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ALFVÉN WAVE HEATING STUDIES IN TOKAPOLE II

F.D. Witherspoon, C.E. Kieras, J.C. Sprott, and S.C. Prager

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ABSTRACT

Alfvén Wave Heating Studies in Tokapole II*. F.D. WITHERSPOON, C.E. KIERAS, J.C. SPROTT, AND S.C. PRAGER, University of Wisconsin-Madison.--Coupling to shear Alfvén wave resonances has been suggested as a promising heating scheme for tokamaks. This technique is being experimentally investigated in Tokapole II. Resonances in the poloidal magnetic wave field have been observed during the RF pulse with resonant peaks on both sides of the separatrix. The location and mode structure of these peaks are consistent with theoretical calculations for the noncircular tokamak plasma indicating the strong possibility that shear Alfven wave resonances are being observed in a tokamak geometry. At present, only basic wave excitation and propagation studies are being performed, with heating studies to follow later.

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ALFVÉN WAVE HEATING STUDIES IN TOKAPOLE II*

F.D. Witherspoon, C.E. Kieras, J.C. Sprott, and S.C. Prager
University of Wisconsin-Madison

Introduction: Coupling energy through the shear Alfvén resonance of a nonuniform plasma has been proposed as a promising supplementary heating scheme for fusion plasma[1-3]. High power RF sources are readily available in the frequency range of interest (~ 1 MHz).

Alfvén wave heating experiments are now in progress in Tokapole II. Our immediate purpose is to determine whether we can indeed excite shear Alfven waves in a tokamak, and if so, to study its predicted mode conversion to the kinetic Alfvén wave inside the shear wave resonant surface. The present source is not properly impedance matched, and so no heating is expected.

Device Description: Tokapole II is a tokamak with a four-node poloidal divertor formed by its four inductively driven, solid copper internal rings. (See Fig. 1.) A typical flux plot for this configuration is shown in Fig. 2 along with the corresponding q-profile (Fig. 3). Note that q actually goes to infinity at the separatrix but is relatively flat over most of the current channel. A pair of retractable stainless steel scrape-off plates oriented perpendicular to the current channel effectively eliminates toroidal current outside the separatrix. Typical parameters obtained with the limiters in position are: B_T (axis) = 4.5 kG, I_{plasma} = 24 kA, $n_e \simeq 10^{13}$ cm^{-3}, $T_e \simeq 100$ eV, minor radius ≃ 8 cm, and plasma lifetime ≃ 5 msec. The parameters are kept well below design limits of the device in order to facilitate probe diagnostics.

Experimental Method: Waves are launched utilizing the existing rings as the antenna, thereby eliminating the need for installing a special antenna. Each ring has three conducting supports separated by 120° and insulated from the vacuum tank wall. RF current is driven through these rings by grounding one of the supports to the tank wall and driving one of the remaining supports with respect to the vacuum tank ground. The third support is unused. The toroidal mode structure obtained with this arrangement is such that all fourier components are present except multiples of three (including zero). The poloidal wave structure is determined by choosing the proper phase differences between the currents in the rings. The data presented here was all acquired with an m = 2 configuration, obtained by driving currents in phase in the upper outer and lower inner rings. The other two rings were left unused.

The RF heating pulse lasts ~ 250 μsec and is triggered 100-200 μsec prior to peak plasma current. The waves are detected using magnetic pick up coils fixed inside movable 1/4" diameter stainless steel tubes which provide electrostatic shielding. Strong signal filtering was required to distinguish the 1.2 MHz wave from the much larger low frequency signals in the plasma.

Experimental Results: A clear resonance structure is evident in the radial profile of the wave poloidal magnetic field amplitude (Fig. 4). As expected for shear Alfven wave resonances in a tokamak, the resonant surface coincides with a flux surface and has the magnetic field

polarized predominantly perpendicular to the equilibrium field. The resonant enhancement of the wave magnetic field amplitude over the vacuum RF amplitude is about a factor of 6-7. In addition, the RF source is clearly coupling to the plasma, as evidenced by the fact that RF drive current with plasma present is only ~ 60% of that in vacuum, reflecting the different impedance seen by the RF source when plasma is present.

