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ABSTRACT

The effect of an applied toroidal magnetic field upon the rotamak configuration has been investigated. It has been found that the configuration can be maintained for at least several milliseconds, but it has not been unambiguously established whether the addition of the toroidal field is beneficial or detrimental to the rotamak discharge.

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PLASMA; TOKAMAK DEVICES; COMPACT TORUS; MAGNETIC FIELDS; CONFINEMENT TIME; ELECTRIC CURRENTS; ELECTRIC DISCHARGES; HYDROGEN; EXPERIMENTAL DATA

CONTENTS

1. INTRODUCTION

The rotamak is a compact torus device in which the toroidal current is driven by a rotating magnetic field. The resulting steady magnetic field consists of a combination of closed and open poloidal field lines, as indicated in figure 1. It is believed that the inclusion of a toroidal magnetic field is unnecessary from a stability viewpoint, consequently nearly all the rotamak research undertaken so far has been performed without such a field. However, a toroidal field may offer other benefits such as improved particle and energy confinement.

Hugrass *et al.* [1980] performed a preliminary investigation in the early high power, short duration rotamak experiments using argon as the filling gas. The limited duration of these discharges made it difficult to establish the merits of including a toroidal field. The present experiments extend the earlier investigation to long duration (~ 15 ms) hydrogen discharges.

2. EXPERIMENTAL EQUIPMENT

The discharge vessel, vacuum system, Helmholtz coils and radio-frequency (RF) current sources have been described by Durance *et al.* [1984a]. However, for the present experiment the frequency of the rotating field has been lowered from 1.85 to 1.0 MHz. The diagnostics described by Durance *et al.* [1984a,b] have been used in the present studies.

The toroidal field is generated by passing a current (~ 500 A) through a metal conductor (3.2 mm diameter) located along the z-axis. The return path is made up of four straight conductors arranged symmetrically about the spherical discharge vessel and at a distance of ~ 19 cm from the central axis. The risetime and duration of the current pulses to the toroidal and vertical magnetic field coils are identical, but the current amplitudes are independently variable.

3. EXPERIMENTS AND RESULTS

All experiments were performed with an initial hydrogen filling pressure of ~ 1.2 mtorr. In conventional rotamak discharges, it has been observed that the magnitude of the driven toroidal current is related linearly to the amplitude of the externally applied vertical field. Such behaviour also occurs when a toroidal magnetic field is applied; this has enabled the poloidal field to be varied with respect to the toroidal field by simply varying the currents through the vertical field coils relative to the current through the axial conductor. From such studies, two general observations can be made: first, for the same vertical field, the driven toroidal current is significantly smaller in the presence of a toroidal field; second, when a toroidal field is present, the driven toroidal current is observed to 'cut off' abruptly before the termination of either the rotating magnetic field or the applied vertical field.

For the present measurements, a relatively small value of the driven toroidal current (~ 150 A) has been chosen to maximise the effect of the toroidal magnetic field relative to the poloidal field. The driven toroidal current, with and without a toroidal field, is shown in figure 2. Also shown is the vertical field which has been kept constant in both cases. Figure 3 shows the radial distribution of the z-component of the poloidal field during the discharge at time t = 10 ms for the two cases. A small correction has been applied to account for pick-up of the toroidal field (estimated to be 1.3 per cent of the toroidal field) arising from imperfect alignment of the probe. When such results taken over the whole discharge are integrated, the radial position of the separatrix can be determined (see figure 4).

The radial distributions at z = 0 of the toroidal field *in vacuo* and during a plasma discharge were measured with a Hall effect probe; the results are shown in figure 5. The toroidal field decreases slightly during the plasma discharge implying that a diamagnetic current is generated within the plasma. It is possible to calculate the magnitude of this poloidal current as follows. The resultant toroidal field, B_θ, due to these poloidal plasma currents must be given by

$$B_\theta(r,0) = B_\theta^{plasma}(r,0) - B_\theta^{vac}(r,0),$$

where $B_\theta^{plasma}(r,0)$ and $B_\theta^{vac}(r,0)$ are the measured toroidal fields with and without a plasma. From Ampere's Law, it follows that the poloidal current (I_{pol}) inside the radius r is given by

$$I_{pol}(r) = \frac{2\pi r}{\mu_0}\left[B_\theta^{plasma}(r,0) - B_\theta^{vac}(r,0)\right]$$

The quantity $r[B_\theta^{plasma}(r,0) - B_\theta^{vac}(r,0)]$ is plotted in figure 6. From the maximum value of this quantity the total poloidal current is estimated to be ~ 75 A. The poloidal current is relatively large compared with the driven toroidal current of ~ 150 A.

