Imaging Complex Three Dimensional Alfvén Wave Currents

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Abstract—**Alfvén waves exist in plasmas in which the ions are magnetized. They are found in the solar wind, the earth's magnetosphere, the solar corona, and possibly in intergalactic space. They play a role in Tokamak edge turbulence. Toroidal Alfvén eigenmodes could effect the confinement of future fusion devices. With the advent of quiescent plasma sources, these waves are now studied in great detail in controlled laboratory experiments. We present measurements of three-dimensional current systems associated with these waves, and illustrate a visualization technique necessary to quickly picture them.**

Index Terms—**Electromagnetic propagation plasma media, plasma waves, scientific visualization.**

T HESE experiments were conducted in the first version of the large plasma device at the University of California, Los Angeles [1]. The plasma was 10 m in length and 500 ion Larmor radii in diameter ($B_{0z} = 1.5$ kG, 40 cm plasma diameter, $n = 1 - 4.0 \times 10^{12}$ cm^{-3}, fully ionized, $t_{rep} = 1$ Hz). The temporal history of the vector magnetic field was acquired at 15 375 spatial locations. The waves were launched with a helical approximately antenna one quarter wavelength (45 cm) long for a shear Alfvén wave in helium at $f/f_{ci} = 0.76$. In argon, the ion cyclotron frequency is $1/10$ that of He, the parallel wavelength is about 8 m, and the antenna is, for all practical purposes, straight. The wave magnetic field was measured with a three axis, differentially wound pickup probe. The probe was moved by a computer controlled stepping motor, over 1025 locations on a 40×20 cm plane transverse to the background magnetic field. Data was collected at 2048 time steps ($\delta t = 400$ ns). The vector magnetic field was averaged over 10 shots at each spatial location. When an individual plane was completed the probe was withdrawn from the vacuum system and placed on the next axial location ($\delta z = 33$ cm) through a vacuum interlock. Data was acquired on 15 planes. The magnetic field was used to calculate three-dimensional (3-D) wave currents using $\vec{j} = (c/4\pi)\nabla \times \vec{B}$. (The displacement current was negligible.) In this paper, we discuss the 3-D wave currents, although density perturbations caused by the waves [2] were also investigated. The magnetic field of the wave in argon and its associated current is shown in Fig. 1. It is not the simple pattern due to a single current channel as described in the previous paper [2]. In argon, the observed wave vectors (Fig. 1) are due to the constructive interference of the fields from two current channels. This is reminiscent of in-
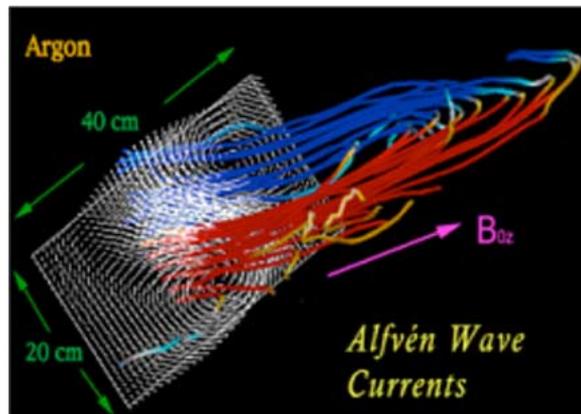
Fig. 1. Measured magnetic field of a shear Alfvén wave in Argon shown as vector field on plane 2.64 m from the antenna that launched it. The 3-D wave current derived from volumetric data is shown as flux tubes. Red denotes current flowing away from the data plane and blue toward it. The image is compressed along the background magnetic field.
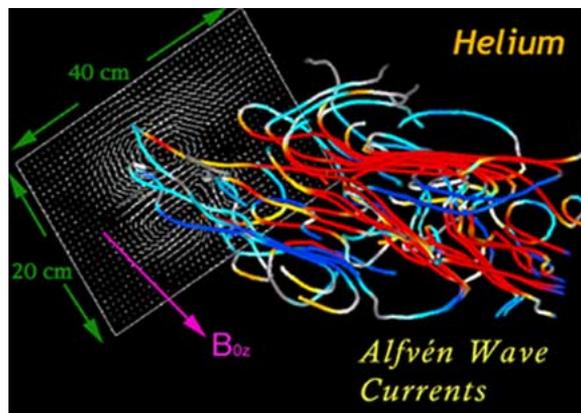

Fig. 2. Measured magnetic field on the same plane and volume as that in Fig. 1, but in a helium plasma. In this case, the antenna excited waves with a variety of superimposed *m* modes. This gives rise to a complex 3-D current system.

terference patterns previously observed [3], which involved the interference of Alfvén waves caused by parallel oscillating currents. The wave currents along the magnetic field are carried by electrons with current density of the order 160 mA/cm [2]. The Alfvén wave current closes across the magnetic field by the ion polarization current

$$j_\perp = ne \left(\frac{1}{\omega_{ci} B \left[1 - \left(\frac{\omega}{\omega_{ci}} \right)^2 \right]} \frac{dE_\perp}{dt} \right)$$

Fig. 3. 3-D currents of Alfvén waves in a helium plasma rendered as snakes using the graphics package "Maya." For this image, the background magnetic field points out of the page. This image is part of a sequence used in the creation of a 3-D movie in collaboration with Eric de Jong, Steve Levoe, and Shigeru Suzuki from the Jet Propulsion laboratory, Pasadena, CA. The movie was shown in a lecture at the Los Angeles County Museum of Art and demonstrates (if nothing else) a link between science and art.

where E is the wave electric field. This current can be seen in the upper right of Fig. 1. The polarization current density was measured to be 100 times smaller than the axial current [4]. The pattern in helium is much more complex and consists of a higher m mode involving five current channels. The magnetic field and current in this case is shown in Fig. 2. At first glance, the current system seems chaotic but it is not. It is an average taken over weeks of experimental time in a highly reproducible experiment. The snakelike current was rendered as such in Fig. 3. How much can we learn from Figs. 2 and 3 other than the current systems are complicated and connect to one another? Care must be taken as all algorithms that follow vector fields encounter difficulties when the field becomes small. The pattern is also sensitive to the start location of each current flux tube. When more than ten or so current streamlines are displayed the image becomes too crowded to decipher. Complicated topological images are a valuable indication of what is occurring but all-important physical quantities (current density, stored energy, helicity) must be quantified from the underlying data. This goes hand-in-hand with the images.

Currents in plasmas are generally never as simple as those shown in Fig. 1 or in the companion paper [2]. They often filament and filaments may effect one another. Visualization techniques are an essential, although somewhat qualitative step in absorbing the physics of the situation at a glance.

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