Phase measurements show that the inner peak has mode numbers $|n| = 2$, $|m| = 1$ while the outer peak has $|n| = 1$, $|m| = 1$ where n is the toroidal and m the poloidal mode number.

Theory: In order to determine if the observed resonance structure is due to the excitation of a shear Alfvén wave, we have been studying the linearized ideal MHD equations in an axisymmetric noncircular tokamak geometry. Previously, Tataronis et al.[4] had shown that in a toroidal magnetic equilibrium, the shear Alfvén modes exhibit spatial singularities on magnetic surfaces for frequencies belonging to the shear Alfvén continuum. These frequencies are determined, as a function of ψ, by the eigenvalues of a set of coupled differential equations in the surface variables. We have written these equations in the Hamada coordinates for an axisymmetric tokamak-type equilibrium and have analyzed them in a small inverse aspect ratio ordering scheme. The lowest order solution in $\varepsilon \sim a/R$ yields an analytic dispersion relation for the shear Alfven resonance frequencies, ω_A:

$$\omega_A^2 = \frac{[mB^2(\psi)+nB^3(\psi)]^2}{\mu_o \rho} \qquad (1)$$

where m, n are poloidal and toroidal mode numbers and $B^2(\psi)$, $B^3(\psi)$ are the equilibrium contravariant components of the magnetic field. For a tokamak,

$$B^2(\psi) = \frac{d\psi_{pol}}{dV} \text{ and } B^3(\psi) = \frac{d\psi_{tor}}{dV} \qquad (2)$$

while, in the cylindrical screw pinch limit, these components become

$$B^2 \to \frac{B_P}{r} \text{ and } B^3 \to \frac{B_T}{R} \qquad (3)$$

Though the metric tensor elements, which appear as coefficients in the eigenvalue equations, have been expanded in ε, the equilibrium magnetic field components have not been expanded, in order to retain characteristic features of a noncircular tokamak. We have evaluated the disperson relation for the Tokapole II experiment, using a[5] model density profile and a numerical solution to the equilibrium which correlate well with the observed parameters. The results of this calculation are shown in Fig. 5 for n = 1 and n = 2.

Conclusions: When the experimental data is compared with the 2-D calculations discussed above, the following points can be made. 1) For the source frequency used in the experiment, the theory predicts a possible coupling to modes at seven different radial locations. As is clear from Fig. 5, these resonant layers all cluster about the separatrix. 2) Only two of the possible modes have actually been observed. However, even if all of the modes were being excited, it would be experimentally difficult, if not impossible, to distinguish each mode since the distance between peaks is virtually the same as the

magnetic pick-up coil dimensions. Smaller probes may help to alleviate this problem. 3) The clustering of resonant surfaces about the separatrix is due to the rapidly changing value of q on both sides of the separatrix.

The antenna structure launches a shear Alfven wave and not a compressional wave. Since the launching structure is fairly close to the plasma, the power loss due to the evanescence of the shear Alfven wave is probably not large. This appears to be borne out since good penetration of the RF to the plasma core is observed.

In conclusion, poloidal wave magnetic field resonances have been observed in Tokapole II, the location and characteristics of which are consistent with a 2-D calculation for shear Alfven resonances. Although it is not yet possible to claim the observed modes are shear Alfven resonances, there is strong evidence to support it. A 1 MW source will be installed in the future to attempt heating.

