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ATOMIC ENERGY ESTABLISHMENT
PLASMA PHYSICS AND ACCELERATORS DEPARTMENT

PLASMA ROTATION IN COAXIAL DISCHARGES

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ABSTRACT

Plasma rotation has been observed near the breech of the coaxial electrodes, which propagates inside the coaxial gun and moreover this has been detected in the expansion chamber. Azimuthal component of plasma current has been detected. The measurement of the axial magnetic field distribution in time along the expansion chamber-axis shows a single maximum peak for all positions. Azimuthal component of electric field exists along the axis of the expansion chamber and results for two angular positions (0°, 180°) at $r = 2.5$ cm has been presented. Thus it is obvious that the whole plasma bulk moves in a screw configuration before and after the focus position.

INTRODUCTION

It is proposed that the current sheath formed at the breech of the coaxial gun, moves at the beginning in a laminar flow, as the radial and axial plasma velocity increases, a vortex will be created within the current sheath front. Turbulence in the plasma sheath will occur, when the plasma velocity reaches a high value. The appearance of a vortex can lead to a local axial magnetic field which is responsible for the rotation of the plasma. Plasma rotation can store large amounts of kinetic energy of mass motion. If this could be converted into random (thermal) motion of the individual particles, heating of the plasma would result. There are certain natural processes, such as outward diffusion and turbulent mixing which tend to convert the nonthermal stored energy into thermal energy.

The plasma sheath velocity and shape has been studied by several authors. Tsagas[1] used a streak photography to derive the velocity of the plasma sheet in coaxial accelerator ($V \approx 8 \times 10^4$ m/s for charging voltage 8 kV and helium gas at P 0.2 torr). The calculated theoretical values of the position and average sheet velocities were very close to that observed photographically. Masoud[2], showed theoretically that the plasma sheath in a small coaxial gun, has a helmetlike shape with a maximum velocity of 14×10^6 m/s, but experimentally it was found to be $\approx 10^4$ m/s with an umbrella-like shape. Bernard[3], studied the structure of current sheath in a coaxial tube of Mather type, (bank energy was 27 kJ at 40 kV). Using a magnetic probe, the results showed that the current circulates in a shell structure and is thicker the greater distance from the central electrode. The measured sheet velocity is $\approx 1.3 \times 10^3$ m/s.

Vargas[4], gave a complete analytical solutions for the kinematics of the current sheath which combined with the circuit equation in a small plasma focus. Also, the current sheath kinematics was determined experimentally by optical method, using Deuterium, argon and air for base pressure varying between (0.2-0.3 torr), external inductance (30-130 nH) and bank charging voltage (13-17 kV). A general agreement between the current sheath shape and the theoretical model was confirmed.

2. APPARATUS

Mather-type plasma focus device[5] is used in the present experiment. The device is operated with the capacitor bank discharge current at 50 kA with rise time of 4.5 usec. The system is filled with hydrogen gas at base pressure 310 u 310 u Hg. A teflon cylinder is used as an insulator between inner and outer electrodes. The expansion chamber has length of 22.3 cm and the outer diameter is 15 cm fitted directly to the muzzle. Fig (1) shows the schematic diagram of the experimental set-up. Miniature Rogovsky coil has been used to measure the azimuthal plasma current. Axial magnetic field measurements along the expansion chamber has been carried out by a magnetic probe, while the azimuthal electric field measurements are recorded by a double electric probe.

3. EXPERIMENTAL RESULTS

Miniature Rogovsky coil is placed in the system which can slide out smoothly to measure the azimuthal plasma current distribution; inside the coxial gun and at the expansion chamber. The plane of the coil is placed perpendicular to the ϕ -direction, the coil has 30 turns with minor cross-sectional of 0.047 cm^2. Figs. (2a,2b) show a typical oscillogram of the obtained azimuthal plasma current for different positions inside the coaxial discharge and at the expansion chamber.

Measurement of axial magnetic field along the axis of the expansion chamber is fulfilled by using a magnetic probe. In the series of measurements, two identical axial megnetic probe are placed at two different axial position close to each other. Similar integrator circuit is connected to each probe. Gig.(3) shows the magnetic probes and the integrator circuit. The magnetic probes are placed in the axis of the expansion chamber at a point near the gun muzzle and it slides out smoothly to measure point to point the axial magnetic field. Trace of axial magnetic field is shown in Fig.(4). Fig (5) shows the variation of the axial magnetic field intensity with distance along the expansion chamber at different times. Fig.(6) shows time variation of the axial magnetic intensity for different positions along the z-axis It is clear from that figure the existance of large peak value (maximum value $\sim$ 0.02k .gauss) of axial magnetic field intensity at each value of z, and the time appearance of that peak changes with axial distances z. Using the experimental values of the magnetic field intensities, peak position - time relation, is obtained in Fig. (7). The velocity of the plasma bulk is the slope of the curve shown in Fig(7) which is $(\frac{dz}{dt})_z \simeq V_z$ at $z \simeq 2$ cm to 22 cm. then plotting the relation between the velocity and the axial distance z as shown in Fig.(8). Results give maximum velocity of $V \simeq 2.5 \times 10^{6}$ cm sec^{-1} at $z \simeq 15$ cm.

