Plasma Configurations

Figure 2: (from left) David Pretty, David Oliver, Santhosh Kumar, John Howard and Boyd Blackwell

The H-1NF is uniquely equipped to study magnetic configurations because of its combination of precisely controllable power supplies, the flexible coil set and the permanently installed wire-tomography mapping system. This precision and flexibility in magnetic configuration make H-1 ideal for magnetic island studies, exploring the range of magnetohydrodynamic (MHD) instabilities appearing in H-1, and mapping out their dispersion relations.

MHD Instabilities

Magnetic fluctuations in the range 1-200kHz are observed in H-1 over a wide range of configurations, when plasma is produced by RF heating (7MHz, 50-100kW).. Typically gas mixtures of hydrogen and helium or deuterium are chosen to optimise plasma production by hydrogen minority heating and to enable spectroscopic diagnostics. Signals range from highly coherent, often multi-frequency in sequence or simultaneously, to approaching broad band. The phenomenon is typical of toroidal confinement devices, and because plasma density tends to scale as the square of the magnetic field, the frequencies are similar across a range of devices, extending even to fusion reactors. The instability is particularly important in fusion reactors, as the correspondence between the fusion alpha particle velocity and the Alfvén velocity provides a channel for significant energy transfer into the instabilities, and back to the alphas, possibly affecting their confinement. As the power into the alpha particles is the main source of energy to sustain the plasma, such instabilities could prevent the achievement of a “burning plasma”.

Classification by Data-Mining

The two 20 coil magnetic probe arrays, the flexibility of H-1 and the high repetition rates provide a challenging quantity of data – measured in gigabytes. To process this, data mining techniques enable automated processing using Fourier and SVD techniques, in the time domain and in space respectively. This reduces the multi-channel timeseries data to a much smaller set of “fluctuation structures” on a much coarser time grid, characterised by a dominant frequency, amplitude, and relative phase of magnetic probe channels. Clustering data with similar relative phase difference is expected to isolate various mode number combinations, as demonstrated in Figure 3. The different colours represent different clusters, and

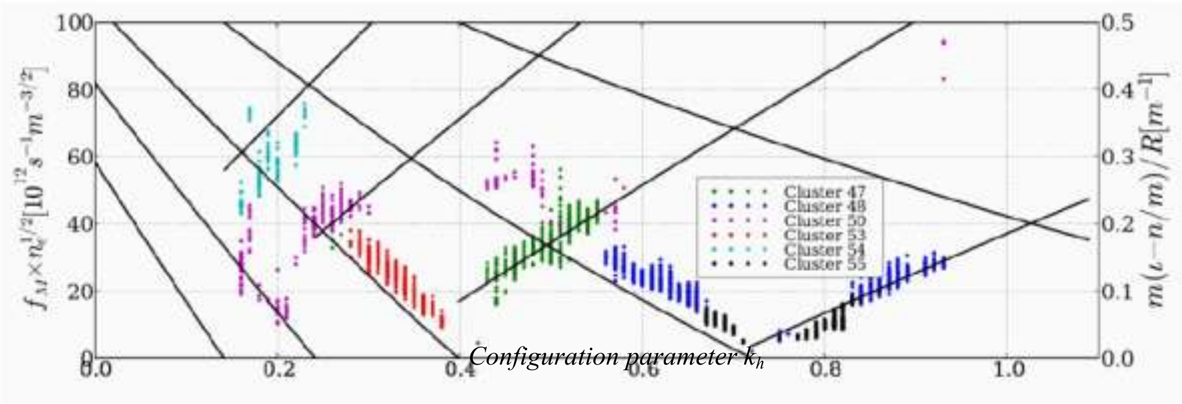

Figure 3: Experimental points obtained from data mining are compared with dispersion relations for Alfvén modes for various mode numbers corresponding to near-resonant values.

show successful classification of the different mode numbers. In the region near $\kappa_h \sim 0.7$, the black and blue points are probably the same mode number (n=4, m=3), and the split into two clusters might be explained by the tendency towards sound mode nature at lower frequencies.

The lines show the Alfvén continuum dispersion for the (simplified) cylindrical approximation. The lines approach zero and then increase as the wave nodal lines become close to being parallel with magnetic field lines ($k_{\|} \sim 0$); that is, the mode structure is "resonant" with the magnetic field structure.

Applications of Data-Mining to other Devices

We have been invited to apply the ANU analysis technique to data from all the leading stellarator experiments, and to the leading Japanese tokamak, JT-60U. Mr. David Pretty extended his thesis work by implementing a new version of the data mining technique in an open-source format to be more flexible and readily adaptable to different data systems. The new implementation has already been interfaced to H-1, Heliotron-J and TJ-II data, and example data and analysis into mode numbers are shown in Figures 4 and 5 respectively. Heliotron-J spectra are typically more complex because of the powerful energy source in the form of neutral beam injected ions, which match in velocity to the Alfvén speed. The plasma shape in Heliotron-J is closer to circular than the crescent shape of H-1 and provides an interesting comparison.

