Suppression of ω_{ci} Instability in a Mirror Confined Plasma by Injection Of an Electron Beam*

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ABSTRACT

A hot ion plasma ($\bar{E}_{i\perp} \simeq 400$ eV, $n \simeq 10^{13}$ cm^{-3}) is trapped in a minimum B mirror system. A strong instability at ω_{ci} is observed for neutral densities $< 10^{11}$ cm^{-3}. We have observed the suppression of this instability when an electron beam (≥ 42 kW) is injected into the plasma. We believe the suppression is due to a population of hot electrons produced and trapped in the mirror by the beam-plasma interaction.

Mirror confined plasmas may exhibit strong microinstabilities driven by the inverted nature of the particle distribution.[1] Recently, it has been shown that the hole in velocity space can be filled by injection of a warm plasma stream. This has resulted in nearly classical loss times of hot, highly ionized plasmas.[2] A problem with this technique is that the warm plasma cools the electrons of the confined plasma. Ioffe, et al.[3] describe a different method of populating the cold part of the velocity distribution. They use electron cyclotron resonance heating to produce a small population of energetic electrons near the mirror mid plane, with $v_\perp \gg v_\parallel$. These are magnetically trapped and produce a local depression of the space potential. It is believed that this inhibits the plasma loss and helps to fill the velocity distribution. In their experiments they were able to suppress the drift cyclotron loss cone instability.

We report here an alternate scheme for suppressing these instabilities, by creating a trapped hot electron population by the interaction of an electron beam and the main plasma. Earlier studies[4,5] of electron beam-plasma interactions have shown that a small population of very hot electrons ($\gtrsim$20 keV) with $v_\perp \gg v_\parallel$ is produced when high power electron beams are injected into mirror confined plasmas.

In order to produce a loss cone distribution that will drive instabilities, the ions must have a mean free path $\gtrsim$100 mirror bounce times. This requires $\bar{E}_{i\perp} > 100$ eV and neutral density $n_o < 10^{11}\,\text{cm}^{-3}$. These conditions have been met in our apparatus, Figure 1. The mirror is of the min B type, with the hexapole field produced by ferrite permanent magnets.

The axial field is produced by an array of 15 coils that form the confining mirror and the guide field for the plasma injected by the Ti-washer plasma gun. A series of baffles and Ti getter pumps keep neutral gas from the gun from reaching the mirror, so that $n_o < 10^{11}$ cm^{-3} during the injection and containment periods of the experiment. The plasma gun pulse length may be varied between 0.1 and 2 msec. To prevent residual plasma from the gun entering the mirror after "turn-off", a divertor coil may be energized that magnetically disconnects the mirror and the gun. This insures that the plasma will not be stabilized by the injection of cold plasma.

Diagnostic equipment includes an 8 mm interferometer, a single channel charge exchange analyzer, three floating-potential probes at mid plane, Langmuir probes at mid plane and just outside the mirror peaks, a diamagnetic loop, and an X-ray scintillator located outside the stainless steel vacuum chamber.

Our results without E-beam injection show a strong instability at ω_{ci}. during the plasma decay and a loss rate exceeding classical. Measurements are made following the turn-off of the plasma gun. At the start of this period the plasma parameters are: $n > 2 \times 10^{13}$ cm^{-3}, $\bar{E}_{i\perp} = 400$ eV, $T_e \simeq 10$ eV. T_e is measured by a Langmuir probe at the plasma edge 4 cm from the axis. Figure 2 shows the density decay and the oscillations at the ion cyclotron frequency detected by a floating-potential probe at mid plane. This type of decay is observed under good vacuum conditions. Insufficient getter pumping or prolonged plasma injection, $\gtrsim 1/2$ msec, results in a stable decay.

