 40 compared to START, mainly due to the increased particle confinement time on MAST. It is encouraging that immediately following the first boronisation on MAST, ELM-like phenomena were observed in Ohmic and NBI heated DND plasmas.

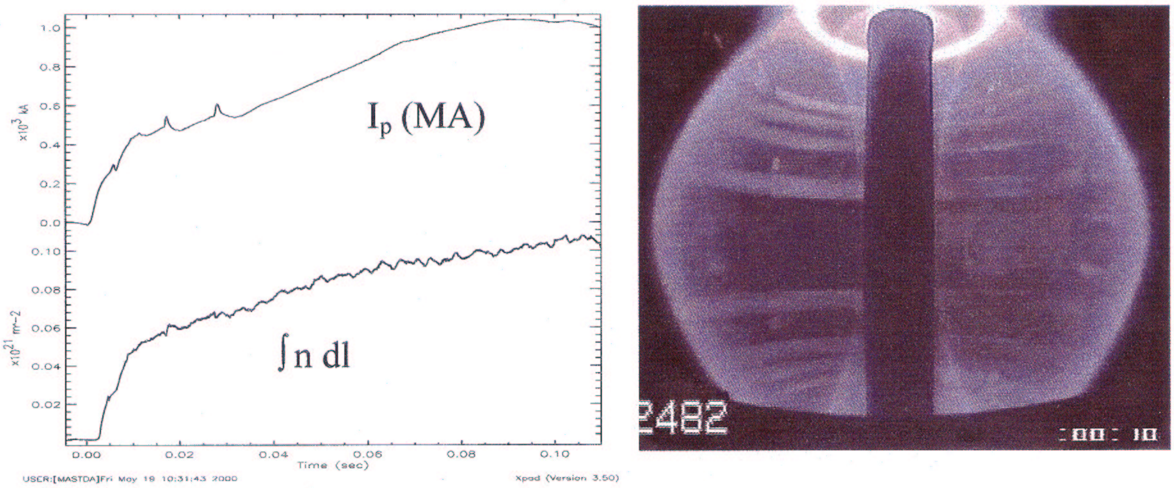
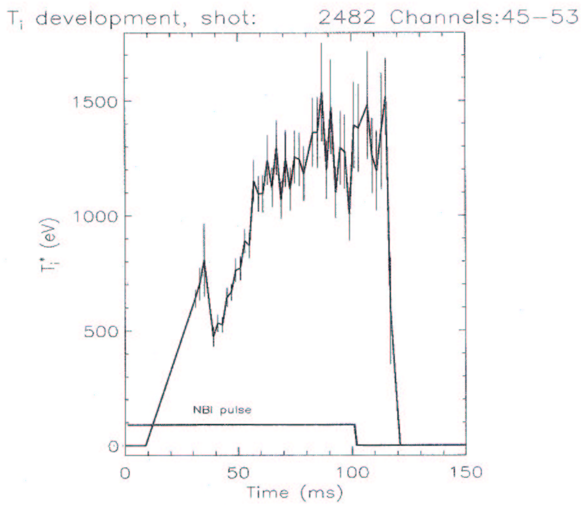


Fig 2 Plasma current, line integral density and CCD image of first 1MA plasma on MAST, May 2000. The CCD image is taken at time t=0.1s



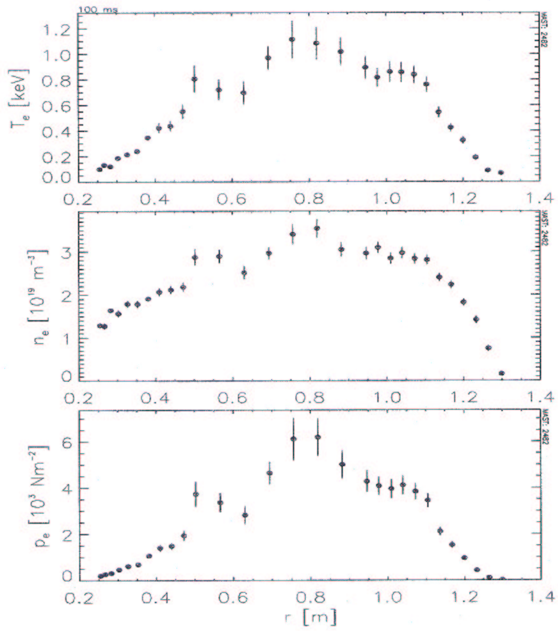


Fig 3 (left) Profiles of electron temperature, density and pressure obtained from Thomson scattering at time 0.1s
(above) ion temperature indicated by NPA exceeds 1keV in shot 2482

First clear H-mode operation was achieved in #2698 (8^{th} June 00) with ~500kW of NBI, when the usual signatures of L-H transition were observed, including a spontaneous rise in density, and the occurrence of ELMs and ELM-free periods (Fig 4). The plasma current in this shot was ~500kA.

