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14. Abstract/Notes

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RFP PLASMA EXPERIMENT AT INPE

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ABSTRACT

Plasma experiments in CECI, a small Reversed Field Pinch (RFP) apparatus, is described. Preliminary measurements in this device have shown the production of a plasma with peak current of 1.3kA and discharge duration of nearly 80μs, when a toroidal DC field of 100G was used. A loop voltage of 40V was measured and a maximum electron temperature of 3eV was estimated for these discharges. Experimental points in the F-θ diagram for CECI indicate that its plasma is approaching the RFP configuration as we optimize the discharge. The probe data also show that the plasma column expands outward. Furthermore, numerical results indicate that leakage fields have to be reduced below 5G to form appropriate magnetic surfaces. These two effects seem to be limiting the plasma current. Hence a compensating vertical field coil is under preparation.

1 - INTRODUCTION

The Reversed Field Pinch (RFP) is a device in which a toroidal plasma is confined by the combination of a poloidal field B_θ generated by the plasma current, and a toroidal field B_ϕ produced by external coils and by currents flowing in the plasma. The RFP, the Tokamak and the Spheromak devices belong to the same family of toroidal magnetic confinement systems. However in RFP the magnitudes of poloidal and toroidal fields are comparable and the toroidal field is reversed in the outer region of the plasma with respect to the field on the axis of the torus. The reversal of the toroidal field results in very strong shear and consequently RFP can confine relatively high-β plasma ($\beta = 10 - 30\%$). Furthermore, in RFP, the plasma current can exceed Kruskal-Shafranov limit ($q < 1$) so that high plasma currents can be used at low toroidal field, opening the possibility of reaching ignition conditions at lower cost and with Ohmic heating alone.

The plasma in an RFP device relaxes naturally to an equilibrium that is a minimum energy state. The spontaneous generation of toroidal field reversal which is widely known as the dynamo effect is a consequence of this relaxation [1].

A small RFP device, CECI, has been built at INPE to study the field reversal process by the dynamo effect. CECI is operated presently with two coil systems: a toroidal coil which produces a D.C. toroidal field of up to 700G and a pulsed poloidal coil that induces the plasma current. A conductive shell surrounding the pirex tube (major radius of 12cm and minor radius of 4.2cm) is used as a toroidal flux conserver with penetration time of about 3ms. A preionized low density plasma is obtained with a plasma gun and continuous flow of helium gas is used so that a 2.0×10^{-5}Torr working pressure is attained during the discharges. The base pressure in CECI is 7.0×10^{-7}Torr.

The main objectives of the CECI experiment are to study:

i) mechanisms for field reversal by the dynamo effect.

ii) transport phenomena and magnetic fluctuations in the periphery of the plasma column.

iii) effects of toroidal magnetic field divertor in high current density regimes.

iv) impurity transport in RFP configurations.

2 - THE EXPERIMENT

In Fig. 1 we show the set-up for CECI experiment emphasizing its electrical systems. In Fig. 2 we show in more detail the device per se and some of the diagnostics in use. The dimensions of CECI apparatus and the proposed plasma parameters of the device are listed elsewhere [2]. Here we discuss mainly the electrical systems and the operational aspects of the device. As shown in the block diagrams of Fig. 1, the electrical system of CECI consists essentially of two D.C. power supply (600A, 30V each) and 3 capacitor banks that can be triggered independently. The first bank (16.85μF, 20kV) is for the poloidal field coil system, the second (8.5μF, 20kV) for vertical field coil and the third (0.25μF, 20kV) for the plasma gun.

In a typical experimental run the following timing sequence is used:

1) Firstly the D.C. toroidal coil is energized providing static fields that can reach 700G,

2) Then the plasma gun is fired in order to generate a preionized low density plasma.

3) After a few microseconds the poloidal coil is energized to produce and confine the plasma. (In the near future a compensative vertical coil will be used for plasma position control and leakage field suppression).

Spark gap triggered with thyratrons are used to switch on the capacitor banks. Pulse delay generator is used to obtain the needed time delays.

The main automatic control unit for charge and discharge of capacitor banks is used to allow continuous pulsed operation for discharge cleaning of the CECI vacuum vessel. Manual mode of operation is used for normal data acquisition.

3 - RESULTS AND DISCUSSIONS

Typical waveforms of the plasma current and loop voltage measured in CECI are shown in Fig. 3. A peak plasma current of 1.3kA is obtained when a toroidal field of 100G and a poloidal bank voltage of 5kV are used. A loop voltage of 40V was measured in that discharge and from it an electron temperature of 3eV was estimated (at peak current) by using the Spitzer conductivity formula. A typical signal from calibrated magnetic probes located in position A of Fig. 2 is shown in Fig. 4(a) and 4(b).