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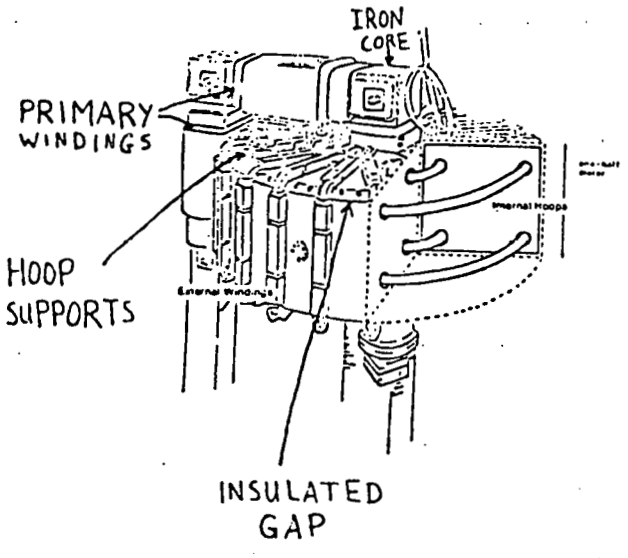


Fig. 1. Tokapole II cutaway view.

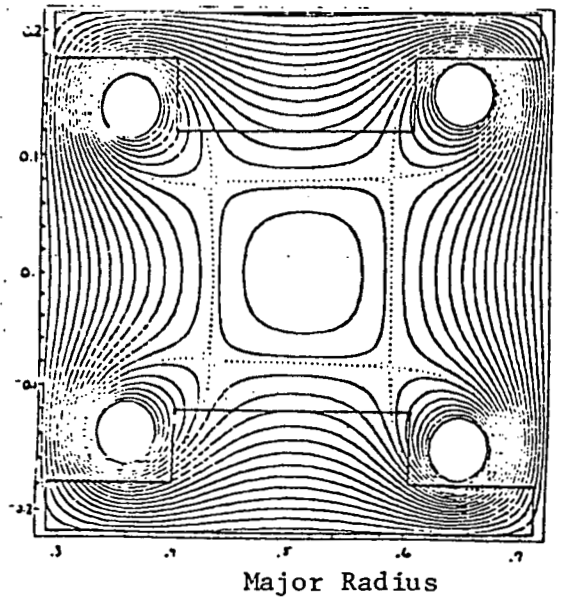


Fig. 2. Typical flux plot showing separatrix and limiters.

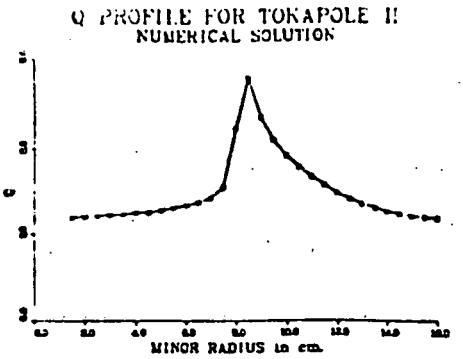
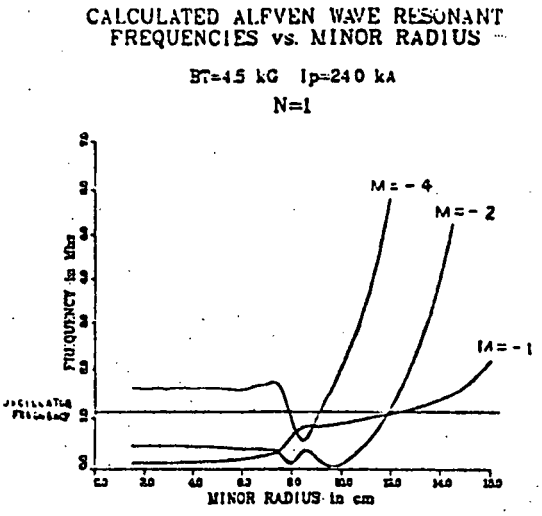