The floating double probe is used to measure the azimuthal electric field E_{φ} at the axis of the expansion chamber (i.e $r = 0$) and for two angular position (0^{o}, 180^{o}) at $r = 2.5$ cm for different axial positions along the expansion chamber. Figs.(9a,9b) show time variation of azimuthal electric field for different locations. The azimuthal electric field intensity is of the order of 50 V cm^{-1}

4. DISCUSSION AND CONCLUSION

Plasma current rotation inside the coazial gun are mainly induced by an azimuthal force F_{φ}

$$F_{\varphi} = J_r B_z - J_z B_r$$

In some experiments axial magnetic field B_z is introduced from external coil but in this experiment axial and radial magnetic field intensity B_z and B_r respectively, may be created due to a deformation of the radial and the axial plasma currents. Wall resistance and viscosity force may be the main cause of this deformation. The rotation of plasma will be continued outside the gun in the expansion chamber by one of the three following mechanisms.

1. The plasma focus rotates and by inertia the expanded plasma rotates.
2. If the plasma rotation collapse due to focusing, the residual axial magnetic field created inside the gun acts on the expanded plasma focus[2] (near the gun muzzle), where J_r exists which rotates the plasma by Lorentz force $J_r \times B_z$.

3. Formation of an instabilities in the expanded shell which are responsible for creation of axial magnetic field, resulting in rotation of the expanded shell which will move in screw configuration.

The axial magnetic field distribution in time along the expansion chamber axis, showed that the magnetic field intensity has a single maximum peak for all positions, this may be due to a rotating plasma current sheet at that point Presence of the axial magnetic field revealed that the expanded plasma moves in a screw form.

The profile of the azimuthal electric field E_{ϕ}, shows that E_{ϕ} has a maximum value at a points far from the axis and minimum value at the axis of the expansion chamber at most of plasma shell existing times and for different axial position z = 12, 15, 17 and 19 cm, this profile is related to plasma rotation mechanism in the expansion chamber.

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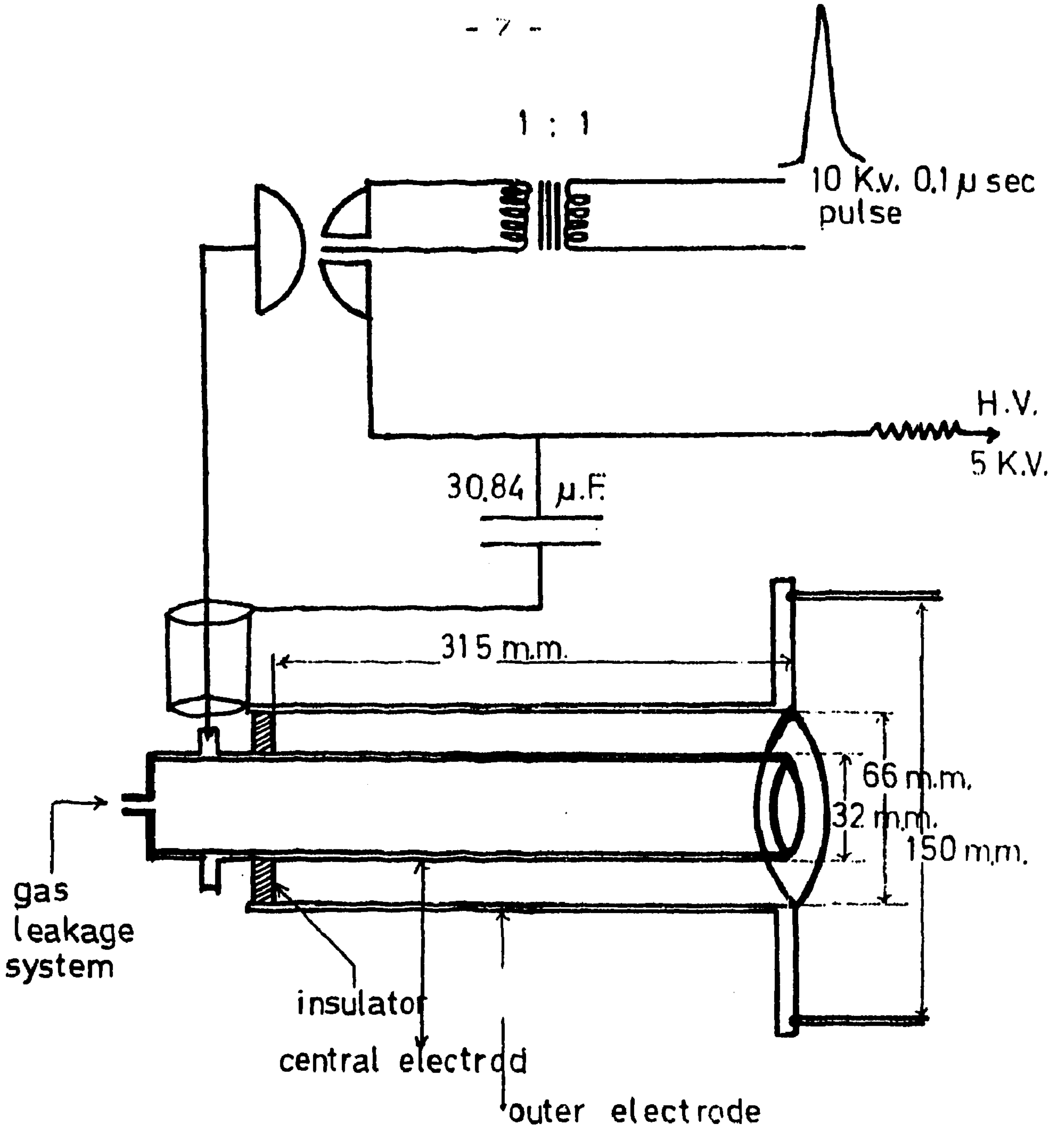
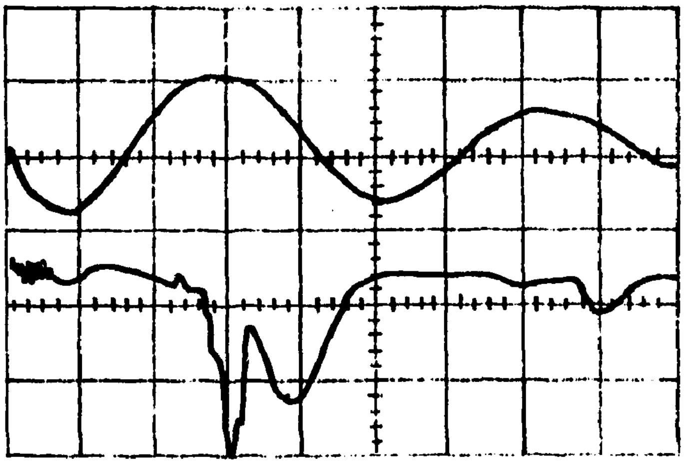