The electron beam was injected from an oxide coated cathode, magnetron injection gun located at the end opposite the plasma gun. It was pulsed for times up to 0.6 msec, and up to 8 kV, 7 amps. The beam was hollow, 1 cm dia and 0.1 cm thick. In the stabilization experiments, the plasma gun and electron gun were fired simultaneously. During the injection period we observed strong signals at frequencies $\gtrsim 30$ GHz, emission of hard X-rays, and increased plasma diamagnetism. These are characteristics of strong electron beam-plasma interactions.

During the decay period we continue to detect hard X-rays and an increased diamagnetic signal, Figure 3, indicating that we have produced and trapped a population of hot electrons by the beam-plasma interaction, as has been observed previously in intense beam-plasma discharges.[4.5] Fig. 4 shows the effect of the E-beam injection on the intensity of ion cyclotron instability. We record the results of 34 consecutive shots. It is obvious that the intensity is a strong function of beam power. At the highest beam powers we had available, the plasma decay time was nearly classical. The enhanced fluctuation levels for beam powers < 42 kW are believed to be due to a combination of bulk heating of the electrons and too small a population of hot electrons. Langmuir probe measurements near the plasma edge indicate an increase of T_e from 10 eV to 17 eV with E-beam injection.

We do not observe the sharp drop in floating potential that Ioffe reports of his stabilization by electron cyclotron heating. Although we have not yet measured the axial distribution of hot electrons, produced by the electron beam, we doubt that they are concentrated at the mid-plane. A possible stabilizing mechanism suggested by D. Baldwin is that the hot electrons may have a high enough ∇B precession to equal the diamagnetic drift speed and may thus short circuit the fields that drive the instability.

In summary, we report a new, and technically simple way of stabilizing ion cyclotron loss cone instabilities. It may have important applications either used alone, or in conjunction with warm plasma injection in the stabilization of mirror confined thermonuclear plasma.

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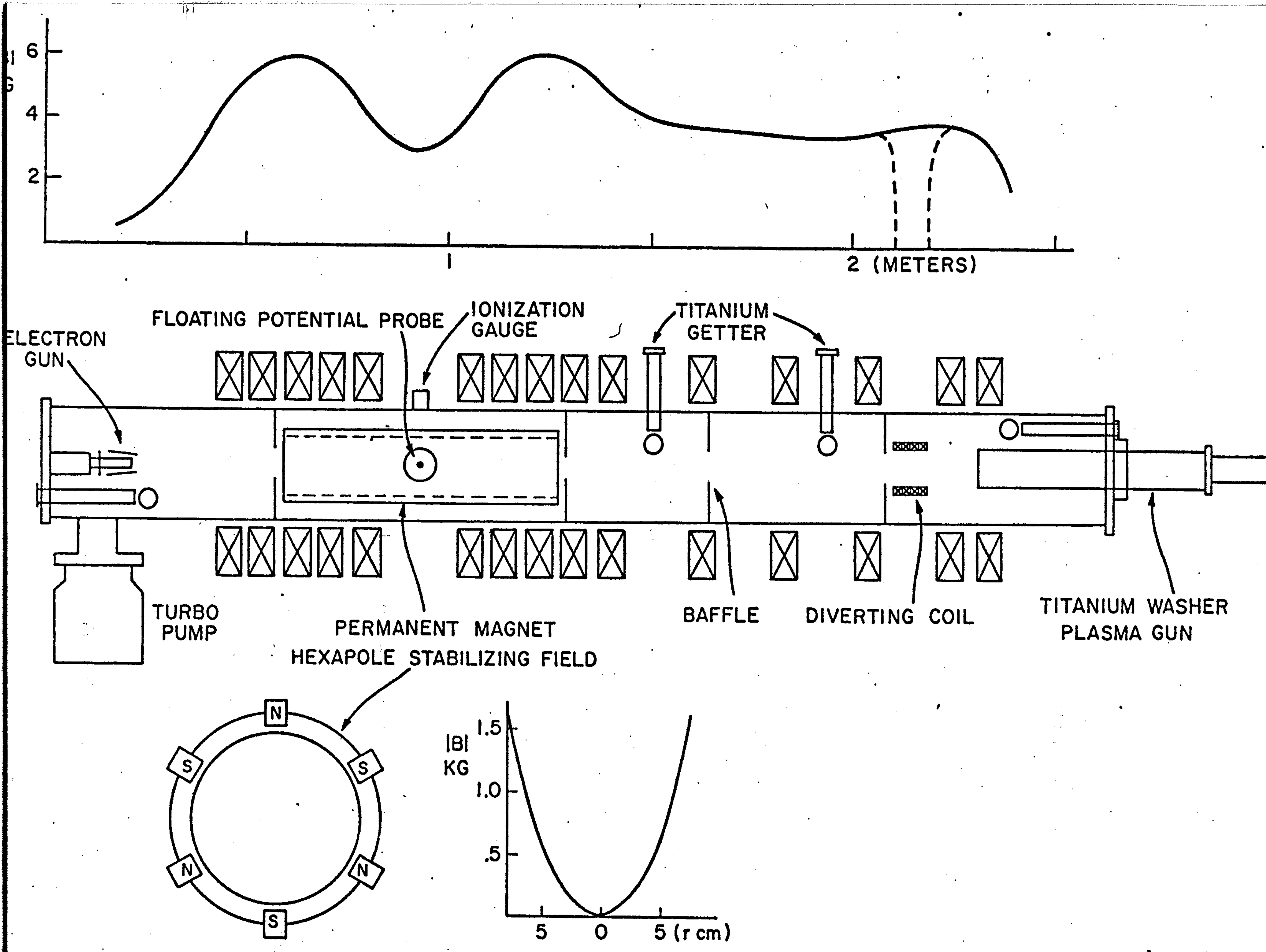
FIGURES

