Current Disruption Wave Generation

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A fast energy wave packet pulse with a velocity greater than 10^8 cm/s has been generated from a T-shock tube, accompanying the discharge current disruption and a sharp voltage peak. The distribution of the disrupted wave increases the plasma temperature by 5 eV, and the density jumps to 2–3 times its initial value. The disruption wave streams through the proceeding plasma and shock wave without noticeable dissipative interaction. The production of a backward shock wave has been referred to the destruction of the wave at the expansion chamber. A propagated magnetosonic wave with a velocity of 6×10^5 cm/s has been detected, which was excited near the discharge electrodes.

Introduction

The current disruptive plasma instability results in the emission of a considerable part of the energy of the plasma column [1]. This has been observed in a TOKAMAK plasma column in relation with hydromagnetic instability modes [1, 2]. In a shock T-tube, a backward shock wave is formed, its generation being due to shock wave-medium interaction [3]. A luminous narrow peak, which is the concern of this paper, has been observed at nearly the same time for all positions of the T-tube.

Experimental Arrangement

The experiment consists of a capacitor bank (110 µF, 5 kV), a 3 electrode high voltage-high current discharge control spark-gap switch (Triggatron type), and a discharge T-tube system. The T-tube has two annular electrodes with 4 cm diameter and 1 cm distance, facing the expansion chamber of 50 cm length and 5 cm diameter. On the other side of the expansion chamber the back current flows through a copper strip.

The discharge current was 20 kA with a rise time of 20 µs. The test gas was hydrogen at 1.2×10^{-2} torr base pressure.

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A biased double electric probe with a 1.2 Ohm load resistor and a 100 µF capacitor was used to measure the plasma density and temperature. A diamagnetic loop of 40 turns fitted with a 10^{-4} s integrator was used to measure the self induced axial magnetic field and the diamagnetic plasma properties in the presence of an external axial magnetic field. A spectrograph with 8 Å/mm resolution power, fitted with a 0.1 mm slit and IP-28 photomultipliers, was used to detect the spectral line intensity, while the whole plasma radiation spectrum (common light) was monitored by an optical collimation system, photomultiplier, and neutral density filter.

Results and Discussion

The discharge current and voltage traces are shown in Fig. 1, where a sharp positive pulse appears on the voltage trace at the moment of the discharge current disruption. Electric probe measurements show that the rest gas is pre-ionized at the start of the discharge by UV radiation and energetic particles from the discharge to a density level of 2×10^{13} cm^{-3} and a temperature of 1.5 eV. Photomultiplier observations showed that the plasma is driven from the discharge electrodes with a velocity of 10^5 cm/s for the first half cycle, which is mainly a hydrogen plasma. The plasma at the second and third half cycles of the discharge is highly contaminated by the erroded material of the electrodes and the discharge chamber walls, which was observed from the traces of the time resolved

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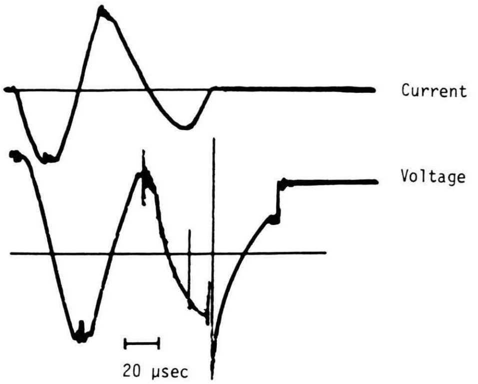

Fig. 1. Discharge current and voltage traces.

spectral lines intensity of hydrogen, oxygen, silicon and carbon.

Successive shock waves were detected at each half cycle of the discharge by the use of a photomultiplier, and an electric probe and a pick-up coil at a distance 4–6 cm from the discharge electrodes. The shock wave velocities V_{sh} were found to be 10^7, 6×10^6 and 2×10^6 cm/s, following the formula $V_{sh} \propto Z^{-\beta}$, with the damping rates $\beta = 0.25$, 0.7 and 0.45, respectively, for the first, second and third half cycles of the discharge current.