The penetration of the rotating RF field into the plasma was investigated using a small wire-wound probe; the results are shown in figure 7. Since the probe output is proportional to dB/dt, the slowly varying toroidal field is negligible compared to the rapidly varying RF component.

Estimates of the power input to the plasma were obtained by measuring the r.m.s. voltage V_0, the r.m.s. current I_0 and their relative phase ϕ_0 in the matching circuit during a plasma discharge. These quantities were also measured during a vacuum shot and the effective circuit resistance, R, derived. The input power, P, is thus

$$P = V_0 I_0 \cos(\phi_0) - I_0 R^2 .$$

The results are shown in figure 8.

All these results were unaffected by reversal of the direction of the toroidal field in the discharge.

4. DISCUSSION

From the experimental results a number of observations can be made:

(a) A compact torus plasma with an embedded toroidal magnetic field has been maintained for at least ~ 6 ms.

(b) Since the toroidal field is non-zero outside the plasma, the resulting plasma/field configuration resembles a compact tokamak rather than a spheromak.

(c) A diamagnetic poloidal current has been generated. This contrasts with the paramagnetic current reported for the earlier short duration experiments with an argon plasma [Hugrass *et al.* 1980].

(d) The driven toroidal current is smaller than that found in the equivalent experiment without a toroidal field.

(e) A simple calculation shows that the net $J_{pol} \times B_{tor}$ force is outwards for a weakly diamagnetic current. This is consistent with the observation that the separatrix radius is slightly larger when the toroidal field is present.

(f) The penetration of the rotating magnetic field into the plasma improves when the toroidal field is present.

(g) Within experimental errors, the RF power input to the plasma remains essentially unchanged by the presence of the toroidal field. This suggests that the additional ohmic dissipation introduced by the poloidal current is largely compensated for by a decrease in the ohmic dissipation from the toroidal and screening currents.

(h) The reason for the abrupt termination of the configuration is not known; the most likely explanations are either that a plasma instability occurs or that insufficient power is available to sustain the equilibrium.

5. CONCLUSIONS

It is concluded that a compact torus configuration with a toroidal magnetic field can be maintained, for several milliseconds at least, in a rotamak device. Within the limited scope of these experiments, it has not been possible to establish unambiguously whether the addition of the toroidal field has had a beneficial or detrimental effect on the rotamak discharges. Such an assessment must await detailed energy and particle confinement measurements.

6. ACKNOWLEDGEMENTS

One of the authors (J. Trowse) wishes to acknowledge the assistance of the Australian Institute of Nuclear Science and Engineering in the form of a research studentship.

