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SHEAR ALFVÉN RESONANCES IN TOKAPOLE II

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SHEAR ALFVÉN RESONANCES IN TOKAPOLE II

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It has been suggested that efficient heating can occur by coupling energy through the shear Alfvén resonance that is predicted to occur at particular locations within inhomogeneous plasmas.¹⁻³ This heating mechanism should be applicable to tokamaks; however, the existence of the resonances in tokamaks has not yet been established experimentally. We present here direct observations of localized enhancement in the driven wave magnetic field which are compatible with theoretical predictions for the shear Alfvén resonance in tokamak geometry. These resonance studies at low absorbed power will be followed by higher power heating (~ 1 MW) presently being developed.

The experiments are performed in Tokapole II a noncircular tokamak in a four-node poloidal divertor configuration.⁴ The plasma is shaped by currents carried in four inductively driven solid copper coils within the vacuum vessel resulting in a poloidal flux plot as shown in Fig. 1a. The safety factor, q , profile is relatively flat over most of the cross-section, becoming infinite at the divertor separatrix. Waves are launched by driving rf currents through the field shaping coils themselves thereby eliminating the need for a separate antenna. Each coil has three conducting supports separated by 120° and insulated from the vacuum tank wall. rf current is excited by grounding one support to the tank wall, driving one support with respect to vacuum tank ground and leaving one support unused (Fig. 1b). The resulting toroidal rf current, shown in Fig. 1c, provides 70% of the rf power with toroidal mode number $n = 1$. By appropriate selection of the phase difference between the currents in different coils one can choose either poloidal mode number $m = 1, 2$ or 4 to dominate.

The rf source provides a 1 msec pulse at $f = 1.2$ MHz and a power of ~ 100 kW. Since, for the present studies of the resonance, the coils are not Faraday shielded, the loading is primarily electrostatic and significant heating is not expected. The waves are detected using 4 magnetic pickup loops fixed upon a moveable stalk which is placed inside a 3 mm stainless steel tube. After extensive conditioning the tube does not significantly perturb the plasma (at $n \sim 10^{13} \text{ cm}^{-3}$, $T_e \sim 100 \text{ eV}$, $I_{\text{plasma}} \sim 24 \text{ kA}$, $B_T = 5.0 \text{ kG}$, discharge length $\sim 10 \text{ msec}$, major radius = 50 cm.)

For several different antenna configurations a clear resonance is observed in the poloidal wave magnetic field, B_{rf} . Figures 2a and 3a display the radial profile of B_{rf} for cases where 2 and 4 coils are driven, respectively. Each case displays two resonant peaks, with the inner peak generally being more persistent and reproducible. The measured mode numbers for the two cases in Fig. 2a is $|m| = 1$ $|n| = 2$ and for Fig. 3a is $|n| = 1$ (m not yet determined). Measurements of the radial B_{rf} profile along various chords indicates that the resonant surface coincides with a magnetic surface as expected for shear Alfvén waves. Although most of the loading is electrostatic, a small amount of resonance loading is observed which correlates with the existence of the resonance in the wave magnetic field.

The linearized MHD equations predict that a singularity in the wave field exists at particular magnetic surfaces. To determine if the observed resonances are indeed shear Alfvén waves these equations have been solved⁵ for Tokapole II equilibria, including noncircularity and toroidicity. The prediction for the resonance location for various mode numbers is displayed in Figs. 2b and 3b where the frequency required for resonances at a particular radius is shown. The radius at which the resonance frequency equals the oscillator frequency in the experiment is also shown. The predicted locations for both the inner and outer peaks (not shown in theoretical plot) agrees very well with experiment. However, the theory also predicts several other resonances that are not observed experimentally for reasons that are not yet understood.

In order to heat through these resonances 4 Faraday shielded antennas will be installed separated 180° toroidally and poloidally. Each antenna will be a two-turn copper loop shaped to follow a 53° toroidal arc. The antennas will be moveable from the wall to the divertor separatrix to optimize coupling to the plasma and will be rotatable to vary the wave polarization. The total power available will be $\sim 1 \text{ MW}$ for $\sim 1 \text{ msec}$.

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FIGURE 1

Fig. 1: (a) Tokapole II magnetic flux plot. (b) rf current flow in a single toroidal coil (used as an antenna). (c) rf antenna current versus toroidal angle.

FIGURE 2

Fig. 2: (a) Experimentally observed radial profile of wave magnetic field. Measured mode numbers for inner peak is $|m| = 1$. $|n| = 2$. Two coils are driven. (b) Theoretical prediction of resonance frequency versus radius, indicating the observed mode.

FIGURE 3

Fig. 3: (a) Experimentally observed radial profile of wave magnetic field. Largest peak is $|n| = 1$. (b) Theoretical prediction of resonance frequency versus radius for $m = 4$, $n = -1$ mode.

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