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The safety factor $q(r) = (\mathrm{B} \cdot \nabla\zeta)$=$(\mathrm{B} \cdot \nabla\theta)$ is a measure of the helicity of the equilibrium magnetic field **B** in toroidal coordinates (r, θ, ζ). Whilst accurate determination of the q profile and its evolution are of major importance for confining the plasma, diagnosis deep inside the plasma is difficult. Alfvén Eigenmodes are very sensitive to q, and by comparison of computational modelling to observational data on fast-ion driven Alfvén eigenmodes at 0-500kHz in fusion-grade plasmas of the Joint European Torus (JET) we determine the degree of corre-spondence between theory and experiment. Such agreement indicates that the simple theory explaining the modes known as Toroidal Alfvén Eigenmodes (TAEs) [1] and Alfvén Cascades (ACs) [2] can be used for q-profile diagnosis. This being the case we can either use computational modelling in order to reconstruct the evolution of a modes frequency with time or use the simple formulae:

$$q = \frac{m-1/2}{n} \quad \text{and} \quad q = \frac{m}{n}$$

n (where n and m are toroidal and poloidal mode numbers and q is for localised TAEs and ACs respectively) to estimate the minimum value of q at the time a given mode is first seen.

Using such computational modelling three types of eigenmodes may be observed: simple localised TAEs and ACs for which starting points are given above and global TAEs. In general discharges exhibiting global TAEs differ from those exhibiting localised TAEs in the gradient of their radial q-profile (their shear). In the high shear case multiple TAEs couple in order to give a global mode across the plasma. Experimental data showing each type can be seen in figure 3.

In undertaking studies of MHD spectroscopy using these modes we consider the plasma-preheating phase of a discharge. During this phase no neutral beams (NBI) have been applied giving no cause for significant rotation of the plasma; as a result there is no necessity consider Doppler shifts. During this phase it is possible to excite the Alfv´ en eigenmodes we wish to study through Ion Cyclotron Resonance Heating (ICRH) on minority hydrogen ions in the plasma.

Here we consider significantly different experimental Alfv´ en Eigenmode data from three discharges on the JET tokamak and attempt to model them during the plasma-preheating phase. Such modelling has previously been seen successfully applied to individual modes as in [3]; here we model both global and localised TAEs and ACs using one process. Parameters for each discharge modelled and the location of the plasma-preheating phase can be seen in figure 1 and the modes present in each case can be observed in figure 3.

Reconstruction was undertaken using the ideal MHD code MISHKA-1 [4] in order to determine the closest mode structure present to a specified frequency for a given equilibrium and n. In order to make use of this code to model experimental discharges the EFIT [5] and HELENA [6] codes were used to reconstruct a computational equilibrium from a variety of experimental data. In undertaking this reconstruction the code is able to make use of data from Motional Stark Effect (MSE) readings where available; this allows the reconstruction of the non-monotonic q-profiles necessary for ACs. Modelling with the MISHKA-1 code proceeded under the assumption that the only parameter change occurring over time was shift in the value of q by an amount constant over space such that q decreases with time. This shift in the q-profile is due to the non-instantaneous penetration into the plasma of the induced toroidal current.

In order to reconstruct the evolution of each of the Alfvén eigenmodes the CSCAS code was used to determine the frequency versus s behaviour of a mode (where s is a measure of flux surface coordinate defined as $s = \sqrt{\psi_p(r) = \psi_p(\mathrm{a}))}$ where $s = 1$ at the edge of the plasma); this narrowed the search in parameter space necessary to find the initial mode using MISHKA-1. The modelling proceeded under the assumption that over a small change in $q(0)$ (0.001 used here) there would be only a small change in frequency; this allowed the frequency of the same mode at a new $q(0)$ close to the original to be found. This process was repeated many times (using trend lines to predict frequencies at which to search where possible) in order to model the evolution of the frequency of a mode corresponding to a particular n and m as $q(0)$ was varied.