One of the most important information needed to characterize an RFP device is its F-θ diagram. Here $F = B_\phi(b)/\bar{B}_\phi$ and $\theta = B_\theta(b)/\bar{B}_\phi$ where $B_\phi(b)$, $B_\theta(b)$ are the toroidal and poloidal field at the wall of the device and $\bar{B}_\phi$ is the average toroidal field. In Fig. 5 results representing three experimental conditions obtained in CECI are plotted. They show that the RFP configuration has not yet been achieved but that the obtained plasma is approaching the RFP regime as we decrease the toroidal field and increase the poloidal bank voltage, hence the plasma current. By increasing further the plasma current it is possible to improve the pinch parameter θ and therefore have access to the region in the F-θ diagram in which the RFP configuration is obtained.

Three effects seem to be hindering the increase of the plasma current in CECI: insufficient preionization, fast expansion of the plasma column in the major radius direction and formation of inadequate magnetic flux surface in the peripherical region of the plasma. The first problem can be overcome by increasing the energy of the capacitor bank used in the plasma gun and/or using an RF source. The second problem has been checked experimentally. A magnetic probe positioned at A (outer) and another at B (inner), as indicated in Fig. 2, were used to measure the displacement of the plasma column and indicated an outward shift of 2-6mm when a minor radius of 40-25mm was assumed. Hence a vertical magnetic field is necessary to control the plasma, keeping it away from the walls and improving its parameter

In Fig. 6 we show the calculated values of the leakage field for a poloidal coil current of 1kA, which corresponds to the actual experimental condition used in the discharge with results shown in Fig. 3. The field values were obtained without including the conductive shell that is actually present between the poloidal coil wires and the discharge tube of CECI. Furthermore, measurements with a magnetic probe showed that a plasma current of 600A produces a poloidal field of 30G near the wall of the discharge tube. That field magnitude is comparable to the calculated leakage field at the walls as is shown in Fig. 6. From these results we infer that the magnetic flux surface in the peripherical region cannot be formed appropriately because the leakage field increases with the poloidal coil current in the present CECI configuration. A leakage field compensating vertical coil is presently under study. A numerically obtained B-field plot for poloidal coil current of 1kA and for a convenient vertical coil set-up is shown in Fig. 7. It clearly shows the effectiveness of the compensating vertical coil system to reduce the leakage field.

4 - CONCLUSIONS

Experimental results obtained in a small RFP device built at INPE have been presented. It was shown that although a stable RFP configuration has not yet been achieved, the plasma in CECI is approaching such a configuration. Preliminary measurements showed that a plasma with peak current of 1.3kA with discharge duration of nearly 80μs was produced when a toroidal DC field of 100G was used. Loop voltage of 40V was measured and a maximum electron temperature of 3eV was estimated for that discharge. Plasma column outward displacement of 2-6mm was measured and will be corrected using an externally applied vertical field. Leakage field has to be reduced below 5-10G in order to obtain an appropriate magnetic flux surface and confine properly the plasma. A compensating vertical coil system for that purpose is presently under construction.