Evidence of heating has also been observed in low density plasmas with ~0.5 MW of 60 GHz Electron Cyclotron Resonance Heating. Emission that is consistent with Electron Bernstein Wave emission via B-X mode conversion and tunnelling has been observed with an EBW Radiometer, indicating possibilities for EBW heating via X-B mode conversion [4].

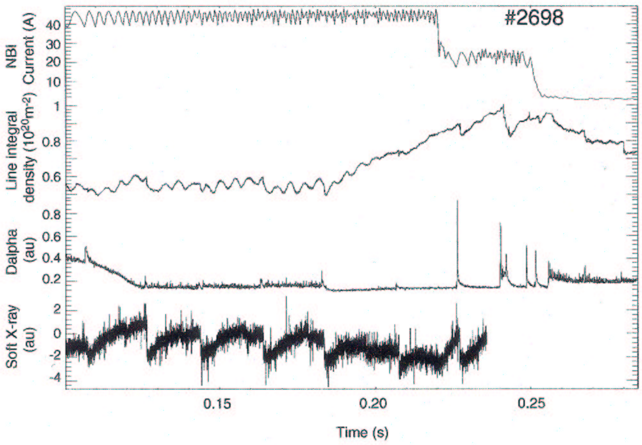
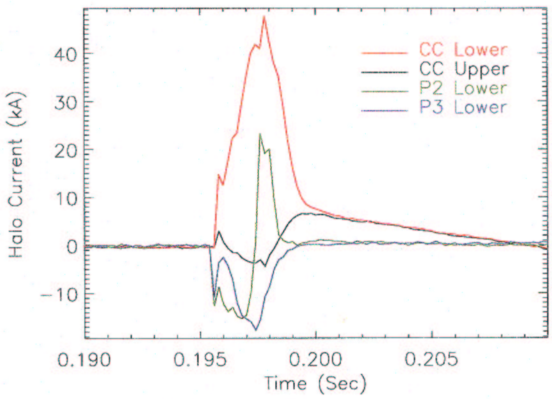


Fig 4 NBI current, line integral density, Dalpha and SXR signals showing L-H transition, large ELMs, and H-L transition after NBI ends

MAST is equipped with a comprehensive set of halo current detectors comprising 175 individual coils. These are divided into three groups; a set of full Rogowski coils around all the P2/P3 coil supports and around the top and bottom of the centre column; arrays of partial Rogowski coils included in the P2 shield to measure radial and toroidal variations in halo currents; and bands containing 12 B_{tor} pick-up coils fixed at four heights on the centre column allowing toroidal and vertical variations in halo current to be determined.

The first few months of plasma operations has provided a large amount of data [3] at plasma currents up to 1MA by enforcing a vertically unstable field. This has produced useful data to develop an understanding of forces due to halo currents in an ST, both to extend the tokamak database and in particular to assess the feasibility of operating MAST up to its eventual design plasma current of 2MA.

Figure 5: Total halo currents measured in P2/P3 supports and centre column for a downwards VDE, I_p~ 390kA (shot 2223)



Results indicate that for low aspect ratio plasmas at high plasma current, halo currents are less than 20% of the plasma current and the degree of asymmetry is low (less than 30%). This confirms results from START and CDX-U that halo currents are relatively low and symmetric in the ST.

In the MAST shot shown in Fig 6, the Greenwald density is exceeded; the density rise is terminated by an internal reconnection event (IRE), which, as usual in spherical tokamaks, redistributes the plasma internally, but does not lead to a termination of the discharge. In other discharges at higher plasma current, MARFEs have been observed as the Greenwald limit is approached.