The results obtained can be seen in figure 4; from comparison of this and figure 3 it can be seen that computational modelling of shear Alfvén modes can produce results remarkably close to those found experimentally. In all cases the modelled frequencies are generally separated from experimental data by no more than 15%. In the case of global TAEs we see the expected uninterupted modes in the correct frequency range in the model data but with a markedly different gradient. In the case of localised TAEs we see in the model the expected variation in frequency of start points but can see some difference between experiment and model in both the shape of the mode evolution and in the magnitude of the frequencies observed. In the case of the ACs there is a notable difference in the increase in the frequency of cascade peaks over time.

In all cases the differences between modelling results and experimental data are likely to be due to either experimental error in the measurement of density or to uncertainty in the reconstruction of the experimental q-profile used in the modelling. In future work we intend to investigate the inverse problem of fitting the frequencies by making modifications to the q-profile given by EFIT; this should allow us determine quantitatively the effect of such changes. The understanding this will give should allow the use of modelling based upon modified q-profiles for MHD spectroscopy on experimental data.

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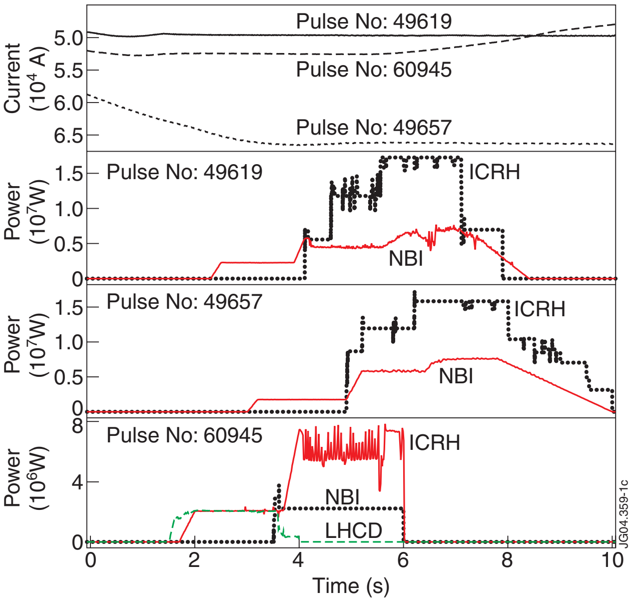

Figure 1: The heating applied and plasma current in JET Pulse No's: 49619, 49657 and 60945. In each case the plasma pre-heating phase can clearly be seen as a lower plateau in heating power prior to the onset of main heating. It can be seen that ICRH heating is applied in each case and that in Pulse No: 60945 Lower Hybrid Current Drive (LHCD) heating is applied during the plasma pre-heating stage; this produces a non-monotonic spatial q-profile.

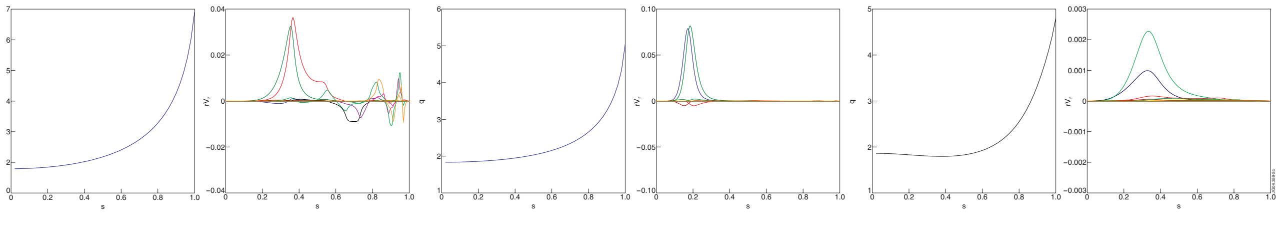

Figure 2: Examples of q-profiles and resulting mode structure from runs of MISHKA-1 used to generate each of the models shown in figure 4. r is radius and V_r is perturbed velocity in the radial direction.