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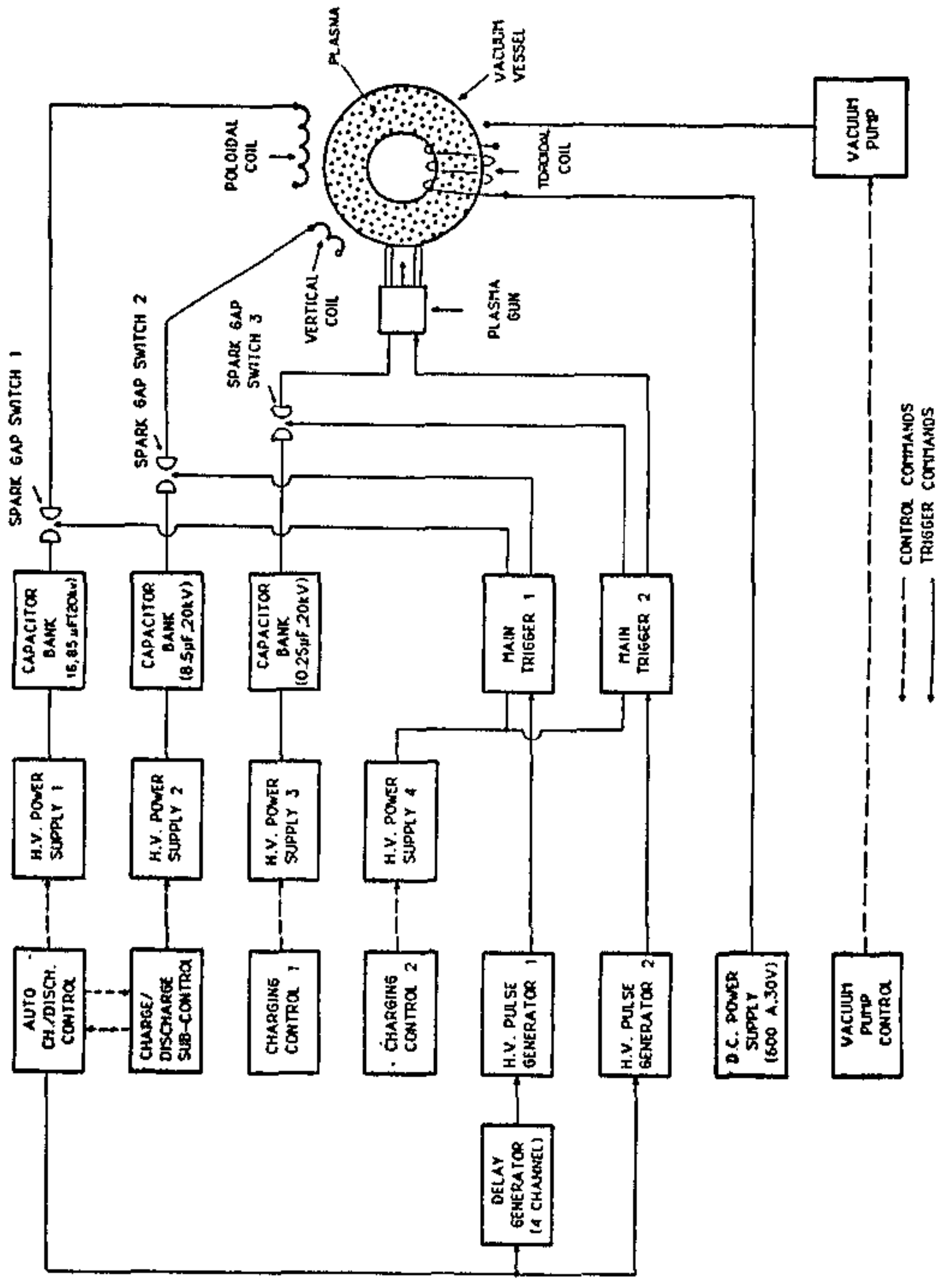

Fig. 1. CECI experimental arrangement.