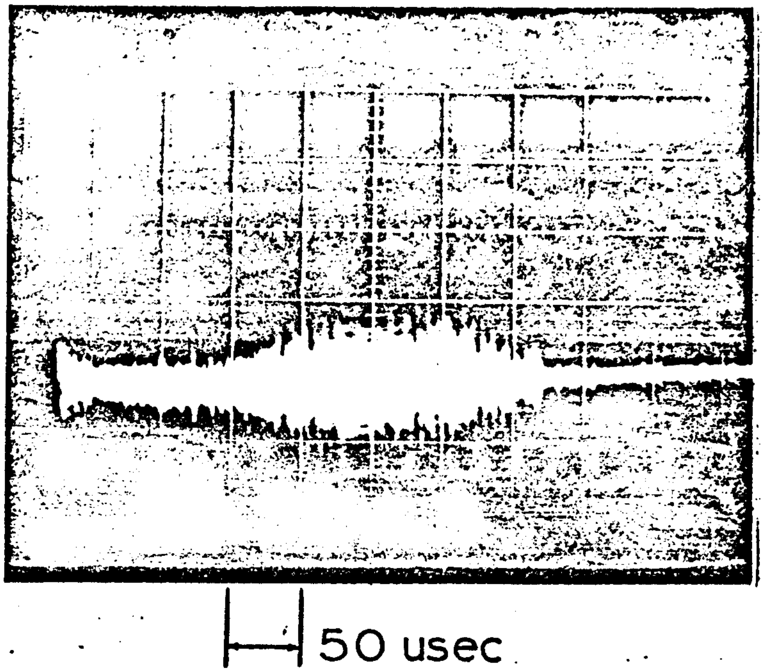
FIG. 1 Experimental apparatus for studying loss-cone microinstabilities.

FIG. 2 Unstable decay of confined plasma following Ti washer gun turn off.
a) High frequency signal of floating potential probe at mid-plane.
b) Line density recorded at the mid-plane.