A backward wave has been detected [3] at $z = 30$ cm from the discharge electrodes with a velocity of 10^6 cm/s and a damping rate of $\beta = 0.25$. The damping rate defines [4] the energy transportation process for the shock wave; for $0.5 \leq \beta \leq 1$ it represents a snow-plough model where the energy is transferred by ion-ion collisions while for the shocks with $\beta > 1$ the electrons-ion collisions are the dominant factor.

The photomultiplier signal at $z = 30$ cm (Fig. 2a) and the spectral line H_β (Fig. 2b) showed an intense sharp peak at the current disruption moment (120 μs) which travels with a velocity greater than 10^8 cm/s. The electric probe signal at 2 cm off centre of the expansion chamber axis (Fig. 2c) showed potential jumps for the waves, while at the moment of current disruption it shows an oscillatory form of the third shock wave.

The compensated diamagnetic loops dB/dt (Fig. 2d) detected a magnetic wave W_B which travels with a velocity of 6×10^5 cm/s. The positive and negative pulses are due to the opposite winding directions of the two pick-up coils. The dotted line drawn on the first portion of the signal represents

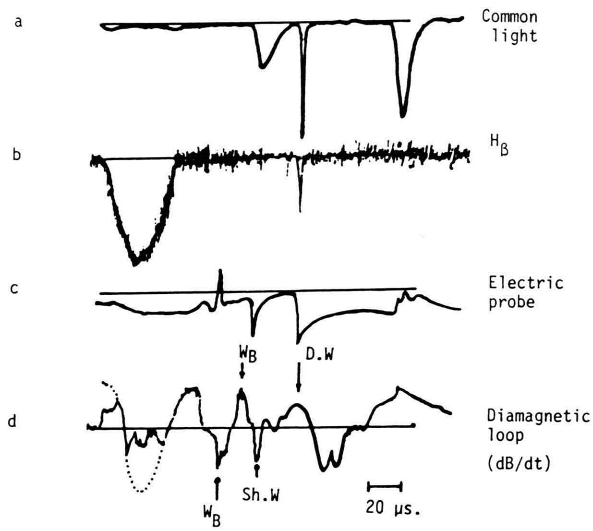

Fig. 2. Traces of the common light, spectral line H_β, electric probe and diamagnetic loop at $Z = 30$ cm.

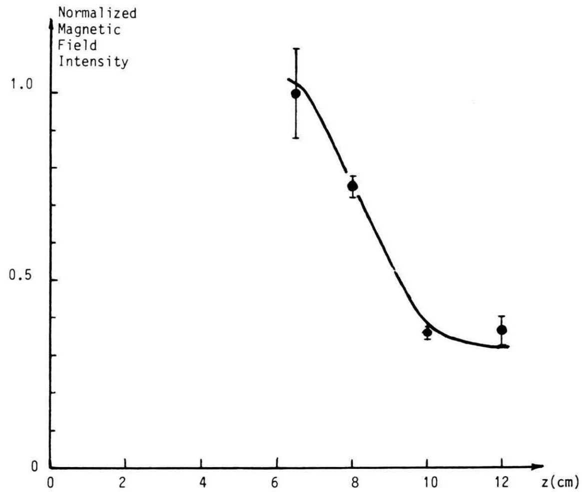

Fig. 3. Magnetic field intensity versus position (z).

the magnetic flux of the discharge current which is disturberd by the plasma flow. The dependence of the wave velocity on the position is $V \propto Z^{-0.7}$. The magnetic field amplitude of the wave decreases with position following the formula $B \propto Z^{-0.18}$ (Figure 3).

