The PROTO-PINCH experiment

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1 - Introduction

Spherical Tori (aspect ratio A=R/a<2) were originally proposed by M. Peng and his collaborators at ORNL.[1] They are based on economical (low aspect ratio=low volume=low cost) and physical (probable no disruptions, low geodesic curvature, high beta) attractive features. These features have been confirmed by the START[2] experiment at Culham.

The decrease in the aspect ratio and the trend to the Ultra Low Aspect Ratio Torus (ULART, A<1.3) is a necessary further step in Spherical Tori. The main problem of a Spherical Torus Reactor is the impossibility of shielding the central rod from the neutron flux, therefore the central rod cannot be superconducting. The PROTO-SPHERA[3] experiment (Spherical Plasma for HElicity Relaxation Assessment), which will be built at Frascati, will be devoted to demonstrate the feasibility of an ULART where a stabilized screw pinch takes the role of the central rod; such a magnetic configuration is known as "Flux Core Spheromak"[4]. Two electrodes, composed by a large number of elementary tubes made of refractory metal (hollow cathodes and hollow anodes), pressed radially and aligned along the lines of force of the disk shaped plasma, will feed the central screw pinch and sustain the ULART by driving poloidal field by DC Helicity Injection (Fig. 1).

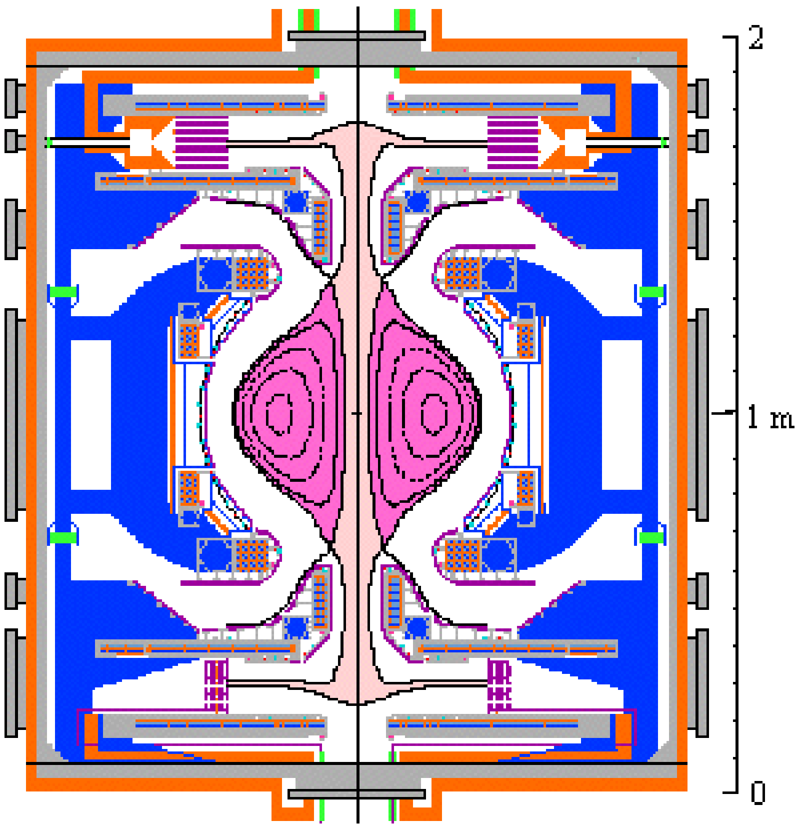

Fig. 1: Load assembly and plasma configuration of PROTO-SPHERA.

The TS-3[5] ULART experiment (Tokyo University) has successfully obtained a similar magnetic configuration that has been sustained for tens of Alfvén times (i.e. for approximately 100 µs). The main goals of PROTO-SPHERA will be the following:

1) form, compress and sustain the configuration on a resistive time scale (>20 ms);
2) assess the steady state operation (≈1 s) and the efficiency of the Helicity Injection;
3) assess the behavior of the global energy confinement time, comparing it with the one obtained in START, as PROTO-SPHERA is comparable in size and plasma current to it.

The key parameters of PROTO-SPHERA are: ULART current I_p=240 kA, longitudinal pinch current I_e=60 kA, ULART aspect ratio A≈1.20, edge safety factor of the ULART q_{95}≈2.8.
The problem of damages to the central rod is however turned to the problem of avoiding damages to the electrodes.