Figure (1) Schematic diagram of the experiment

(a)



10 V./div.

10mV/div.

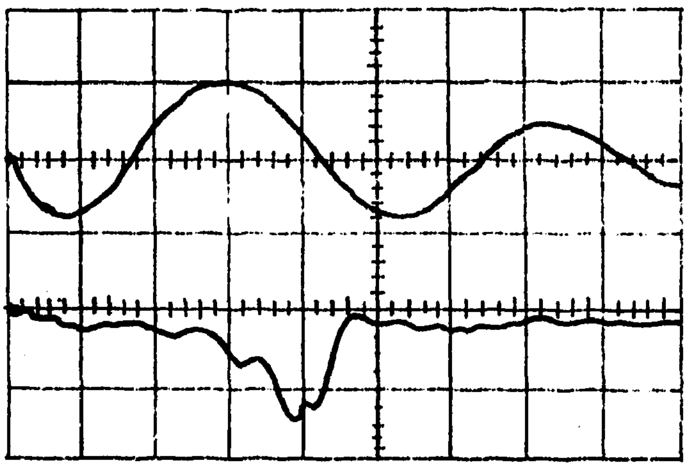
L = 20 cm.

5 μ.sec./ div.

Upper beam - total discharge current

Lower beam - azimuthal plasma current

(b)



10 V. / div.

10mV/div.

Z = 8 cm.

5 μ.sec./ div.

Figure (2) Azimuthal plasma current oscillogram
(a) inside the coaxial discharge.
(b) at the expansion chamber.

