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EXPERIMENTAL GENERATION OF PLASMA ALFVEN WAVES*

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Alfvên[1] has postulated the existence of hydromagnetic waves to explain certain sunspot phenomena. Some rather complex experimental observations have been reported.[2] We have attempted to generate such a wave at one end of a cylindrical plasma, and to detect the transmitted wave at the other end. This hydromagnetic wave guide consists of a conducting cylinder, 34 in. long and $5\frac{3}{4}$ in. in diameter, filled with hydrogen gas to a pressure of 100 microns, and mounted in a uniform axial magnetic field. At each end of the cylinder there is an insulator and a small coaxial electrode, 2 in. long and 2 in. in diameter. The velocity of propagation of these waves can be derived[3] from the formula $v_A = c/\sqrt{K}$, where K, the dielectric constant of a plasma, is equal to $1 + (4\pi\rho c^2/B^2)$; ρ is the plasma density, B the magnetic field, and c the velocity of light. Since $K >> 1$, we have

$$v_A \simeq B/(4\pi\rho)^{1/2}. \quad (1)$$

The tube is preionized by discharge of a "slow" condenser bank (45 μf) between the two central electrodes. This current reaches a maximum value of 50 kiloamperes in 17 μsec, and then "rings" a few times. A fast condenser bank (1.2 μf) is then discharged between one center electrode and the outer cylinder. This current reaches a maximum value of 25 kiloamperes in 0.7 μsec and also rings a few times. The radial electric field thus produced and the steady axial magnetic field generate a torsional hydromagnetic wave. When this wave arrives at the far end of the cylinder, the radial electric field $\vec{E}_r = -\vec{v}_\theta \times \vec{B}_z$ produces a voltage difference between the center electrode and the outer cylinder. In Fig. 1A, the bottom trace of the dual-beam os-

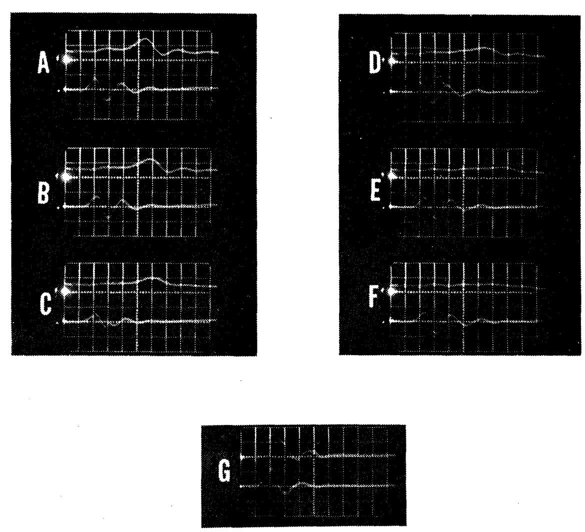

FIG. 1. Dual-beam oscilloscope traces of the transmitted wave form (top) and the driving wave form (bottom). The time scale is 1 μsec/cm. The top voltage scale is 500 volts/cm, and the bottom is 2500 v/cm. The hydrogen gas pressure is 100 microns. The magnetic fields are 9.0, 8.1, 7.2, 6.3, 5.4, and 4.5 kilogauss in pictures A through F, respectively. Picture G shows the "prompt" transmission at low ion density.

cilloscope shows the driving wave form, while the top trace is the transmitted wave form. The time scale is 1 μsec/cm. The transmission time of the wave is measured from the first peak of the driving wave form to the first peak of the transmitted wave form. From this transmission time and the known length of the cylinder we have a direct measurement of the wave velocity.

The operation of the measuring circuits can be checked by discharging the fast condenser bank when there is very slight ionization in the tube. In this case the transmitted wave arrives at the far end, as would be expected, with no measurable delay (Fig. 1*G*).

The change in the transmitted wave form as the magnetic field is varied is shown in Fig. 1, *A* through *F*. The transmission improves with the larger magnetic fields. The experimental velocities are plotted versus magnetic field in Fig. 2, where the solid curve represents the theoretical value given by Eq. (1). One might expect the experimental velocities to be somewhat larger than the theoretical velocities, as follows. From the nature of the preionizing pulse we would expect the ionization to decrease at large radii. The wave velocity would then be a function of the radius. This would increase the average velocity, and also make the period of the transmitted wave form greater than that of the driving wave form, as observed in Fig. 1.