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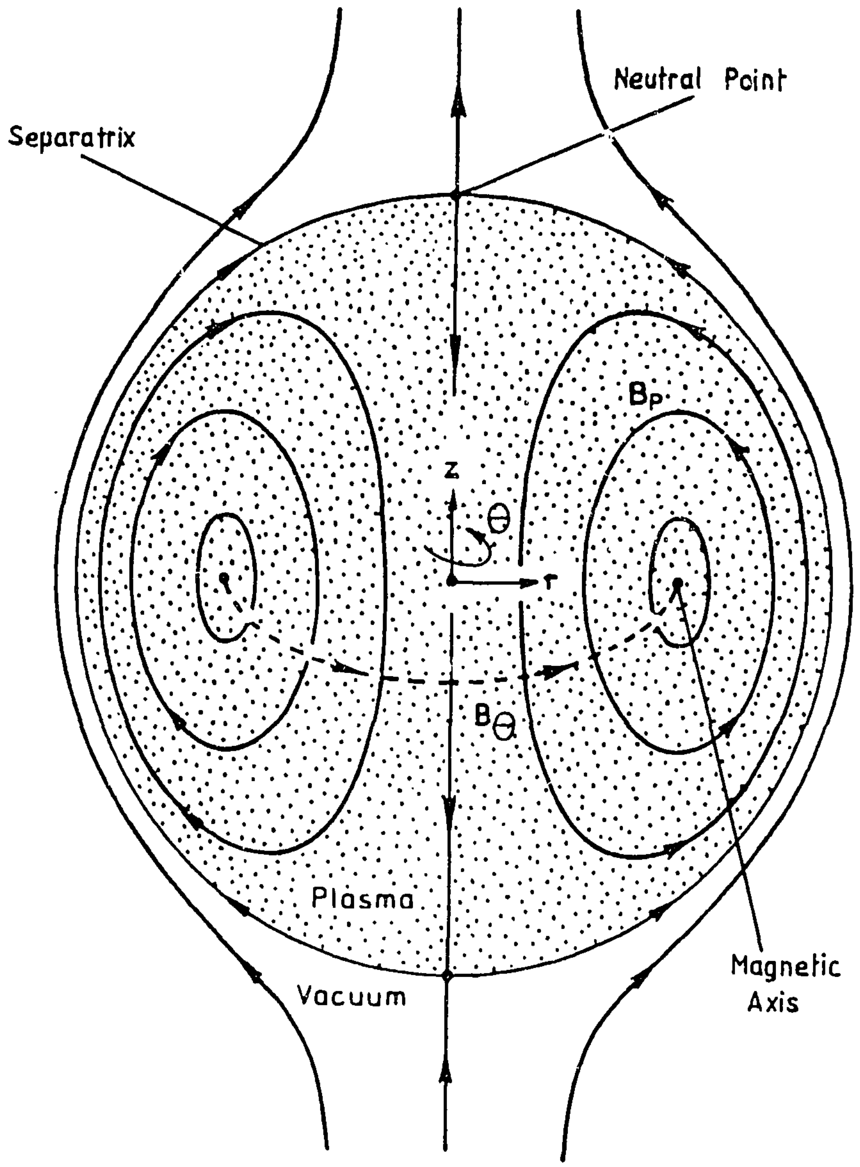

Figure 1 The magnetic field configuration of a compact torus device. B_p is the poloidal magnetic field ; B_θ is the toroidal magnetic field. The origin of the cylindrical coordinate system (r,θ,z) is also indicated