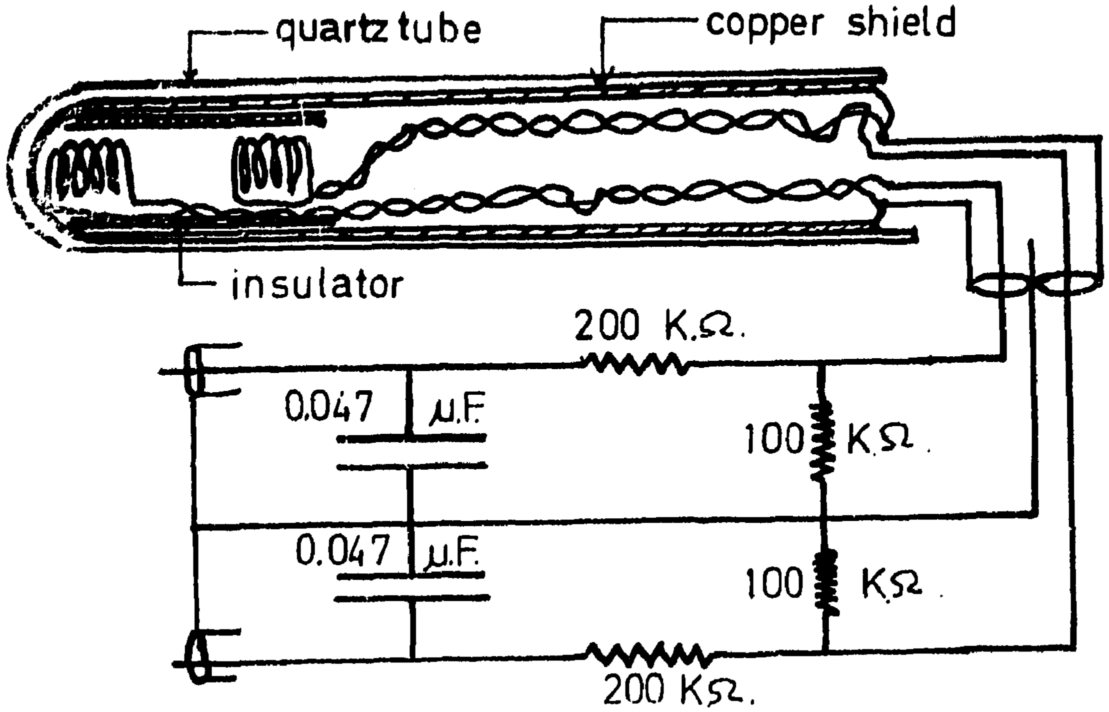


Figure (3) Magnetic probes and the integrator circuits

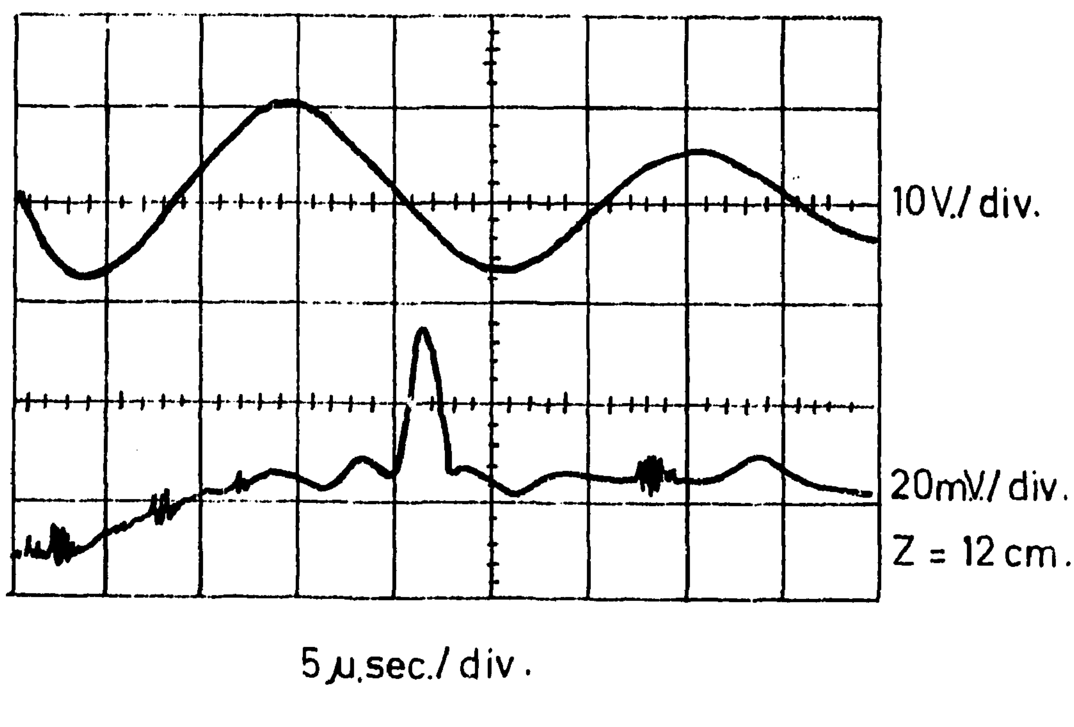


Figure (4) Trace of the axial magnetic field (lower beam) and the discharg current (upper beam)

