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REVERSED FIELD PINCH DISCHARGES WITH ELONGATED MINOR CROSS-SECTION

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by

A.A.M. Oomens, H.S. Lassing and A.F.G. van der Meer

ABSTRACT

SPICA II is a toroidal pinch device with an insulating tube and a minor cross-section of racetrack shape. Reversed field pinch (RFP) discharges have been produced by fast programming, relying on either self reversal or aided reversal. The plasma current is increased to 300 kA in 10 μs, and reversal is sustained for about 0.1 ms, although a quiescent state is not reached. The F-Θ trajectories are similar to those obtained in devices with a circular minor cross-section.

1. INTRODUCTION

Experiments in the reversed field pinch (RFP) configuration in the past were carried out in 'fast' devices with small bore insulating tubes or in intermediate-sized machines with metal liners, all of them with a circular minor cross-section. Results in a metal liner with a vertically elongated cross-section and an internal figure-eight separatrix were reported from the Multipinch, LAHAYE (1986). Although there are no indications from theory to expect a markedly different behaviour when the shape of the cross-section is changed, we thought it interesting to investigate RFP discharges in SPICA II. This is a toroidal device with a racetrack minor cross-section (R = 0.45 m, b/a = 0.7 m/0.3 m), an insulating liner (quartz), and a tight-fitting conducting shell (aluminium, 4 cm). SPICA II was designed to study the production and evolution of plasmas in the screw pinch configuration, SPICA II TEAM (1983). The RFP experiments were performed in October 1987 prior to the dismantling of the machine. Due to the restricted machine time and manpower available the programme had to be modest, so the existing circuitry and diagnostics were used without any modifications. The only goal was to see whether or not it is possible to produce RFP discharges in insulating vessels with an elongated cross-section and we have operated with only small changes in timing, field, current, and filling pressure. Shortly after dismantling, the results of RFP discharges in a non-circular aluminium vacuum vessel with indented sides were reported, ALMAGRI (1987). In Section 2, a brief description of the machine and the diagnostics is given; the discharge characteristics are presented in Section 3, and the final Section, 4, contains some concluding remarks.

2. EXPERIMENTAL SET-UP

The design and construction of the SPICA II device were described in SPICA II TEAM (1978) and SPICA II TEAM (1980). An updated version can be found in LASSING (1989). In this section only those details which are relevant for the operation as an RFP will be given. A cross-sectional view of the SPICA II load assembly is given in Fig. 1. The vacuum vessel is a one-piece clear quartz toroid with an average wall thickness of 6 mm. The base pressure is below 5×10^{-6} Pa. A cast aluminium shell with an average wall thickness of 4 cm acts as the toroidal field coil. It surrounds the discharge chamber tightly (average distance 4.5 mm). To induce the plasma current, four toroidal coils are placed around the shell. As described in HOEKZEMA (1980) great care has been taken to minimize stray fields associated with the ports and the vertical and horizontal gaps. The simplified schemes of the electrical circuits as used in this RFP study are shown in Fig. 2. A typical discharge is produced by filling the vessel with 0.25 Pa of D_2 a few seconds before the shot. A toroidal field of ≈ 0.1 T is applied and then crowbarred. At field maximum (125 μs), a small fast condenser bank (FPD) is fired for pre-ionization. After 220 μs the plasma current is induced by firing the implosion bank and rapid reversal occurs. In the case of aided reversal the typical sequence is as follows. The toroidal field is applied and crowbarred at the first negative maximum (≈ 375 μs). At t = 400 μs the plasma current is induced (T/4 = 10 μs). A few μs later (≈ 3), the toroidal field is aided to reversal by firing a small part of the original implosion bank.

As diagnostics were used: - a CO_2-interferometer to measure the line density along a horizontal chord in the midplane; - a HeNe-interferometer for $\int n_e dl$ in vertical direction; - a Rogowski loop to measure the plasma current I_p; - magnetic pick-up coils to measure the toroidal field just inside the shell at three poloidal positions; - two sets of coils (20 and 12) to measure the poloidal field at the wall; - a voltage divider for the voltage drop over the poloidal gap; - a loop to measure the toroidal flux; - the emission of light in the near-infrared for a digital streak picture and for a tomographic reconstruction (LASSING (1988)). The multi-point Thomson-scattering diagnostic was not suitable to measure at these low temperatures.