The measured velocity decreases as the gas pressure is increased, but the variation is not as large as predicted by Eq. (1). Since the energy from the preionizing condenser bank is approximately constant, the percent ionization decreases at higher pressures and causes a deviation from the theoretical velocity. If the ionization parameters are not optimized, the measured velocity is larger than the Alfvên velocity, and in the limit of very low ionization the "prompt" transmitted pulse of Fig. 1*G* is observed.

At 12.6 kilogauss the peak of the driving wave form is about 1200 volts and the peak of the transmitted wave form is about 500 volts. This factor of 2.4 in the attenuation could result from several causes. The radially dependent wave velocity mentioned above can significantly decrease the transmitted wave peak. Sheath effects

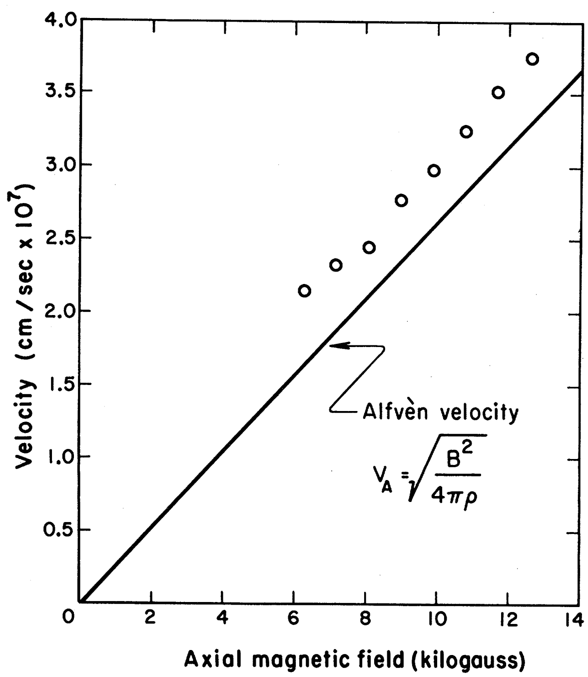

FIG. 2. Wave velocity vs magnetic field. The circles are experimental points and the solid curve is the Alfvên velocity. The hydrogen gas pressure is 100 microns.

may cause only part of the driving voltage to be effective in actually driving the wave. Some of the wave energy may be lost to the insulators. Finally there is the attenuation of the wave passing through the plasma.

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[1]H. Alfvên, Arkiv Mat. Astron. Fysik 29B, No. 2 (1943).

[2]See T. G. Cowling, Magnetohydrodynamics (Interscience Publishers, Inc., New York, 1957), Chap. 3, for a review to 1957; also Sawyer, Scott, and Stratton, Phys. Fluids 2, 47 (1959).

[3]L. Spitzer, Jr., Physics of Fully Ionized Gases (Interscience Publishers, Inc., New York, 1956).

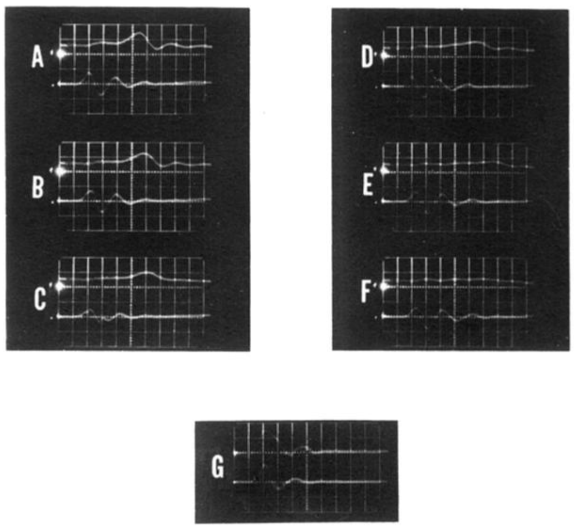

FIG. 1. Dual-beam oscilloscope traces of the transmitted wave form (top) and the driving wave form (bottom). The time scale is 1 μsec/cm. The top voltage scale is 500 volts/cm, and the bottom is 2500 v/cm. The hydrogen gas pressure is 100 microns. The magnetic fields are 9.0, 8.1, 7.2, 6.3, 5.4, and 4.5 kilogauss in pictures A through F, respectively. Picture G shows the "prompt" transmission at low ion density.