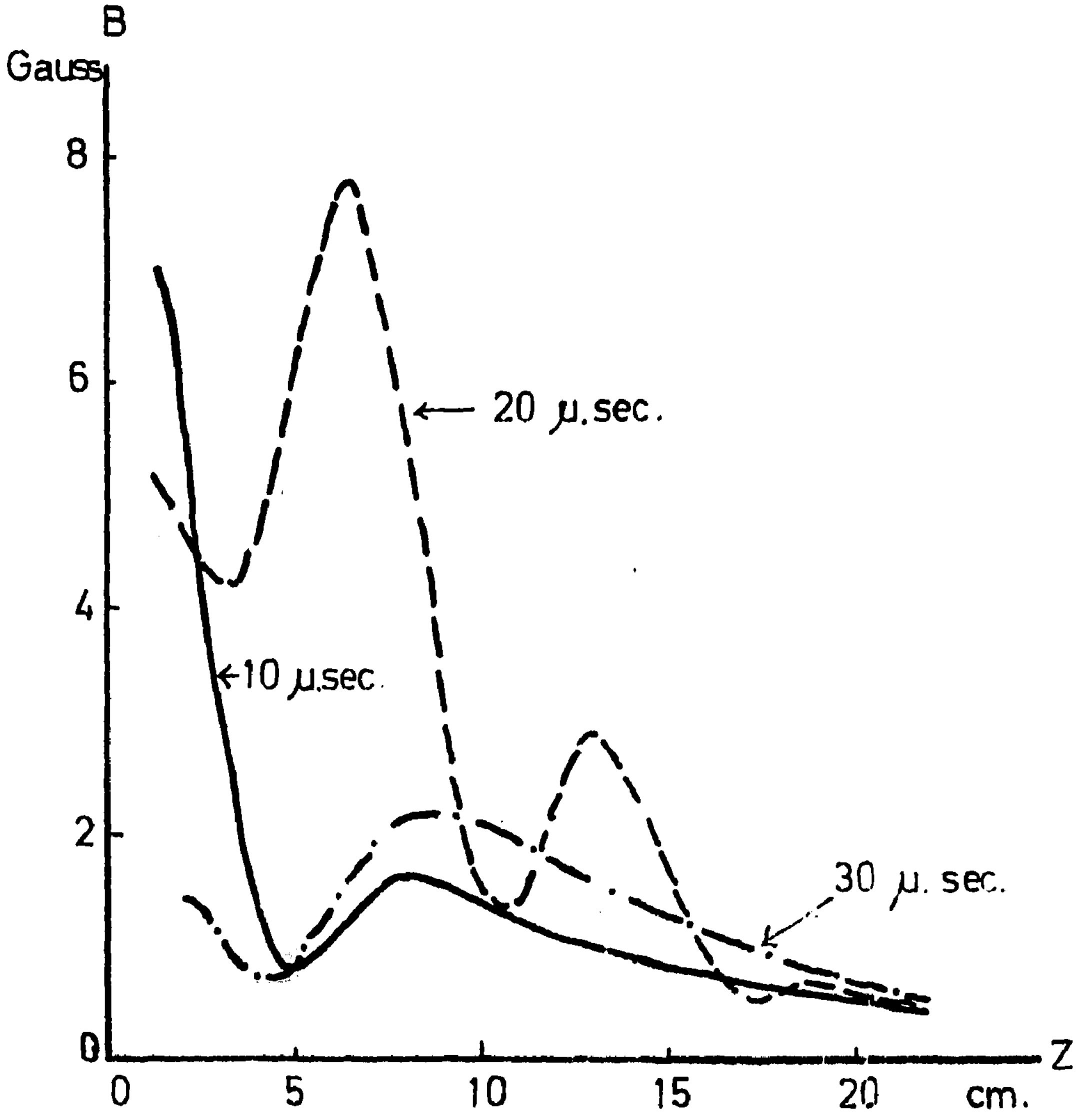


Figure (5) Axial magnetic field intensity versus distance along the expansion chamber.