2 – The Electrodes' Benchmark (PROTO-PINCH)

A benchmark for the electrodes is required because the high value of power handled by them. The electrodes' benchmark PROTO-PINCH (Fig. 2) has been built and operated. It has produced a screw pinch with roughly the same geometrical dimensions of the screw pinch of PROTO-SPHERA, with a simpler mechanical configuration of the electrodes.

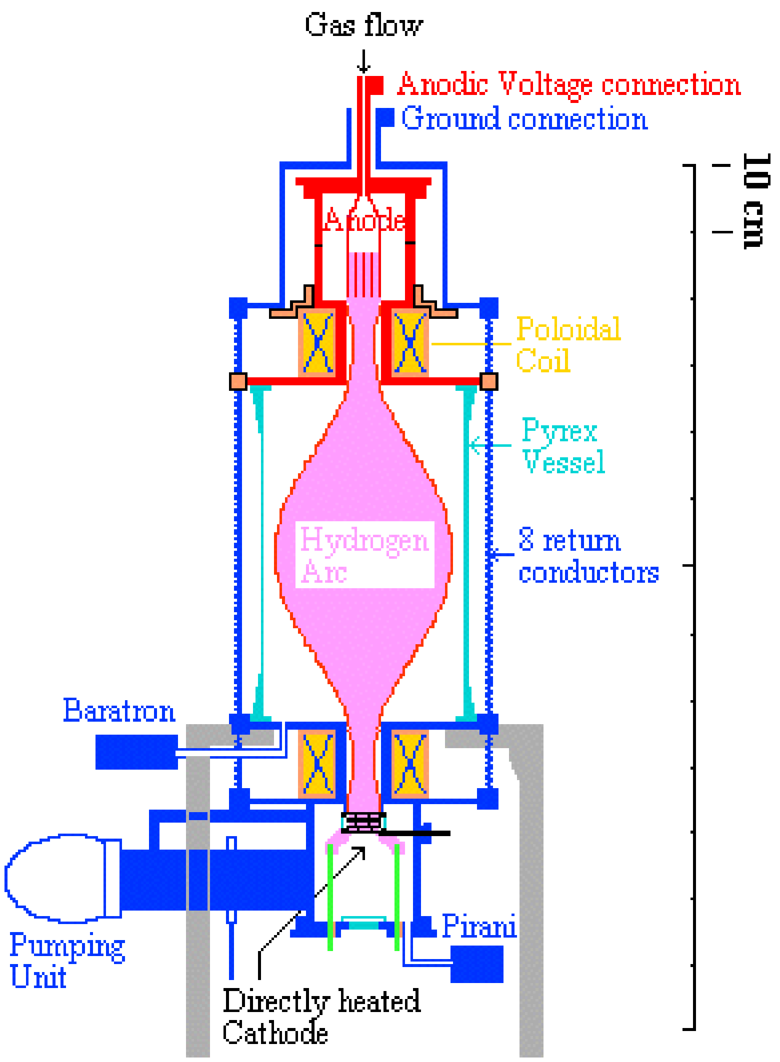

Fig. 2: Load assembly and plasma configuration of PROTO-PINCH

PROTO-PINCH, with an anode-cathode distance of 0.75 m and a stabilizing magnetic field B=1.5 kG, has a current capability of I_{Pinch}=1 kA, (with $q_{Pinch} \geq 2$). The technical solution for the 5 cm diameter electrodes are: i) a water cooled hollow anode (Fig. 3a), built in copper and/or stainless steel, through which the H_2 gas is puffed (a feed-back system stabilizes the pressure p_H in the vessel); ii) a directly heated Thoriated Tungsten hollow cathode (6 spirals of W-Th), that is shown in Fig. 3b.