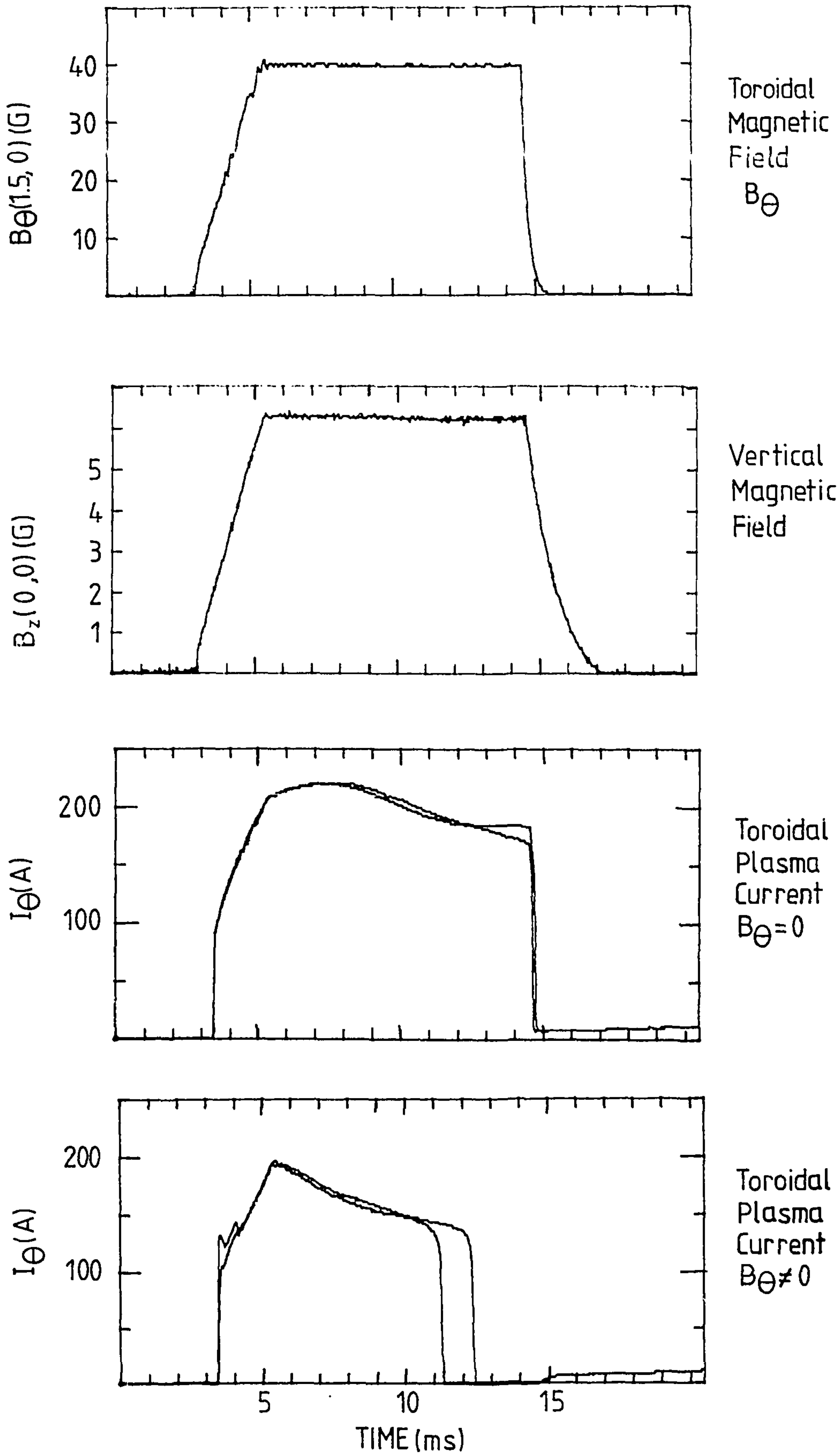

Figure 2 The applied toroidal and vertical magnetic fields are shown. The toroidal plasma current is also shown for the cases with and without the toroidal magnetic field. The two overlying current traces are shown to indicate their reproducibility

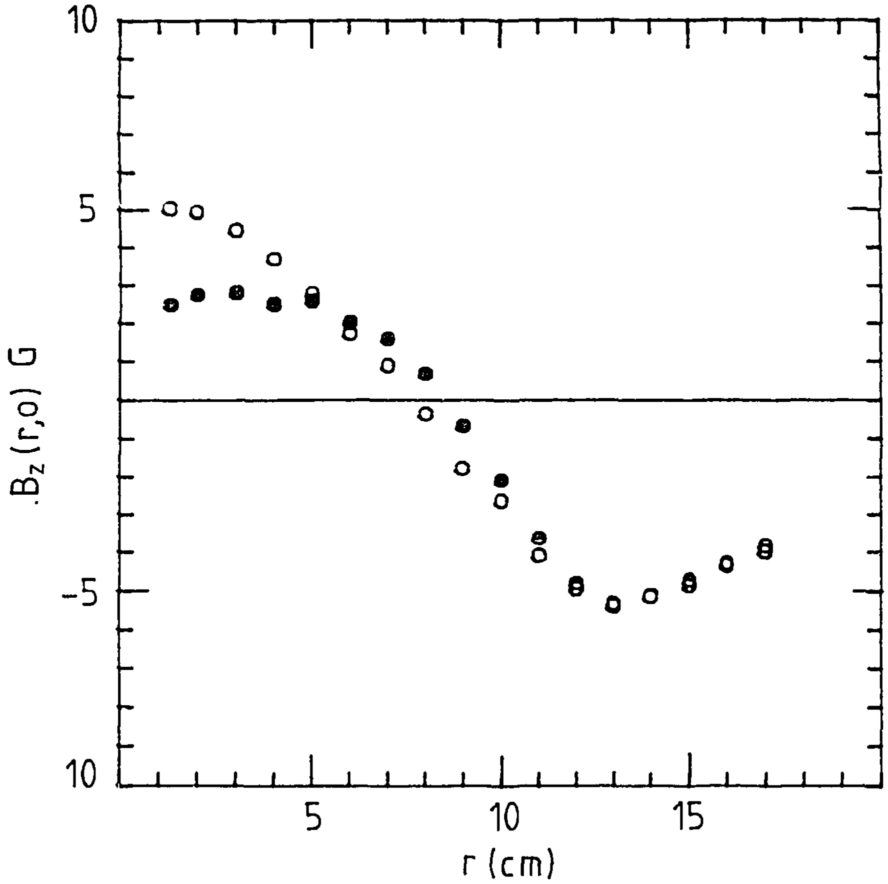

Figure 3 The radial distribution of the z-component of the poloidal field during the discharge, both with (solid circles) and without (open circles) the applied toroidal field at time t = 10 ms