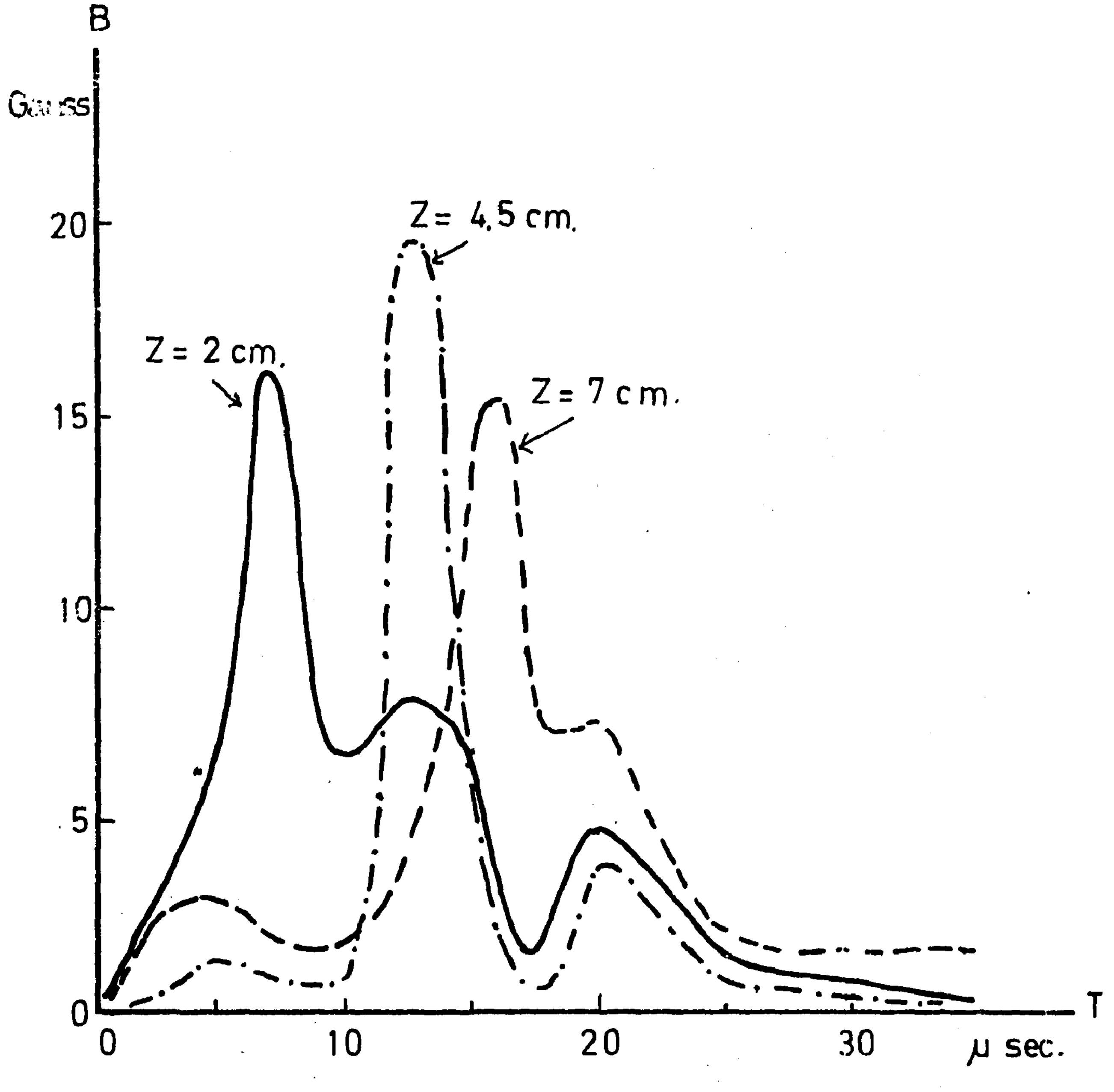


Figure (6) Axial magnetic field intensity versus time.