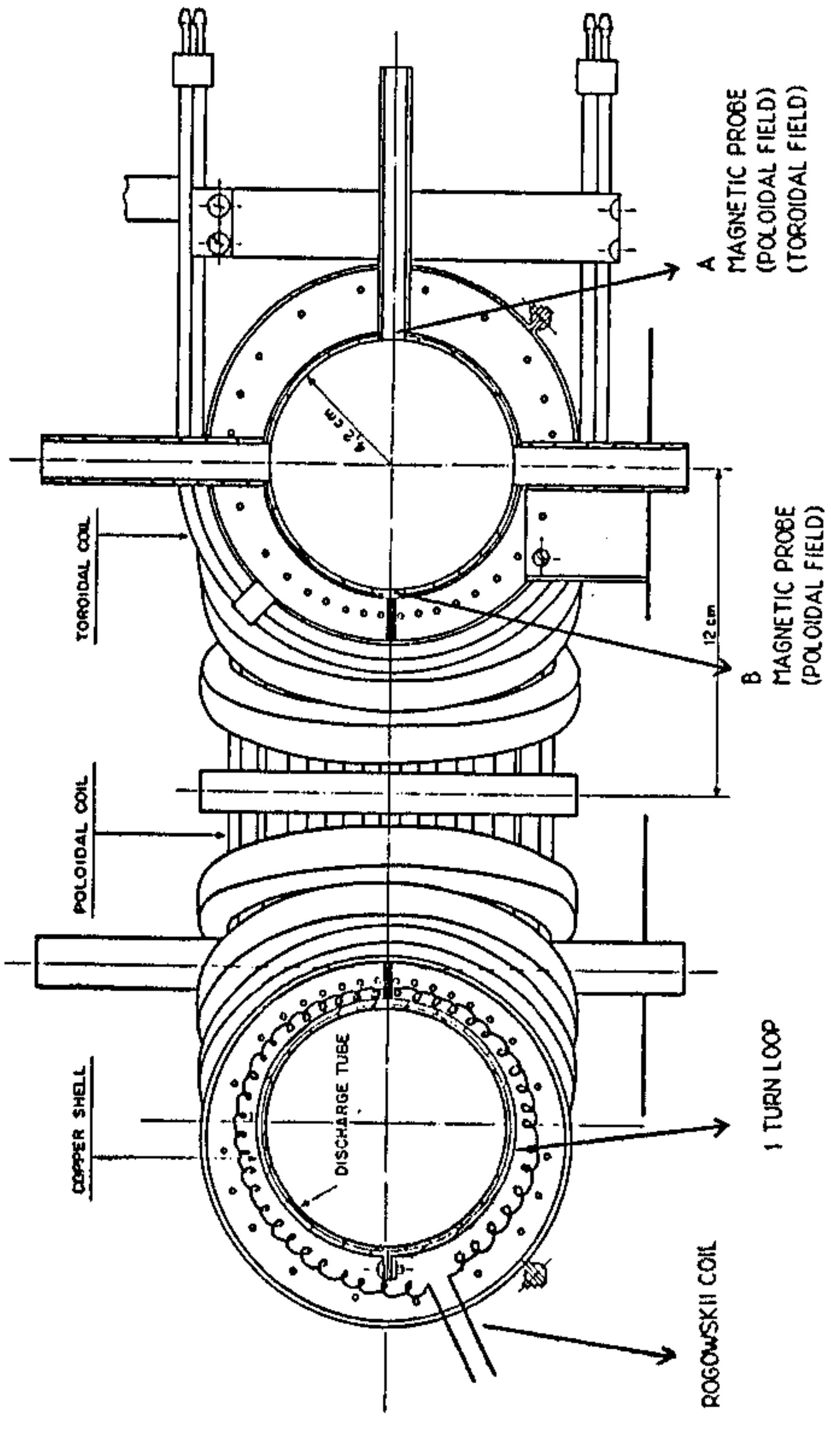

Fig. 2. CECI device and diagnostics.

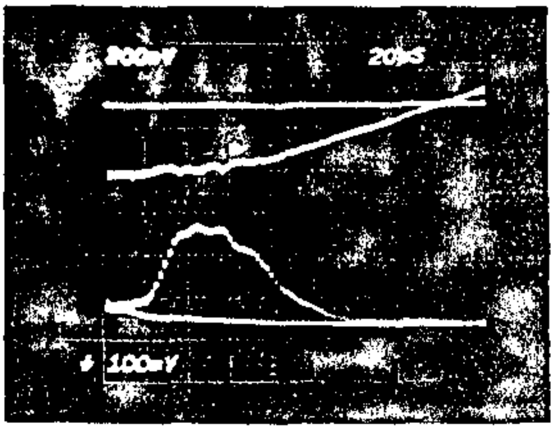

Fig. 3. Loop voltage (upper trace) and plasma current (lower trace). Loop voltage: 30V/div; plasma current: 300A/div; horizontal axis: 20μs/div; toroidal field $\bar{B}_\phi$ = 100G; poloidal bank voltage V_c = 3kV.

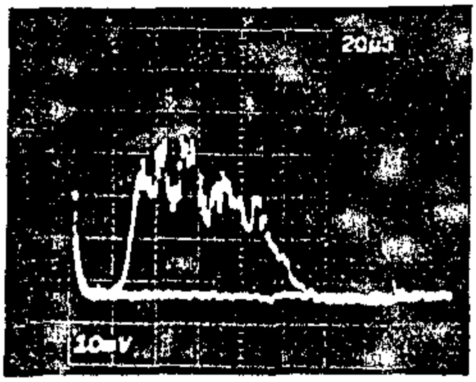

Fig. 4(a). Signal from a magnetic probe (for poloidal field) located at A. Vertical axis: 10.9G/div; horizontal axis: 20μs/div.

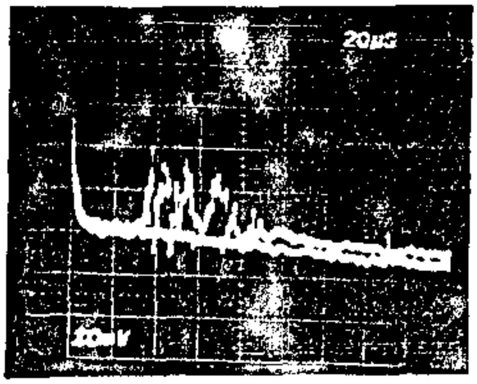

Fig. 4(b). Signal from a magnetic probe (for toroidal field) located at A. Vertical axis: 11.4G/div; horizontal axis: 20μs/div.