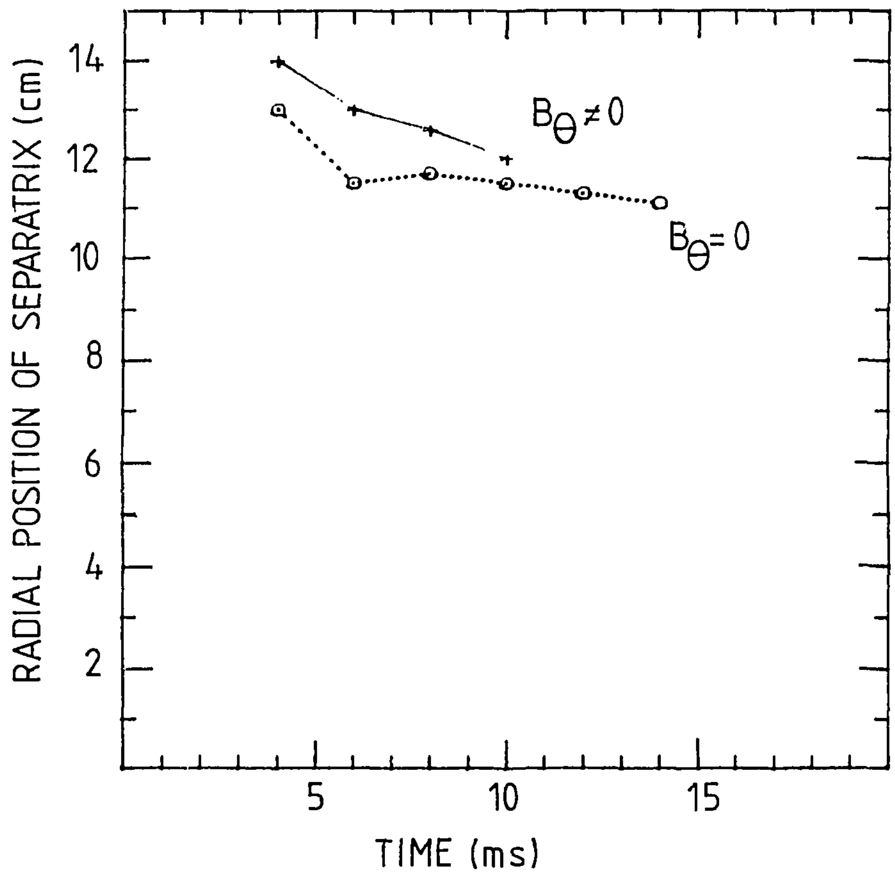

Figure 4 The radial position of the separatrix at z = 0, both with and without the applied toroidal field