Fig. 3



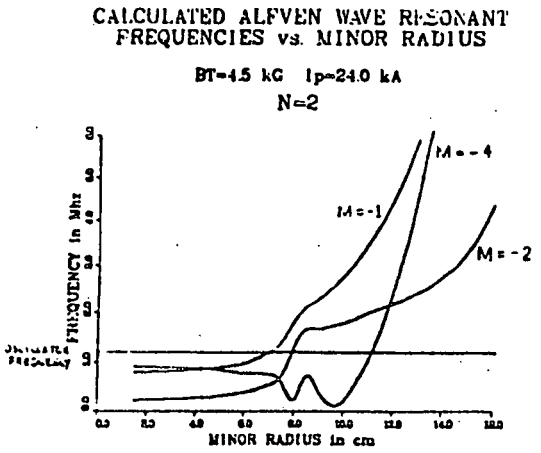
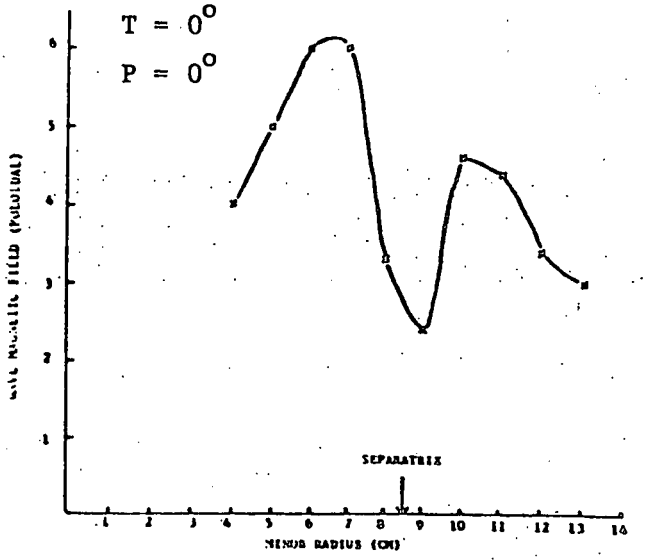
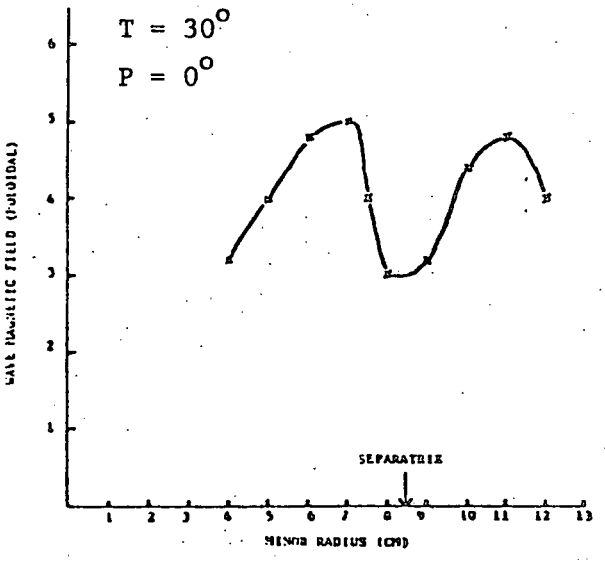


Fig. 5





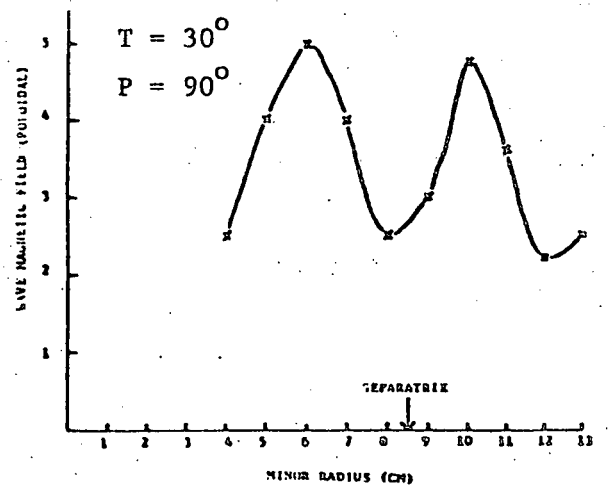


Fig. 4. Wave magnetic field amplitude (poloidal). T and P are toroidal and poloidal azimuths.

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