Observation of Mode Conversion of $m = -1$ Fast Waves on the Alfvén Resonance Layer

Y. Amagishi
Faculty of Liberal Arts, Shizuoka University, 836 Ohya, Shizuoka 422, Japan

(Received 22 December 1989)

Fast waves or MHD surface waves with $m = -1$ (poloidal mode number of left-hand rotation) have been observed to undergo mode conversion on the Alfvén resonance layer. The converted waves are a quasielectrostatic form of the shear Alfvén waves, i.e., kinetic Alfvén wave and/or resistive mode.

PACS numbers: 52.40.Db, 52.30.Jb

Recently, the first radial eigenmode of $m = -1$ fast waves (compressional Alfvén waves) has been found to behave like a MHD surface wave at frequencies below ω_{ci}, its dispersion relation merging with that of the shear Alfvén wave (SAW) at the position of the maximum plasma density when a limiting axial wave number $k_{\parallel}^{*}$ and a limiting frequency ω^{*} ($<\omega_{ci}$) are reached.[1-4] The surface-wave properties of this mode were experimentally demonstrated using a helical antenna.[5,6] This fast wave is of particular interest for Alfvén-wave heating[2,7-9] as it is expected to undergo mode conversion to the SAW near the position of the maximum plasma density in an inhomogeneous density profile.[2,4] It should be noted that the SAW excited by mode conversion has a very short wavelength in a direction perpendicular to the ambient magnetic field. In a cylindrical plasma with an axial magnetic field B_0, the dominant magnetic field and current components for the SAW are $\tilde{B}_\theta$ and $\tilde{j}_z$, suggesting that the SAW can be found from the observation of $\tilde{B}_\theta$ using a magnetic probe. In a resistive plasma ($\nu_{ei} > \omega$), it experiences strong damping and its energy is deposited around the Alfvén resonance position r_0, so this mode is called the resistive mode. In a warm plasma but under the condition $\omega > k_{\parallel} v_e$ (v_e is the electron thermal speed), electron inertia becomes important, and the SAW, which in this case is often called the surface electrostatic wave, usually propagates into the lower-density side. In a hot plasma ($\omega < k_{\parallel} v_e$), electron pressure dominates and the quasielectrostatic wave (QEW) propagates away from r_0 to the higher-density side; it is then generally called the kinetic Alfvén wave[10] (KAW) and it is of importance for the Alfvén-wave heating of the central plasma. The KAW has recently been observed in low-frequency heating experiments in the TCA tokamak.[11]

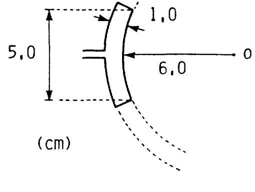

FIG. 1. Cross section of a loop antenna located near the wall.

In this Letter, we report the use of small magnetic probes to demonstrate mode conversion of the $m = -1$ fast wave into SAW's in an inhomogeneous plasma. The experiment was conducted in the linear device TPH (15 cm diam) of Shizuoka University with a maximum density of 4×10^{20} m^{-3} of a singly charged helium plasma and an electron temperature $T_e \sim 5$ eV at the center of the plasma column. The axial magnetic field $B_0 = 0.30$ T gives an ion cyclotron frequency $f_{ci} = 1.14$ MHz. In previous papers,[12,13] we confirmed the Alfvén resonance in an inhomogeneous plasma density beneath a ladder-type Stix coil, which was used to launch axisymmetric ($m = 0$) waves of fixed wave number. In this experiment, however, we used a pair of small-loop antennas (Fig. 1) with currents in the r-θ plane and with a spacing of 20 cm along the magnetic field B_0. They are located at the edge of the plasma column. The components of the magnetic field excited directly by the antennas are essentially $\tilde{B}_z$ and $\tilde{B}_r$.

The two currents that were fed into the two loop antennas were chosen to be in phase, so that a standinglike wave of one wavelength was created in the plasma, whose peak axial wave number $k_{\parallel}$ at $r = 2$ cm was estimated to be ~ 0.25 cm^{-1} from the maximum-entropy method.[6] The $m = -1$ mode of the fast wave was successfully selected in the plasma from the modes $|m| = 0, 1, 2, \ldots$ by fixing both wave number and frequency; the $m = 0$ fast wave suffers a cutoff in this range of frequency below ω_{ci}, and other modes, except $m = -1$, have smaller axial wave numbers or much smaller amplitudes for a given frequency. Figure 2 shows such a selected excitation of the $m = -1$ mode of frequency ~ 650 kHz when a wave packet with a peak frequency of 300 kHz was launched; we should note that the magnetic field of 300 kHz oscillates simply like a dipole field excited in a vacuum by the loop antennas. The $m = -1$ mode of $f \simeq 650$ kHz and $k_{\parallel} \simeq 0.25$ cm^{-1} can be confirmed from a previous experimental result[5,6] to be the $m = -1$ fast wave, whose axial phase velocity equals that of the SAW at $r = 2$-3 cm.