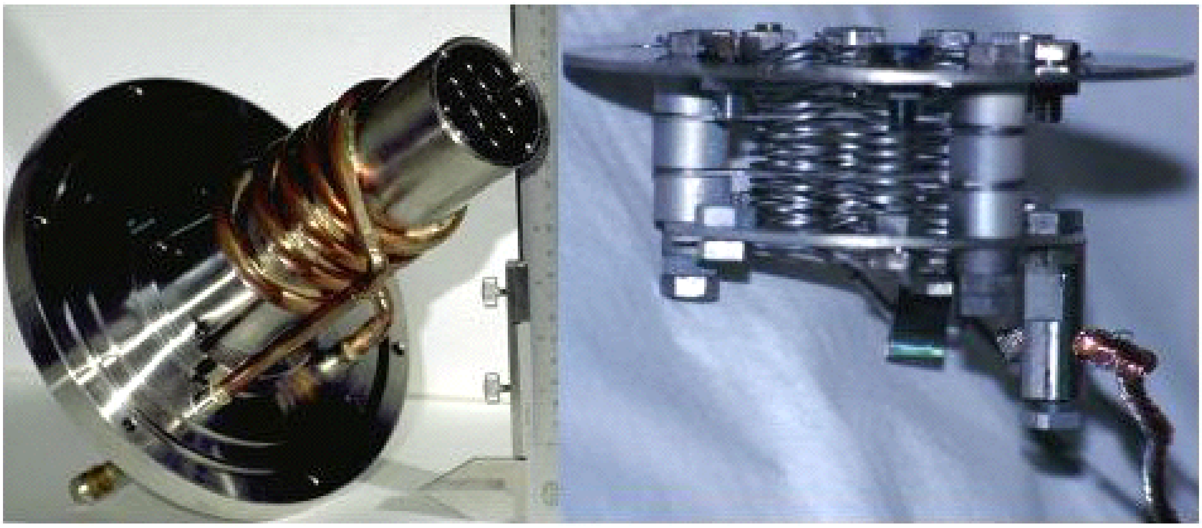

Fig. 3: a) Hollow anode; b) directly heated cathode.

The cathode structure is built by refractory metals (Molybdenum and Tantalum) and high temperature resistant insulators (Alumina); the W-Th spirals can be heated up to 2300 °K in few seconds by a total current $I_{cath} \approx 200$ A with a voltage $V_{cath} \approx 20$ V ($P_{cath} \approx 4$ kW), in order to obtain the needed electron emissivity.

3 – PROTO-PINCH Results

Self-sustained pinch discharges have been obtained with B=0.8 kG, $I_{Pinch} \leq 400$ A (limit of present power supply) and V_{Pinch}=40÷80 V, therefore no high voltage is required. The pinch current has been obtained in filling pressure range $p_H = 1 \cdot 10^{-3} \div 1 \cdot 10^{-2}$ mbar, namely the typical

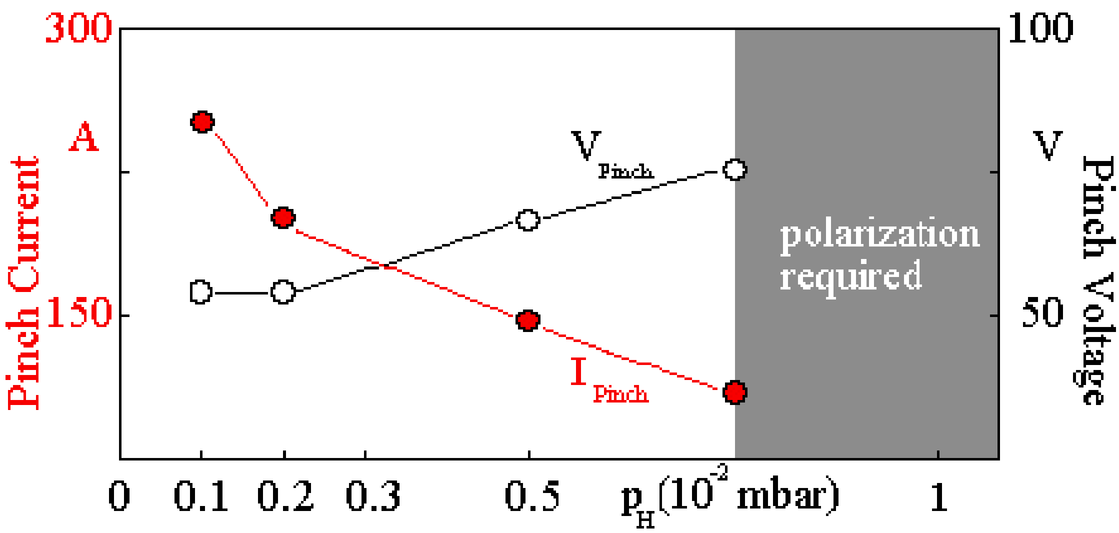

Fig. 4: Characteristic of the PROTO-PINCH primary arc Vs. the filling pressure p_H

values of a standard Tokamak break-down. The characteristics of the PROTO-PINCH primary arc are shown in Fig. 4: the behavior of I_{pinch} and V_{pinch} Vs. the fluxed filling pressure p_H are well reproduced by a Paschen curve. The typical duration of a plasma pulse at a pinch current of 300 A is 5÷10 s; it has to be remarked as the energy deposited on the electrodes by a discharge with I_{pinch}≈700 A, V_{pinch}≈80 V in 5 seconds is comparable with the one of the standard pinch discharge in PROTO-SPHERA (I_e=60 kA, V_e=200 V, 1 second pulse).