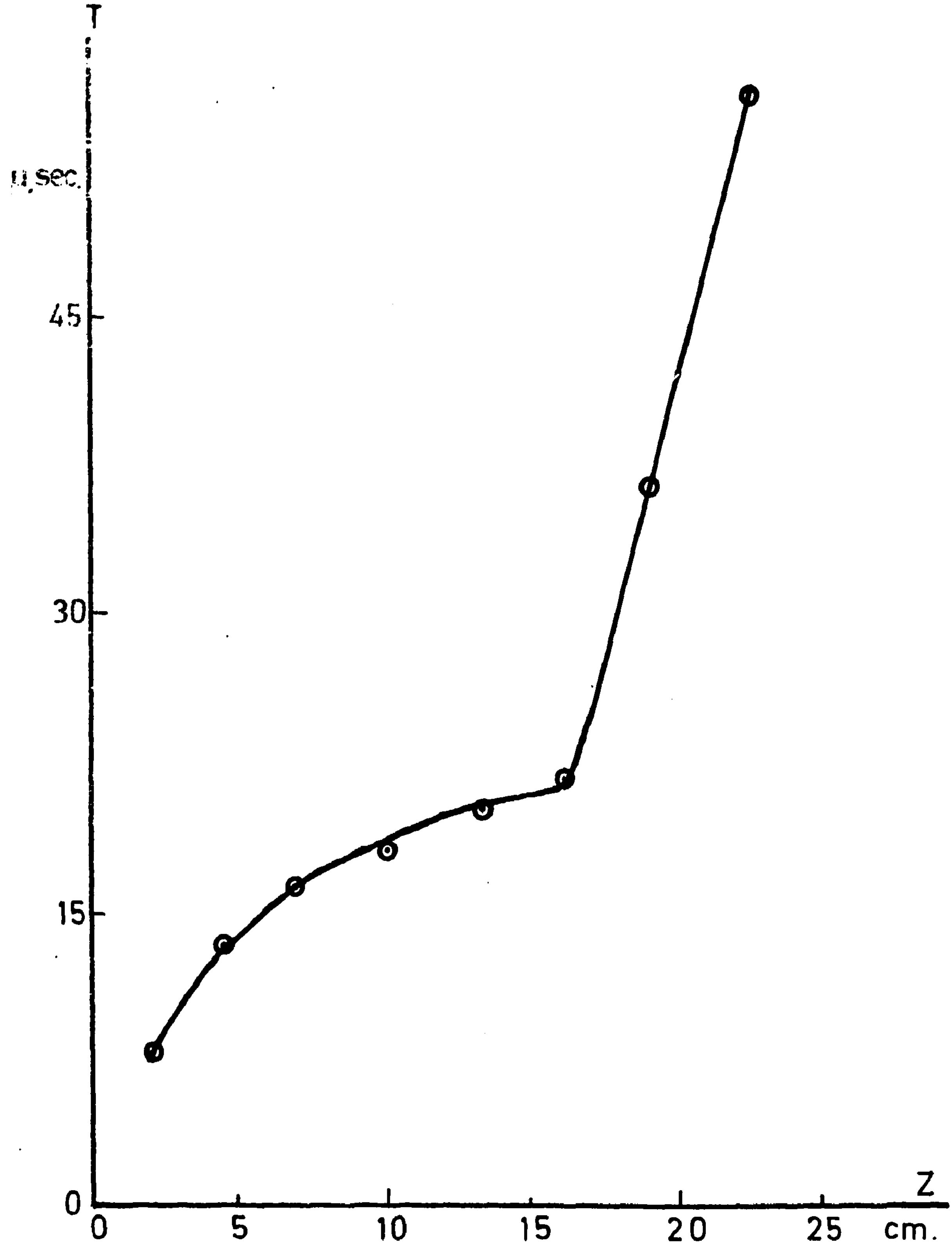


Figure (7) Time - position relation of the peack axial magnetic field intensity.