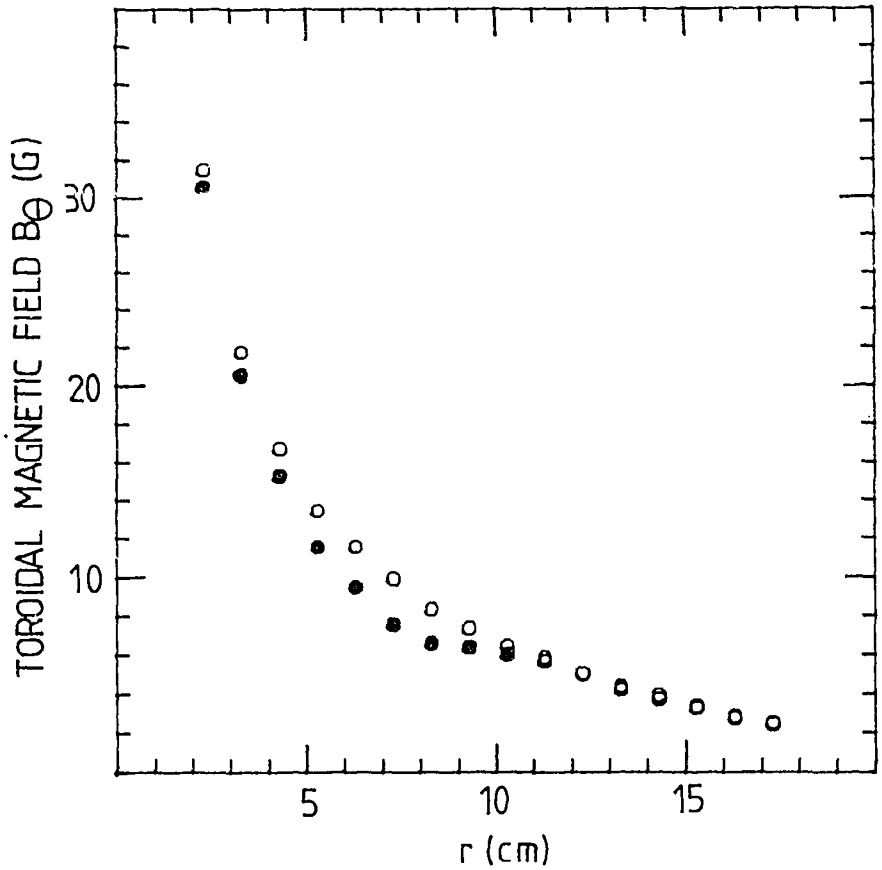

Figure 5 The radial distribution of the toroidal magnetic field *in vacuo* (open circles) and during a plasma discharge (closed circles)