Up to now, only few tens of PROTO-PINCH discharges at 300-400 A has been performed: the extensive campaign that must assess the electrode capability of surviving at hundreds of full power plasma pulses (I_{pinch}=700 A) is in progress.

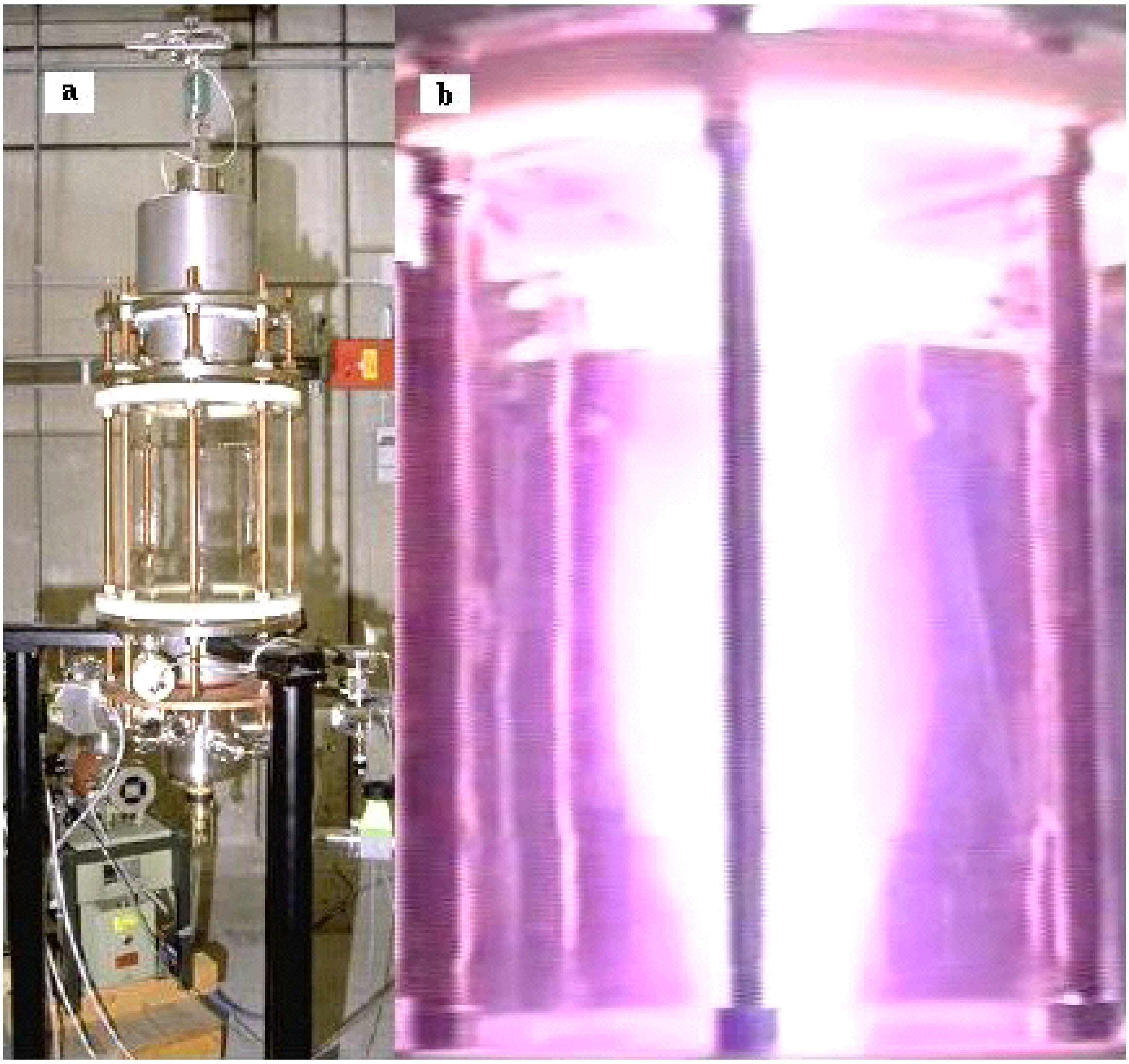

Fig. 5: a) PROTO-PINCH electrode benchmark; b) Hydrogen arc discharge in PROTO-PINCH

An image of the PROTO-PINCH experiment, together with a photo of a standard plasma discharge, is shown in Fig. 5.

References

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