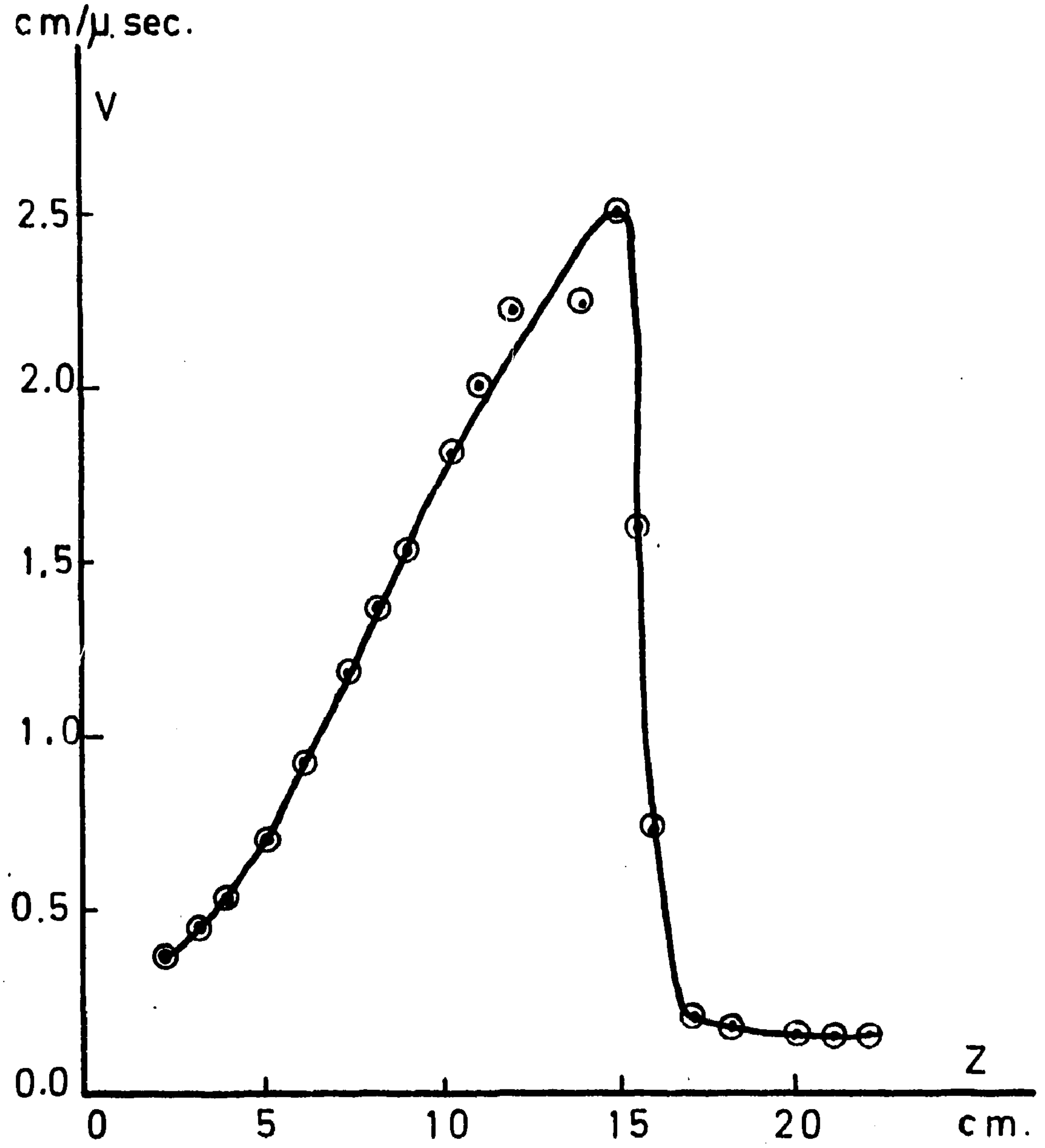


Figure (8)   Velocity of the rotating plasma versus position.

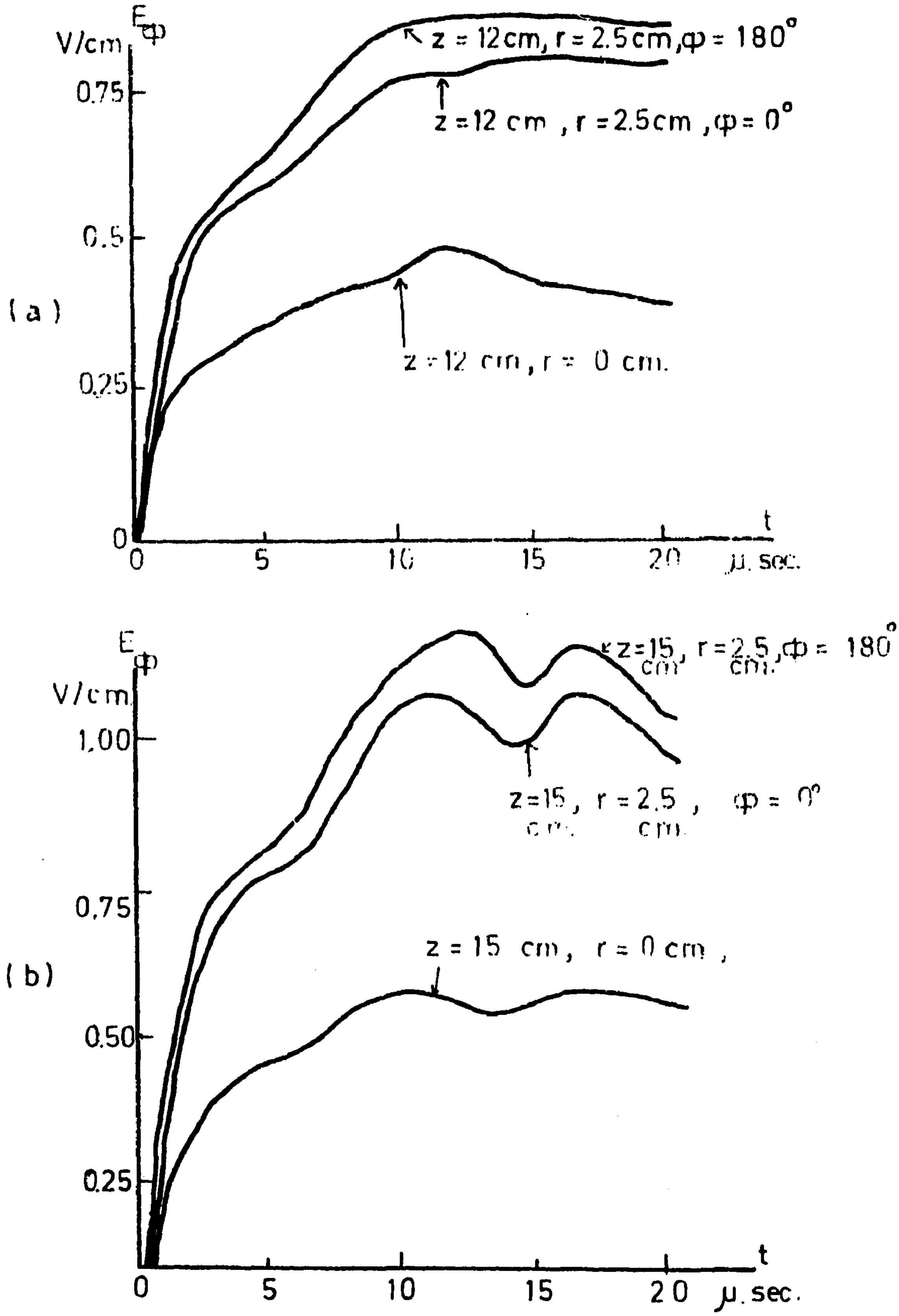


Figure (9) Time variation of azimuthal electric field intensity.