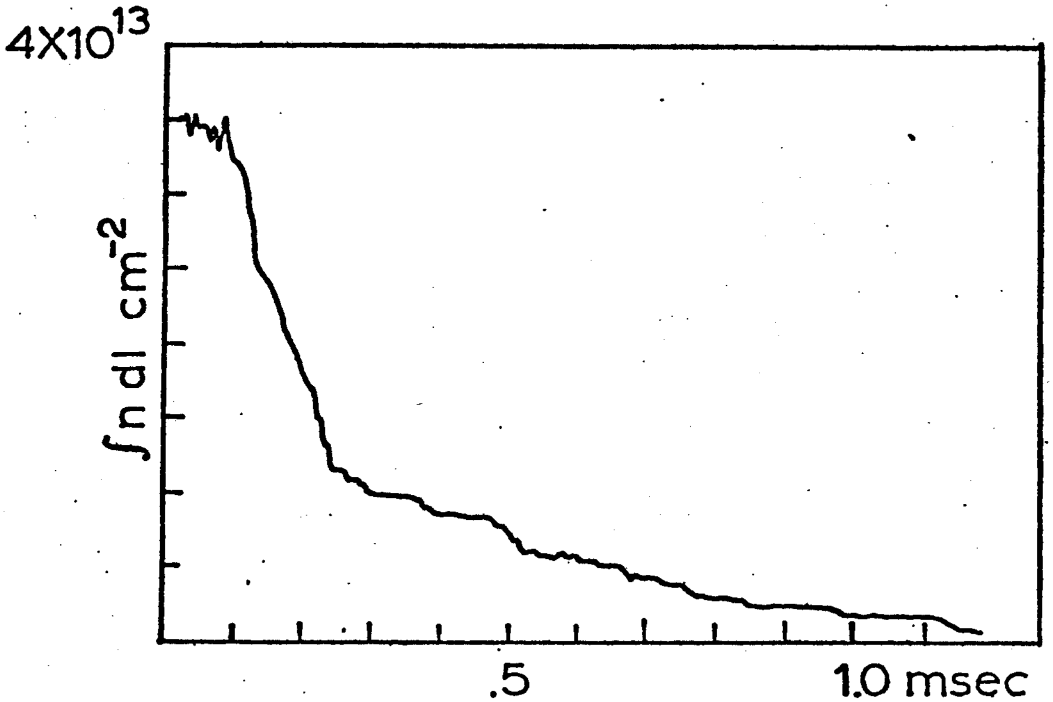
FIG. 3 Evidence of E-beam plasma interaction.
a) X-ray signal recorded outside the stainless steel vacuum chamber.
b) Diamagnetic signal recorded by loop at mirror mid-plane.

FIG. 4 High frequency signal of floating potential probe versus E-beam power.