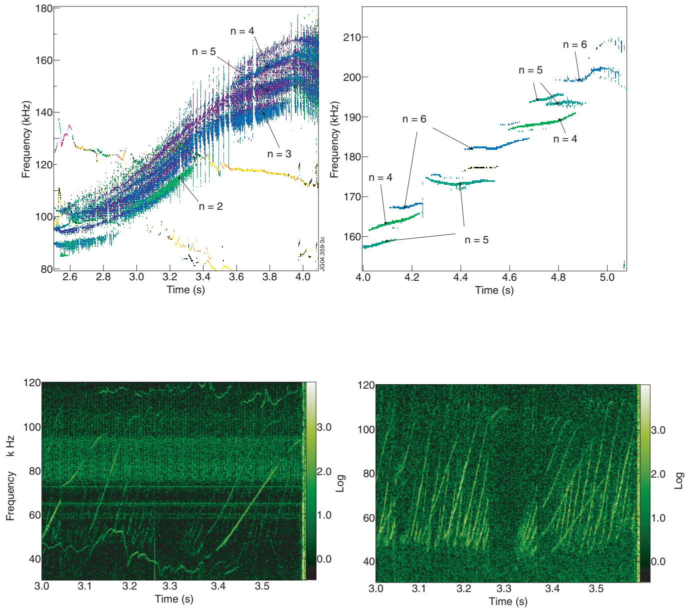

Figure 3: FFT images of JET data showing some of the various shear Alfvén modes observed in tokamak plasmas. (a) and (b) show the results of calculation of the toroidal mode number from the phase difference in data obtained from Mirnov coils at different toroidal angles; (a) shows global TAEs whilst (b) shows localised TAEs. (a) shows data from JET Pulse Number: 49619 whilst (b) shows data from JET Pulse Number: 49657. (c) and (d) show data from JET Pulse Number: 60945 in which Alfvéen cascades can be seen; the presence of multiple cascades at multiple gradients indicates the presence of a range of toroidal mode numbers. The data in (c) is from magnetic field amplitude data measured using Mirnov coils whilst the data in (d) is taken from the total amplitude of interferometry data.

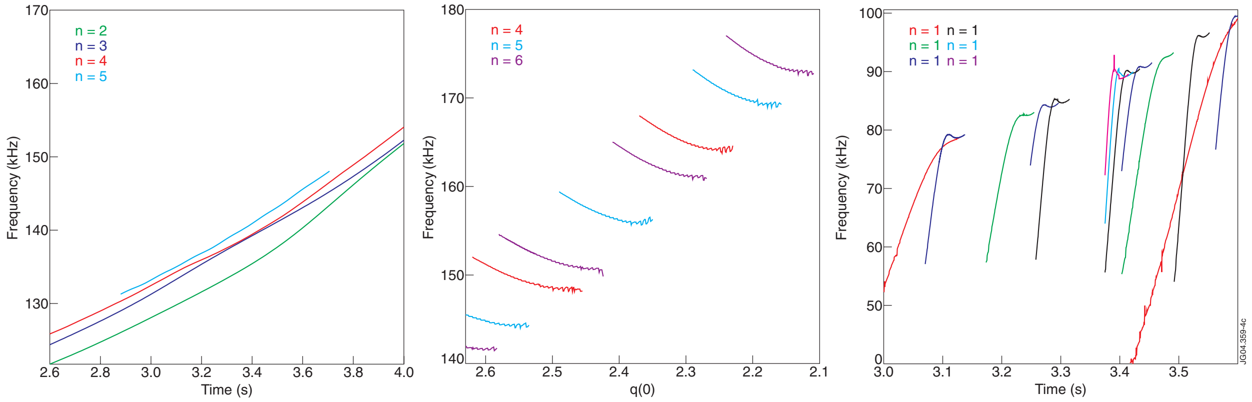

Figure 4: The result of modelling the shear Alfvén modes seen in figure 3. In each case the EFIT and HELENA codes have been used to reconstruct an equilibrium for the plasma at a time close to that being modelled. (a) and (b) show modelling of the TAEs seen in figures 3 (a) and (b). In (a) the shift in q has been mapped to time by assuming a linear decrease in q with a gradient given by the EFIT code. In the case of (a) the equilibrium used was at 3.0 seconds; in the case of (b) it was at 4.5 seconds. (c) shows modelling of the Alfvén Cascades seen in figure 3 (c) and (d) for a selection of m; the HELENA equilibrium was based upon MSE data taken at 4.0 seconds. In calculating the frequencies shown density was taken from experimental LIDAR data; this data has an error of around ±10%. In the case of (c) a matching of features observed in model and experimental results has been used to fit a time scale to the model results and density and magnetic field values have been varied accordingly.