Some broadband frequency spectra for the wave field

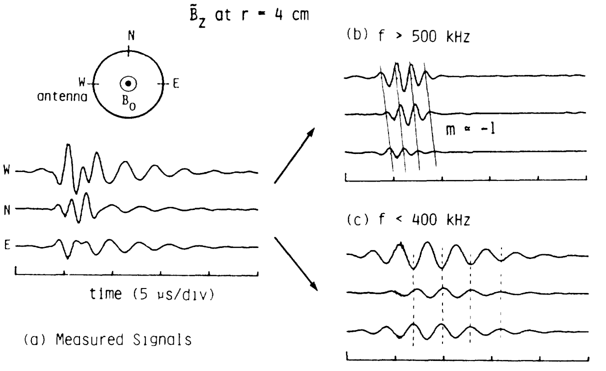

FIG. 2. Observation of the poloidal number of the waves launched from a pair of loop antennas. Signals were obtained using three $\tilde{B}_z$ probes azimuthally separated by 90° at $r=4$ cm. Measured signals (a) are digitally decomposed into (b) $f>500$ kHz and (c) $f<400$ kHz. Higher-frequency components shown in (b) indicate $m=-1$ rotation.

$\tilde{B}_z$ are given in Fig. 3(a) for six radii. It is obvious from this figure that the power of the field $\tilde{B}_z$ in the $m=-1$ fast-wave range of frequency 550–700 kHz is rather strongly absorbed at $r\leq 4$ cm, while the power in the cutoff range of frequency ~ 300 kHz in the plasma remains as it is in a vacuum. On the other hand, Fig. 3(b) shows the power spectra of the $\tilde{B}_\theta$ component in the plasma which are mainly excited at $r=2$–4 cm with a broad frequency spectrum. Figure 4 shows the observation of standing waves of $\tilde{B}_\theta$ excited at $r=2$ cm, decomposed into two parts using a digital filter, i.e., the resonant $m=-1$ mode at $f\sim 650$ kHz and nonresonant (cutoff) mode at $f\sim 300$ kHz. One should note that although the $\tilde{B}_\theta$ component is not contained in the vacuum field, the fast waves have a $\tilde{B}_\theta$ component whose amplitude is equal to that of $\tilde{B}_r$ in the plasma. To justify the mode-conversion observation we need to show that $\tilde{B}_\theta > \tilde{B}_r$ near the Alfvén resonance layer, in addition to the $\tilde{B}_\theta$ profile being localized as shown in Fig. 3(b). Figure 5 shows the polarization for the higher-frequency component $f\sim 650$ kHz in the cross section on the midplane, indicating $\tilde{B}_\theta \simeq 2\tilde{B}_r$ across the radius. It is then concluded that SAW's are mode converted from fast waves on the Alfvén resonance layer.

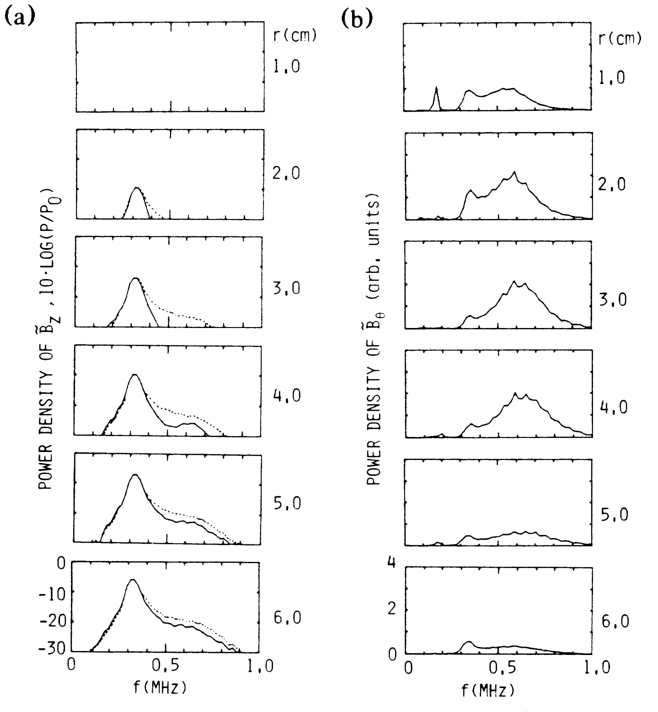

FIG. 3. (a) Auto-power density spectrum of $\tilde{B}_z$ launched from a pair of loop antennas with (solid line) and without (dashed line) plasmas. (b) Auto-power density spectrum of $\tilde{B}_\theta$ mode converted from the $m=-1$ fast wave with frequency 600–700 kHz. The peak at frequency ~ 200 kHz at $r=1$ cm is a spontaneously excited shear Alfvén wave of $m=0$.