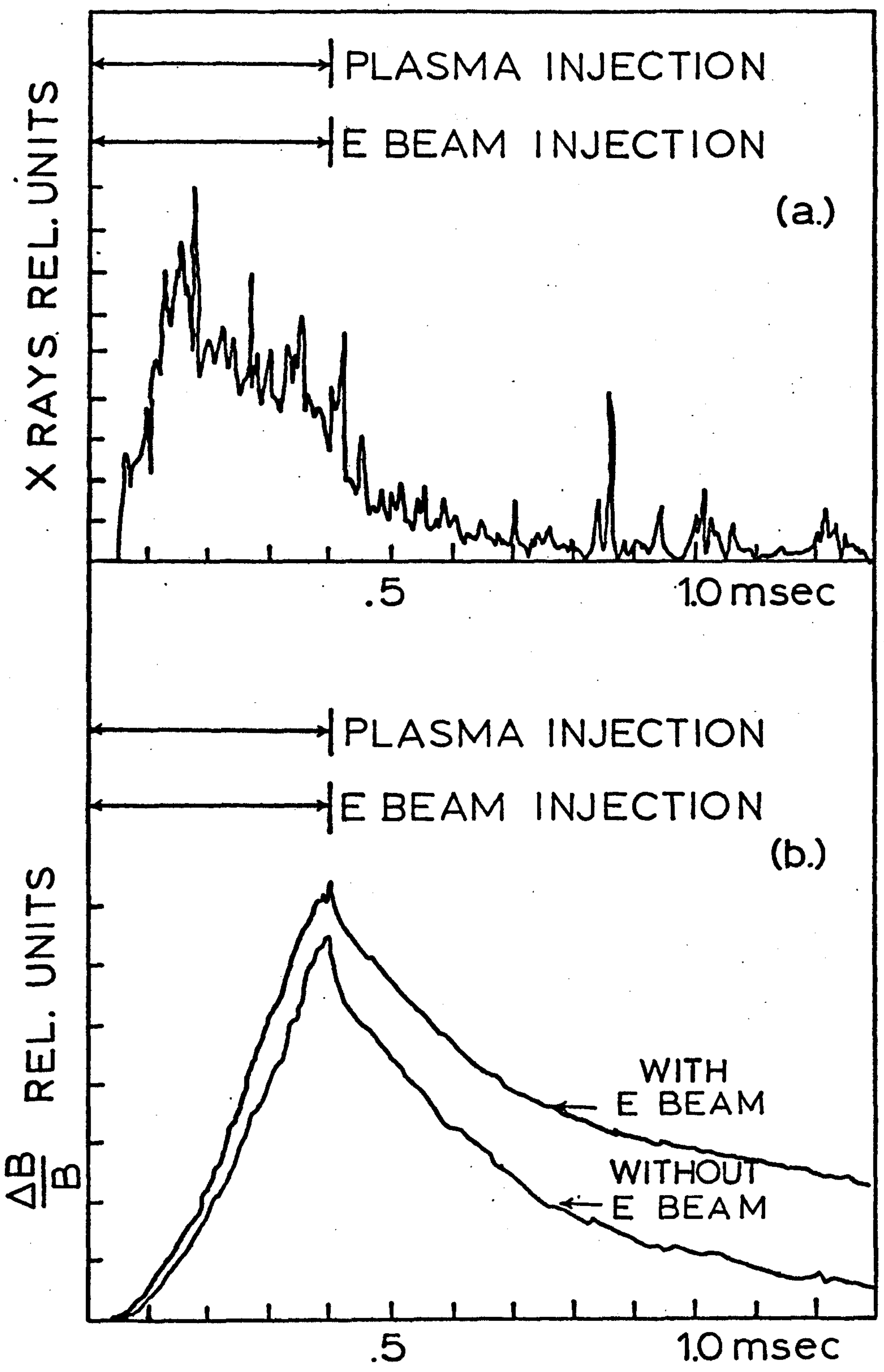

6
4
2
1
2 (METERS)
FLOATING POTENTIAL PROBE
IONIZATION GAUGE
TITANIUM GETTER
ELECTRON GUN
TURBO PUMP
PERMANENT MAGNET
HEXAPOLE STABILIZING FIELD
BAFFLE
DIVERTING COIL
TITANIUM WASHER PLASMA GUN
N
S
S
N
N
S
|B| KG
1.5
1.0
.5
5
0
5 (r cm)