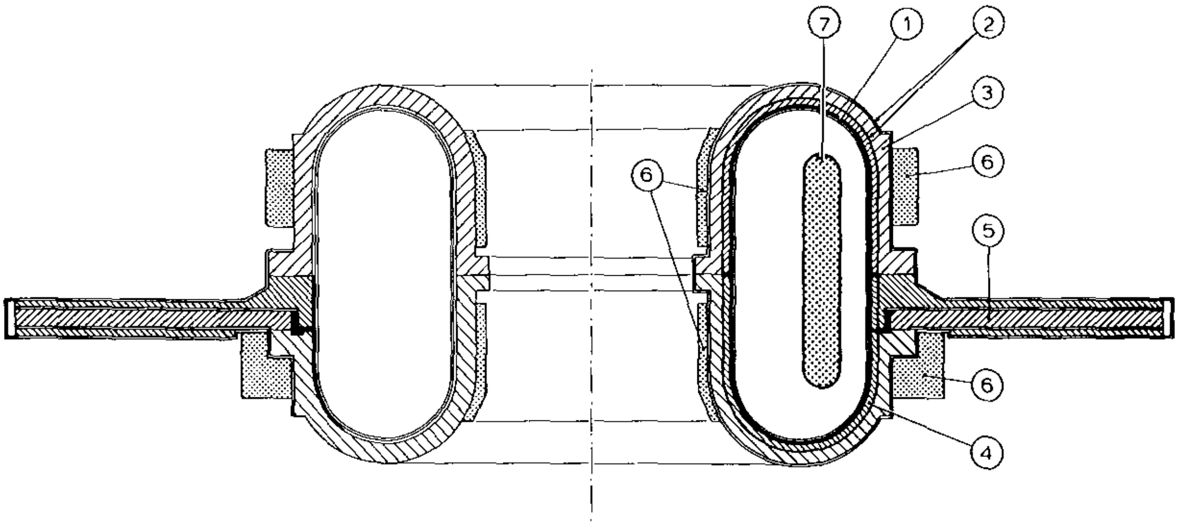
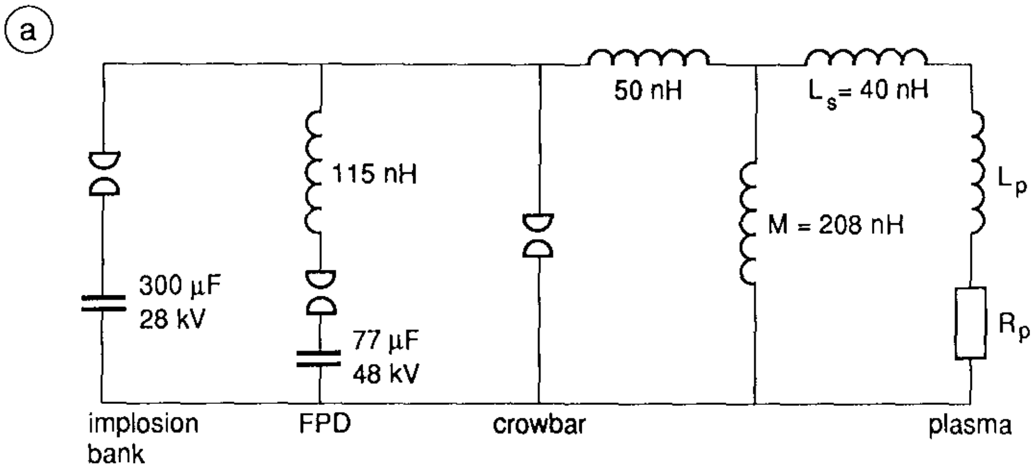


Fig. 1. *A cross-sectional view of the SPICA II load assembly at the toroidal gap (right) and at an arbitrary position.*

1. Quartz vacuum vessel.
2. Epoxy resin insulation.
3. Aluminium shell, also poloidal coil.
4. Metal shield to screen the gap.
5. Feeding flange of the poloidal coil.
6. Primary toroidal coil.
7. Plasma.



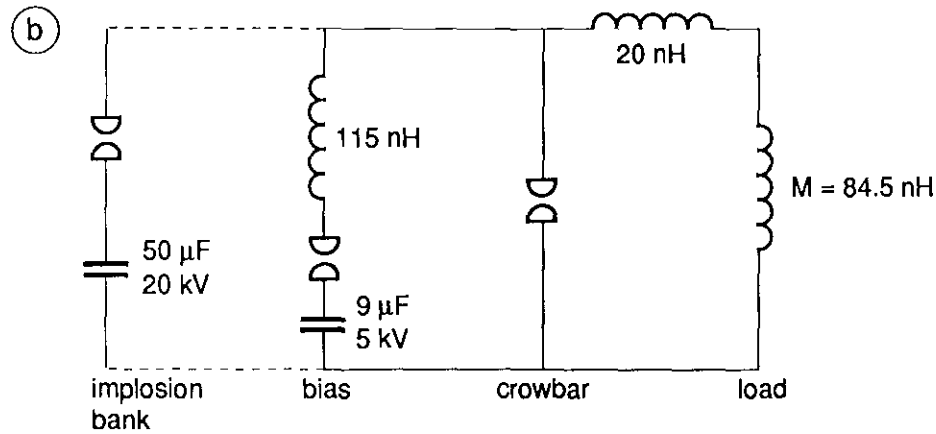


Fig. 2. The simplified electrical schemes of the circuits. The time sequence is described in the text.

a. The toroidal current circuit. The FPD bank is used for pre-ionization. L_p and R_p represent the loading of the circuit by the plasma.

b. The circuit for the toroidal field (poloidal current). The dashed part is used for aided reversal only.