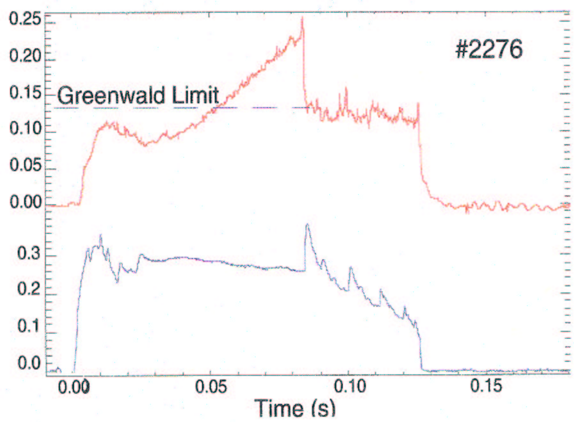


Fig6 In shot # 2276 , with plasma current ~200kA Greenwald density is exceeded by a factor ~1.8

Measurements of target parameters in MAST DND plasmas have been made using arrays of Langmuir probes across the strike point regions [2]. A clear in/out asymmetry was observed. All the plasma parameter scale lengths were increased on the outboard side as a result of strong flux expansion. The peak power density at the inner strike point is about 4~5 times higher (~1 MWm^{-2}) than at the outer strike point for the Ohmic plasmas considered, but with a strike point width nearly 10 times as narrow (~1.5cm).

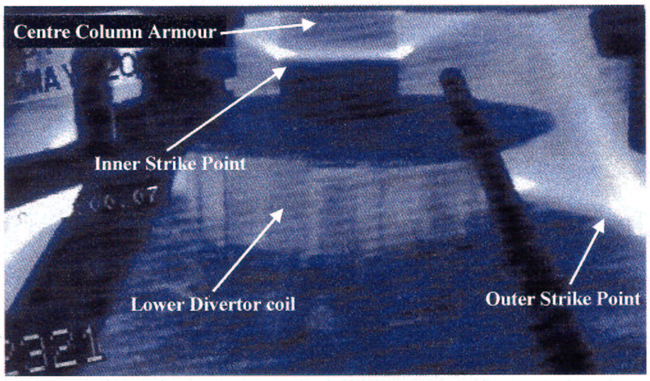


Fig. 7 Visible light image for Ohmic shot 2321 showing lower inner and outer strike points at time 140 ms.
The inboard strike points fall on the ~40 cm diameter centre column. This is protected by graphite tiles. The outboard strike points fall on a series of radial graphite ribs on the floor of the vacuum tank, one of which is installed with an array of 90 flush-mounted probes, spaced 10mm apart.

The total power incident on the targets has also been calculated from the probe data, and again a strong in-out asymmetry was observed. The ratio of the average power to the inboard targets to the average power to the outboard targets was ~1:6.5. This exceeds the ratio of ~1:3 for the inboard and outboard separatrix surface areas. About two thirds of the power entering the SOL reached the target compared to one third on START (the difference probably arising from higher charge exchange losses in START). Work is now on-going to derive relationships between the edge plasma parameters and allow extraction of cross-field transport coefficients, which may be significantly different from those in the SOL of conventional devices as a result of strong divertor throat mirrors and large ion Larmor radii in the ST.

Summary

Initial operation of MAST has been very successful. Spherical tokamak plasmas of over 400kA can be produced without use of the central solenoid flux; and application of the solenoid can then ramp the current up to over 1MA. The neutral density in the tank and the plasma edge is some 50 times lower than in START, and mega-ampere plasmas have central temperatures ~1keV. Both NBI and ECRH auxiliary heating has been demonstrated, the NBI producing significant heating of both electrons and ions and providing access to H-mode operation. High densities exceeding the Greenwald density can be achieved. Studies of the halo currents induced by forced VDEs confirm results from START and CDX-U that these are lower than in conventional tokamaks, and first results from divertor loading confirm results from START that most of the power flows to the outboard strike points. Rapid progress should now be possible on the twin objectives of MAST, namely to clarify tokamak physics and to explore the potential of the ST as a future fusion device.

References

[1] A. Sykes et al, Phys Rev Lett 84 (2000) p495
[2] G. Counsell, this conf
[3] R. Martin , this conf.
[4] V.Shevchenko, this conf.

Acknowledgement

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