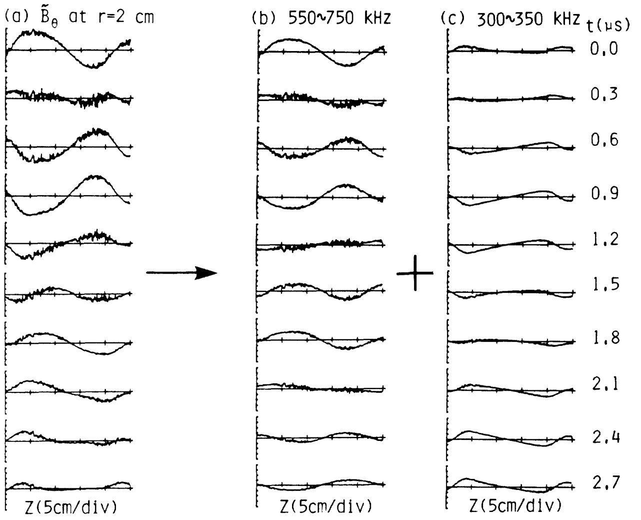

FIG. 4. Formation of $\tilde{B}_\theta$ standing waves at $r=2$ cm. (a) Raw data, (b) main component corresponding to the mode-converted wave, and (c) cutoff component.

In this experiment $\nu_{ei} \gg \omega$, so the mode-converted wave is classified either as a KAW or as a resistive

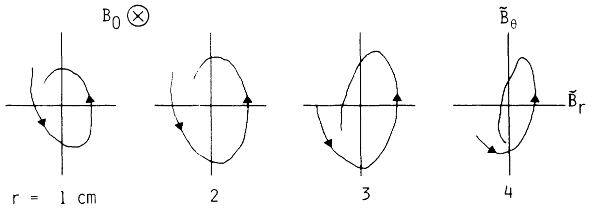

FIG. 5. Vector diagrams of transverse magnetic field for the component shown in Fig. 4(b) for the first 17 μs, showing left handed and elliptical polarization across the radius.

Alfvén wave depending on whether $(v_e k_\parallel)^2$ or $\omega\nu_{ei}$ is larger.[14] Our experimental conditions give the following relation near the plasma center:

$$(\omega\nu_{ei})^{1/2}/k_\parallel v_e = 42 T_e^{-5/4} B_0^{1/2} [(1-\Omega^2)/\Omega]^{1/2} \geq 1.3 \, ,$$

where $\Omega = \omega/\omega_{ci}$, T_e is in eV, and B_0 is in T. It may therefore be expected that the mode-converted SAW's experience heavy resistive damping while propagating towards the high-density plasma. The observed half-width ~ 3 cm of $\tilde{B}_\theta$ in the radial direction from Fig. 3(b) is roughly in good agreement with the estimation for a collisional plasma obtained from Eq. (18) of Ref. 14. It is also confirmed from Fig. 5 that the polarization of the mode-converted wave is left handed over the entire radius; this is again in agreement with the calculation.[14] The cutoff mode was, however, almost linearly polarized because of the large $\tilde{B}_r$ component and the negligibly small $\tilde{B}_\theta$ component in the plasmas. Furthermore, Fig. 5 suggests the formation of an eigenmode (standing wave) of QEW's inside the Alfvén resonance layer in a cylindrical column, as pointed out in Ref. 4.

Consequently, we have observed $\tilde{B}_0$ converted from the $m = -1$ fast wave on the Alfvén resonance layer. This component is considered as the QEW, i.e., the kinetic Alfvén wave and/or the resistive mode. Further details of the experiments will be described elsewhere.

I would like to acknowledge stimulating and helpful discussions with Dr. I. J. Donnelly and Dr. K. Saeki.

---

[1] G. A. Collins, N. F. Cramer, and I. J. Donnelly, Plasma Phys. Controlled Fusion **26**, 273 (1984).

[2] K. Appert, J. Vaclavik, and L. Villard, Phys. Fluids **27**, 432 (1984).

[3] H. Akiyama, M. O. Hagler, and M. Kristiansen, IEEE Trans. Plasma Sci. **13**, 125 (1985).

[4] I. J. Donnelly and N. F. Cramer, Plasma Phys. Controlled Fusion **26**, 769 (1984).

[5] Y. Amagishi, Phys. Rev. Lett. **57**, 2807 (1986).

[6] Y. Amagishi, K. Saeki, and I. J. Donnelly, Plasma Phys. Controlled Fusion **31**, 675 (1989).

[7] D. W. Ross, G. L. Chen, and S. M. Mahajan, Phys. Fluids **25**, 652 (1982).

[8] I. J. Donnelly, B. E. Clancy, and N. F. Cramer, J. Plasma Phys. **35**, 75 (1986).

[9] A. Hasegawa and L. Chen, Phys. Rev. Lett. **32**, 454 (1974).

[10] A. Hasegawa and L. Chen, Phys. Rev. Lett. **35**, 370 (1975).

[11] H. Wiesen, K. Appert, G. G. Borg, B. Joye, A. J. Knight, J. B. Lister, and J. Vaclavik, Phys. Rev. Lett. **63**, 2476 (1989).

[12] A. Tsushima, Y. Amagishi, and M. Inutake, Phys. Lett. **88A**, 457 (1982).

[13] Y. Amagishi and A. Tsushima, Plasma Phys. Controlled Fusion **26**, 1489 (1984).

[14] I. J. Donnelly and B. E. Clancy, Aust. J. Phys. **36**, 305 (1983).