3. EXPERIMENTAL RESULTS

For both kinds of discharges (aided and self reversal), an example of the time dependence of various plasma quantities is shown in Figs. 3 and 4. The field reversal parameter F and the pinch parameter Θ are calculated according to AMALGRI (1987). Thus $F = B_{Tw}/\langle B_T \rangle$, in which $\langle B_T \rangle$ is obtained from the measurement of the toroidal flux loop and B_{Tw} from a pick-up coil, is normalized to 1 for $I_p = 0$. The value of Θ is calculated from $\Theta = \mu_0 I_p / l_0 \langle B_T \rangle$, where l_0 is the length of the poloidal circumference. The safety factor q_w is evaluated according to $q_w = |(l_0^2 \langle B_T \rangle)/(2\pi R_0\, \mu_0 I_p)|$. In the case of self reversal, the values of the safety factor are much closer to zero than in the case for aided reversal. In both cases reversal occurs within a few μs, but only at values of $\Theta \geq 1.2$. It is also observed that after self reversal the plasma current decays roughly twice as fast in the discharges with aided reversal. In the best discharges the reversed state is maintained for almost 200 μs. Due to technical restrictions the maximum value of I_p could only be varied between 250 - 300 kA, which means that the current density is close to 1 MA/m^2. In both cases, aided and self reversal, the plasma is in contact with the quartz wall during the formation and the temperature is below the threshold of the Thomson scattering (< 20 eV) at 40 μs after the start of the plasma current. The electron density decreases always during the whole discharge; a typical value is $n_e \approx 1.5\times10^{20}$ m^{-3}, which means that the parameter $I/N \leq 10^{-14}$ A.m. In the few discharges at a lower filling pressure, the reversed state was not reached. In all discharges large-scale m=1-instabilities (up to $\Delta B_p/B_p \approx 0.5$) were observed on the magnetic pick-up coils. The toroidal mode number could not be determined. From the tomographic reconstructions it is observed that the density distribution is very smooth and rather broad already early in the discharge. It decays gradually in amplitude without fluctuations, but it should be remarked that the data near the wall are not very reliable, due to the small number of channels.