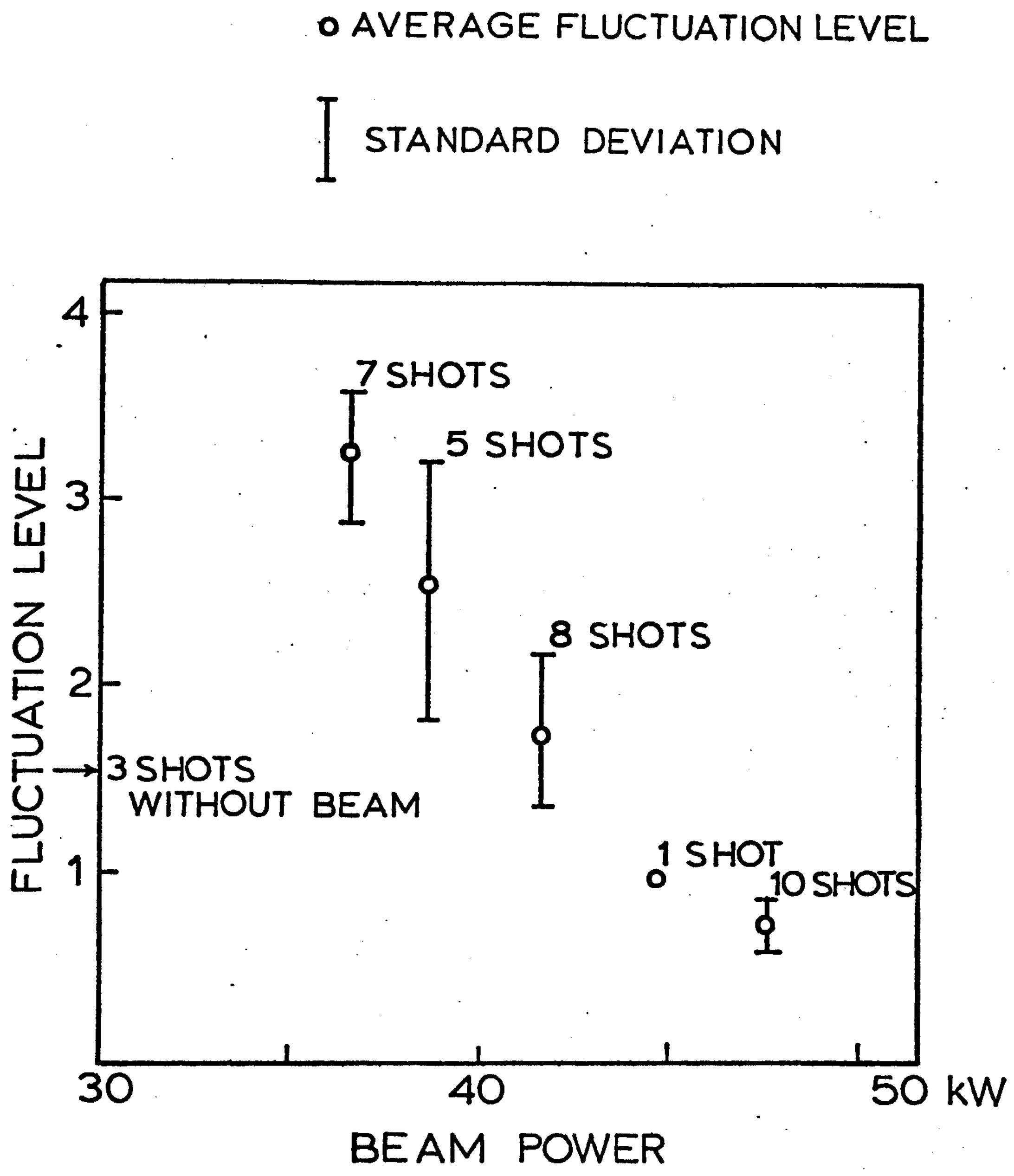


(a.)



(b.)


PLASMA INJECTION
E BEAM INJECTION
(a.)
X RAYS REL. UNITS
.5
1.0 msec
PLASMA INJECTION
E BEAM INJECTION
(b.)
$\frac{\Delta B}{B}$ REL. UNITS
WITH E BEAM
WITHOUT E BEAM
.5
1.0 msec



o AVERAGE FLUCTUATION LEVEL
STANDARD DEVIATION
FLUCTUATION LEVEL
4
3
2
1
7 SHOTS
5 SHOTS
8 SHOTS
3 SHOTS WITHOUT BEAM
1 SHOT
10 SHOTS
30
40
50 kW
BEAM POWER