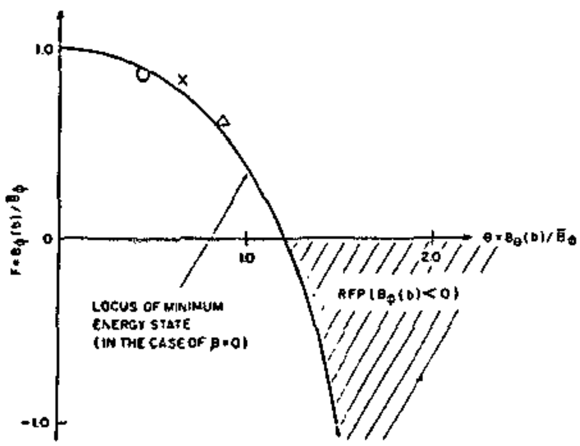

Fig. 5. F- diagram for CECI. $B_\phi(b)$: toroidal field at wall; $B_\theta(b)$: poloidal field at wall; o: $\bar{B}_\phi$ = 50G, V_c = 3kV; X: $\bar{B}_\phi$ = 50G; V_c = 4kV; Δ: $\bar{B}_\phi$ = 30G, V_c = 4kV.

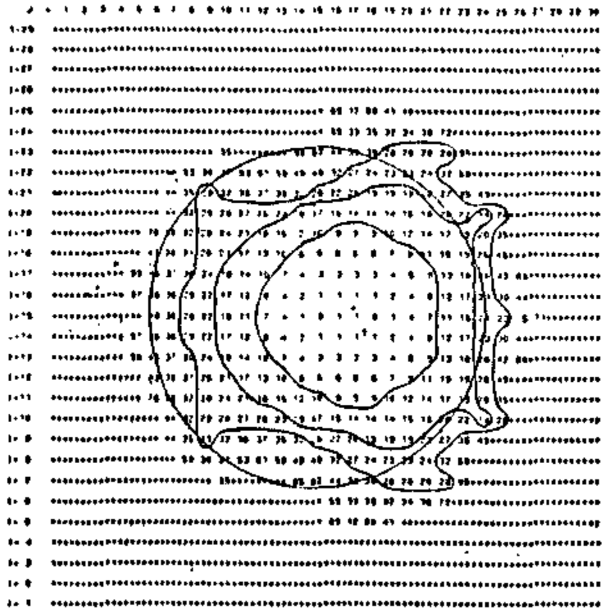

Fig. 6. Calculated leakage field inside the discharge tube by the poloidal coil current. Solid circle indicates the discharge tube. The magnitude of the magnetic field produced by a current of 1kA in the poloidal field coil is mapped in CGS units. The region indicated by asterisks (*) corresponds to a strong magnetic field region with more than 100G (for example B_θ = 7kG at r = 6cm).

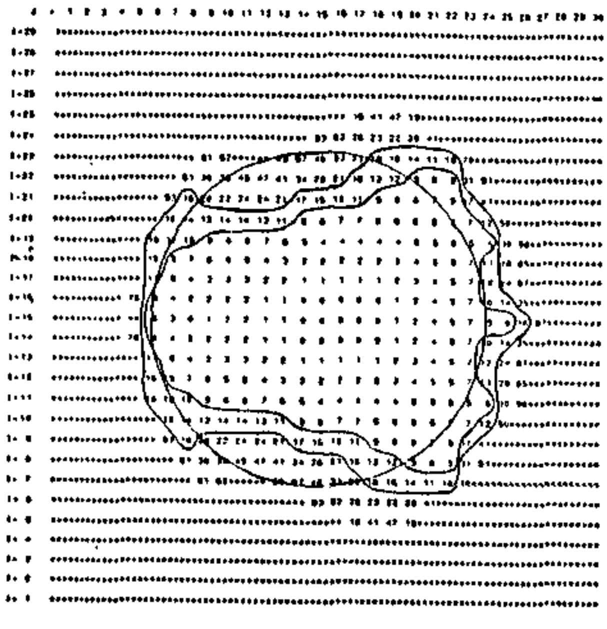

Fig. 7. Calculated leakage field for the conditions of Fig. 6 when compensating vertical field coil is used.