The Alfvén wave velocity, which might be excited, has a value of $V_a = B_0/(4\pi\varrho)^{1/2} = 5.7 \times 10^5$ cm/s. Since the magnetic field was perturbed by the plasma flow from the discharge, a magnetosonic

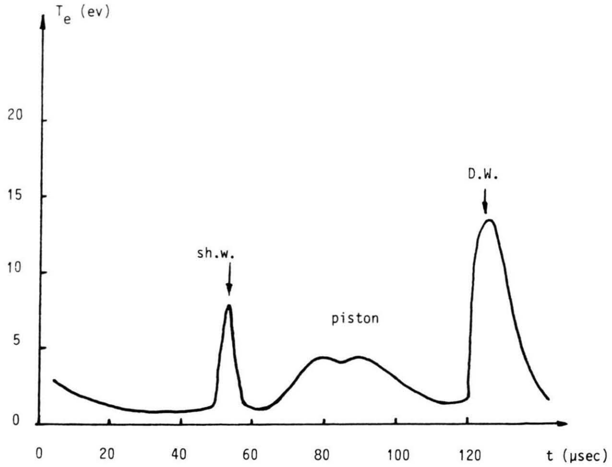

Fig. 4. Temperature variation with time, at $Z = 45$ cm.

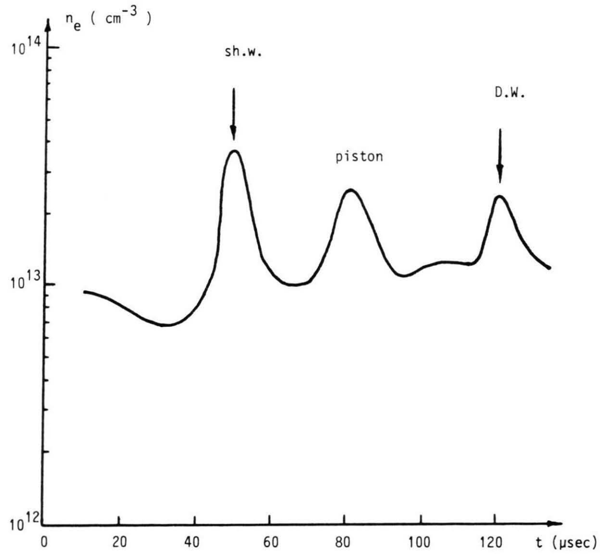

Fig. 5. Density variation with time, at $Z = 45$ cm.

wave might be excited [5, 6] when the magnetic pressure is much greater than the plasma kinetic pressure, i. e. $B^2/8\pi \gg nkT$. The excited magnetosonic wave will propagate perpendicularly to the direction of the magnetic field with a velocity $V_{WB} = (V_a^2 + V_s^2)^{1/2}$, where V_s is the sound wave velocity, which is in conformity with the measured values.

The disruption wave pulse is to propagate as a wave packet without noticeable dissipation and is accompanied by an oscillatory magnetic field of frequency $\omega \approx 10^5\ s^{-1}$. The disruption wave is completely distructed at $z = 45$ cm near the end of the expansion chamber, and has also been distructed by the electric probe placed at its path. Sometimes one or two small peaks are formed and continue to propagate.

The density and temperature measurements at the destruction position showed that the plasma is heated up to 8 eV (Fig. 4), and the density increases by a factor of 2−3 from its initial value (Figure 5). The instabilities which occur due to the current disruption cause an acceleration of the charged particles which was observed previously [1], while in that case a solitary wave has been generated.

Conclusions

In a T-shock tube a solitary wave is generated due to the instabilities occurring by the current disruptiln. The plasma temperature and density are increased due to the destruction of the disrupted wave. The detected magnetic wave is most likely a magnetosonic one, which will propagate with a frequency in the low frequency range.

[1] V. G. Merezhkin, Fizika Plasmy **4,** 275 (1978).
[2] B. V. Waddel, B. Carreras, H. R. Hicks, and Z. A. Holmes, Phys. Fluids **22,** 897 (1979).
[3] W. Sharkway, A. H. Saudy, and M. M. Masoud, J. Fiz. Mal. **6,** 151 (1985).
[4] M. M. Masoud, T. A. El Khalafawy, and V. A. Souprunenko, NUcl. Fusion **9,** 49 (1969).
[5] A. I. Akhiezer, I. A. Akhiezer, R. V. Polovin, A. G. Sitenko, and K. N. Stepanov, Collective Oscillations in a Plasma, Pergamon Press, London 1967, p. 61−62.
[6] D. A. Tidman and N. A. Krall, Shock Waves in Collisionless Plasmas, John Wiley, New York 1971, p. 79.