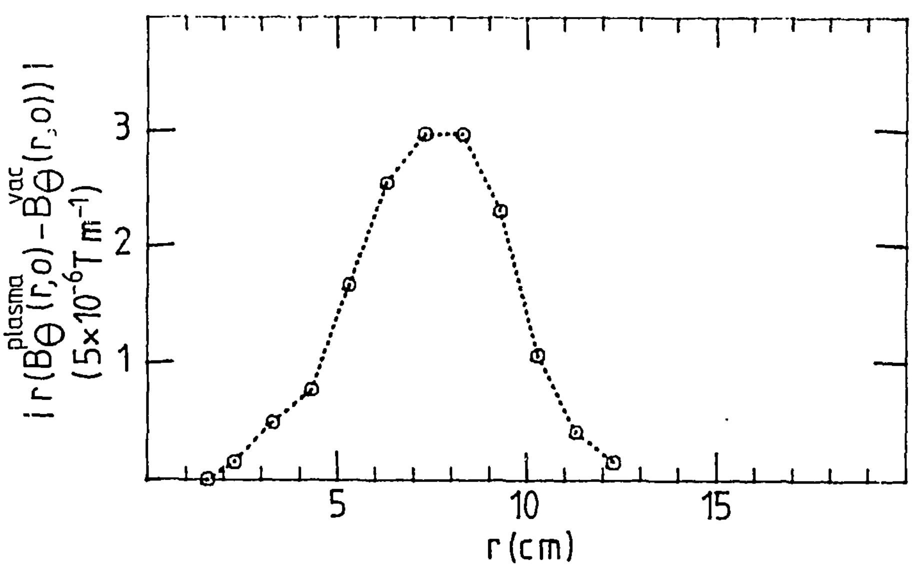

Figure 6 The quantity $r[B_\theta^{plasma}(r,0) - B_\theta^{vac}(r,0)]$ *vs* r

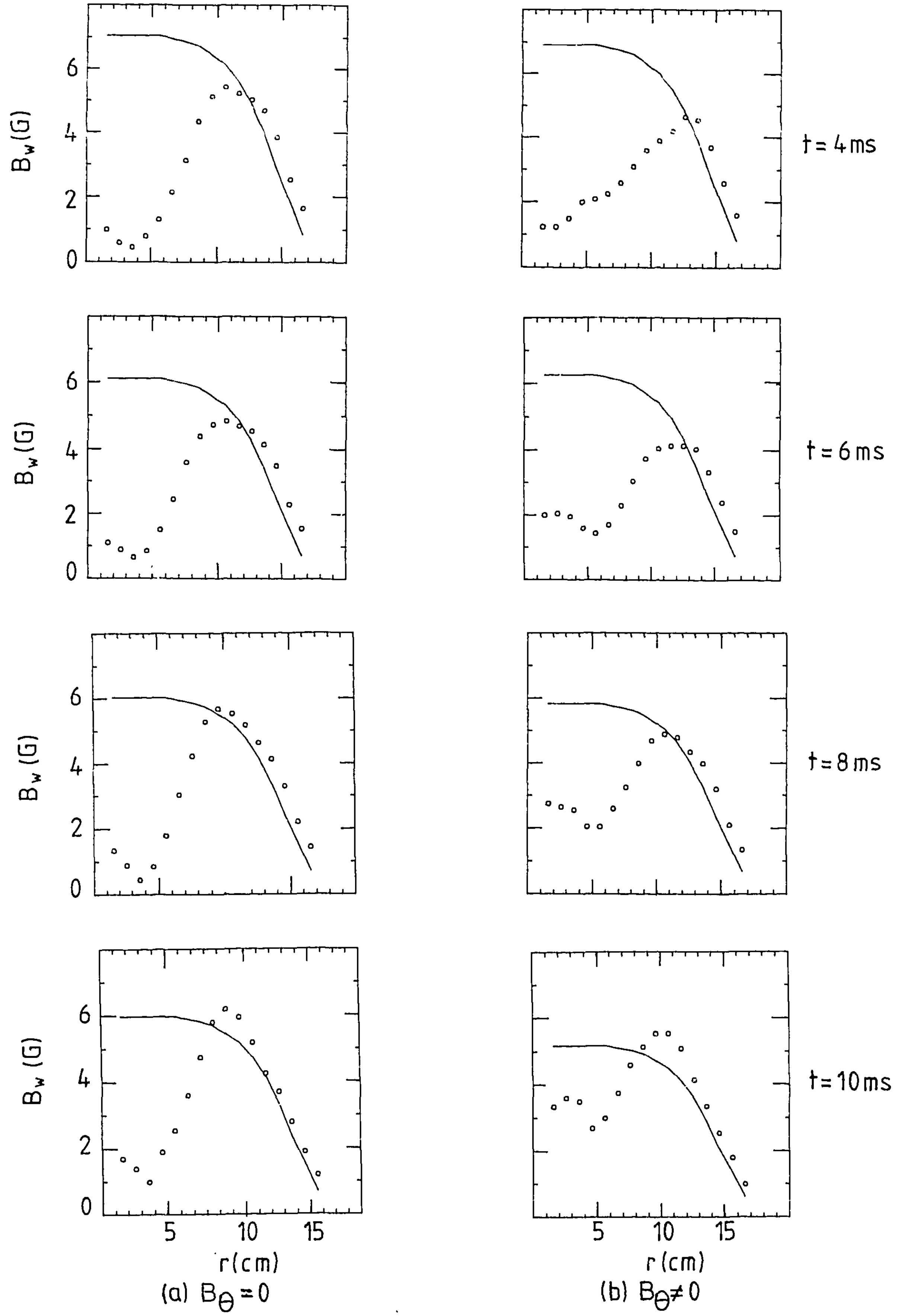

Figure 7 The penetration of the RF rotating field into the plasma both (a) without and (b) with an applied toroidal magnetic field. The solid line represents the distribution of the field with no plasma

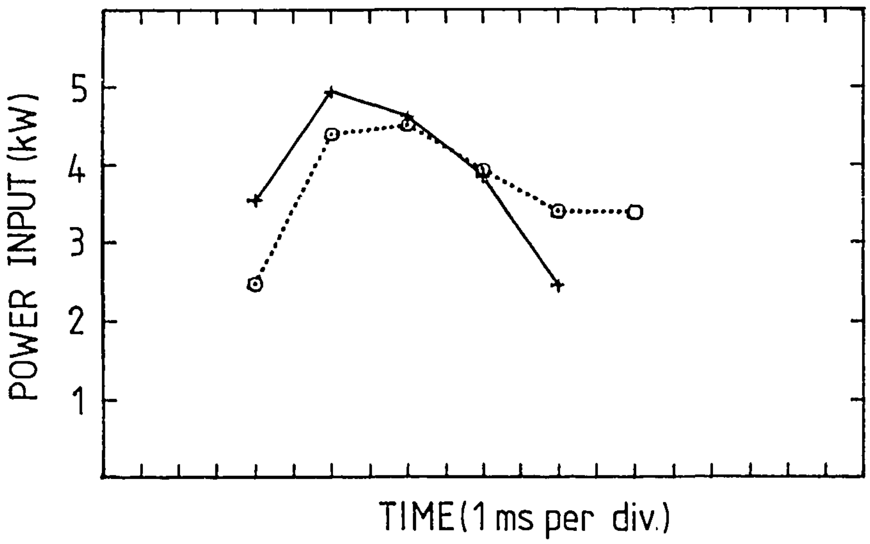

Figure 8 Estimates of the RF power input into the plasma, both with (solid line) and without (dotted line) the toroidal field