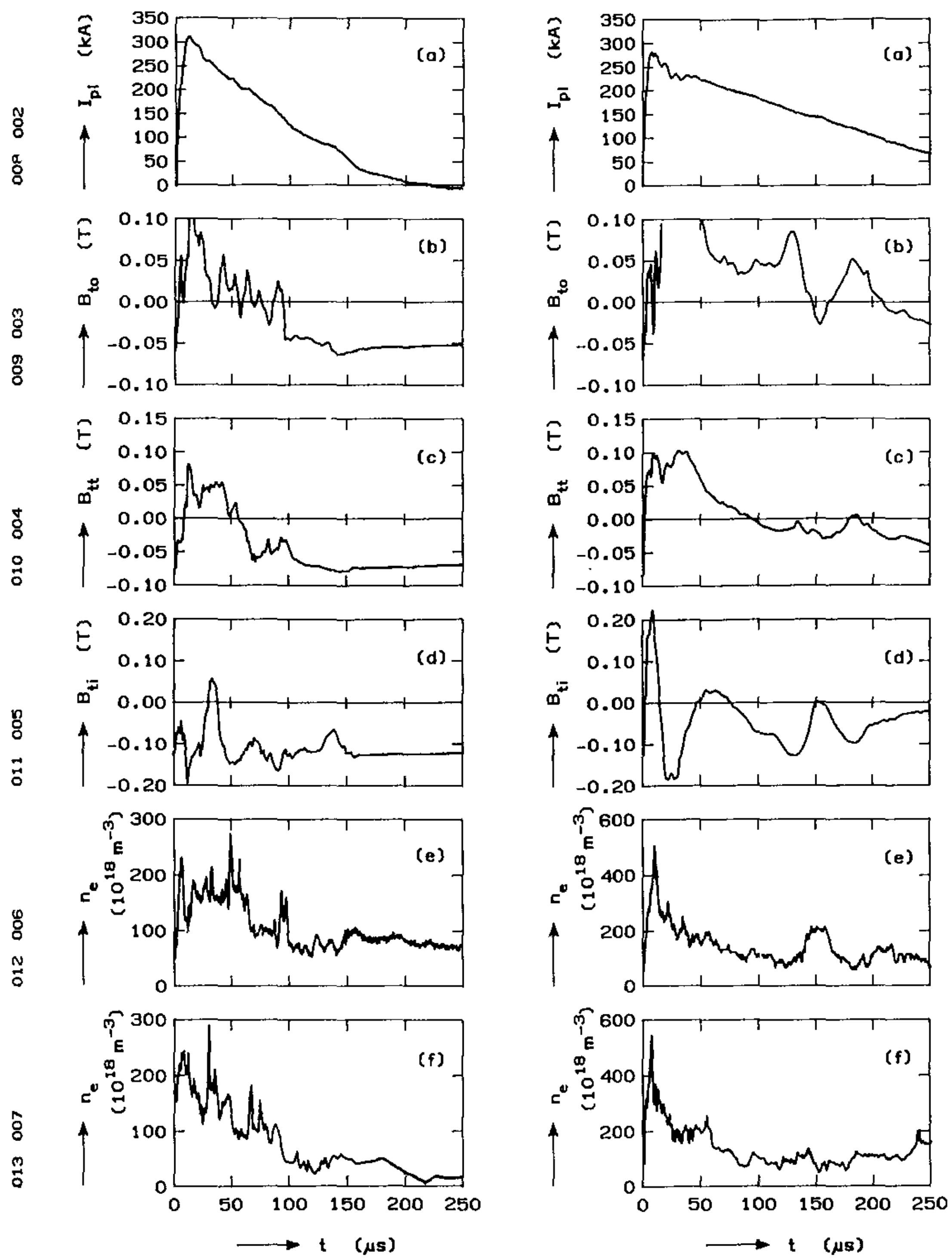


Fig. 3. Plasma parameters of two 0.25 Pa RFP discharges in SPICA II: Self reversal (left column) and aided reversal (right column).

a. Plasma current.

b. B_T at the outboard side.

c. B_T at the top.

d. B_T at the inboard side.

e. $1/L\int n_e dl$ along a vertical chord.

f. $1/L\int n_e dl$ along a horizontal chord.

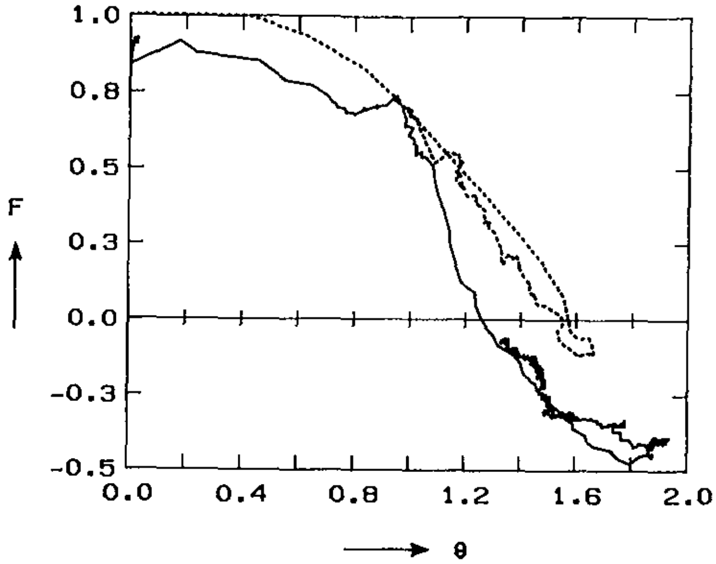


Fig. 4. *F-Θ diagram of the same discharges as in Fig. 3. The dashed line represents the discharge with self reversal, the full line the one with aided reversal.*

4. CONCLUSIONS

We have demonstrated that non-circular RFP plasmas in an insulating vessel can be obtained with characteristics comparable to those of earlier 'fast' experiments (CAROLAN (1979), TAMARU (1979), BUFFA (1977), BAKER (1977)). The reversed state, reached by self or aided reversal, involves large-amplitude instabilities. The magnetic configuration remains close to a relaxed state and the common F-Θ curve is observed. The reversed state can be sustained as long as the current is maintained and $\Theta \geq 1.2$. Discharges set up with aided reversal show, generally, a longer lifetime. The electron temperature later in the discharge is low, most probably due to the influx of impurities caused by wall contact early in the discharge. We therefore conclude that changing the minor cross-section from circular to racetrack does not seem to alter the general behaviour of RFP discharges.

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