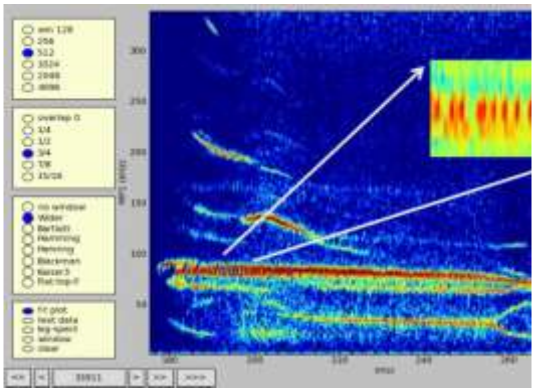

Figure 4: The complex spectrum of MHD activity

A collaboration between C. Nührenberg of MPIPP Greifswald, B. McMillan of CRPP Lausanne, R. Dewar, M. McGann and M. Hole of the ANU Department of Theoretical Physics, and B. Blackwell and J. Howard is comparing the these experimental observations of MHD activity with eigenvalue calculations using the CAS3D code.

Magnetic Island Studies

The accuracy of the H-1 configurations, mapping apparatus and the corresponding magnetic model described in previous reports provides an excellent foundation for studies of the effects of magnetic islands on plasma.

The iota ~3/2 configuration was chosen because the islands inherent in the shape (elongation/indentation) of the heliac, are large enough that an effect could be expected, but not so large as to totally destroy confinement. Experiments in the vicinity of iota ~3/2 were performed in Argon plasma over a range of parameters, and do not show any clear degradation in confinement or any noticeable features at the island position (δ), as measured by Langmuir probe estimates of density and temperature. However, for lower neutral densities, there is a small increase in confinement within the island (Fig. 6), and a

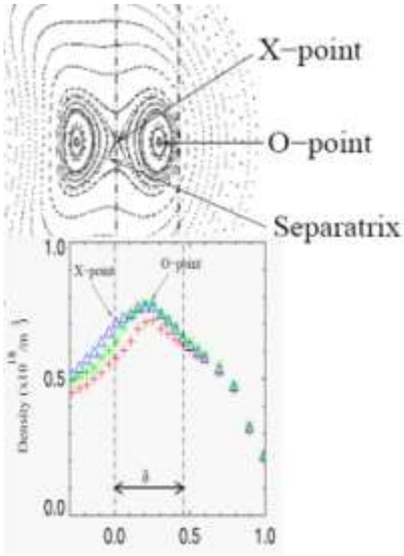

Figure 6: Plasma density is peaked near the O-point of the outer island. The extent of the island is marked δ.

steepening of the potential profile in the vicinity of the core. Investigations into similarity with "core electron root" enhanced confinement are ongoing.

Alfvén Spectroscopy

Combining electron beams techniques with MHD observations, the excellent agreement of dispersion with theory allows observations to be used to diagnose plasma conditions ("Alfvén Spectroscopy"). If iota is inferred from the Alfvén mode frequency measurements, the agreement is very good (δƚ/ƚ ~0.4%) when compared to direct electron beam measurements at low magnetic field. Thus we have a way to measure iota in the presence of plasma. Agreement was found to be even better when the mapping system was upgraded to allow scans fast enough to allow partial imaging at full operating magnetic field. This showed a small change in iota due to helical distortion of conductors under the magnetic force loading, which when extrapolated to the conditions of Fig. 7c, reduces the discrepancy to δƚ/ƚ <0.2%. This confirms the potential of this technique in measurement of rotational transform in the presence of plasma.

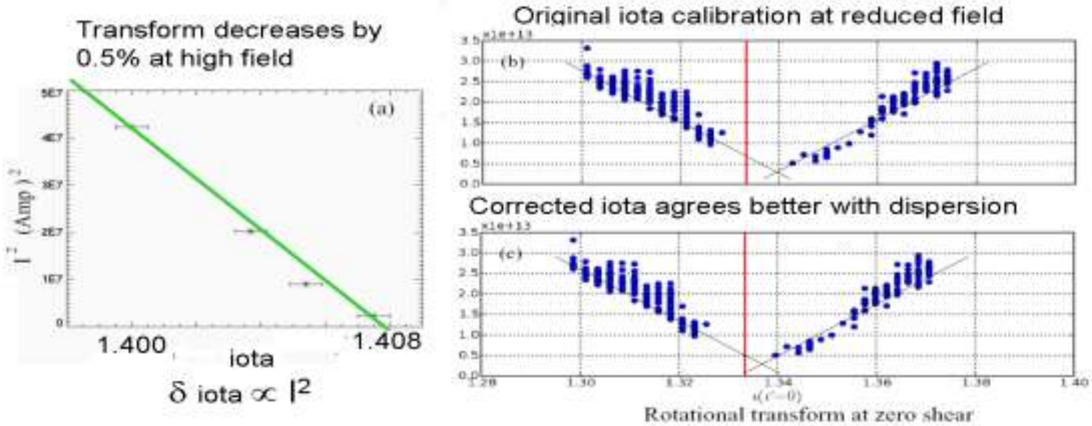

Fig. 7: Comparison of transform determination using Alfvén eigenmode resonance and direct electron beam mapping(a). The discrepancy between the transform obtained from the symmetry point in the "V" structure of the observed frequency (b) and the computed transform value, is halved (c) if the computed transform is corrected for a small distortion in the magnetic field coils due to the magnetic forces inferred from the results (a) of electron beam mapping at high field.