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TBR-1 (BRAZILIAN TOKAMAK) - RECENT RESULTS

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TBR-1 (Brazilian Tokamak) - Recent Results*

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ABSTRACT

The TBR-1 is a small Tokamak installed at the Physics Institute of the University of São Paulo. The machine was designed in 1977 and begun to be used in plasma scientific research in early 1980. Its main characteristics are: Major radius, 0,30 m; Minor radius (limiter), 0.08 m; Toroidal field, 5 kG; Plasma current, 10 kA (typical); Current duration, 6 ms (typical). In this paper we report the results of recent experimental research done in the TBR-1.

1. INTRODUCTION

Most of the work carried out on TBR-1 is related to the development of diagnostic techniques, mainly electrostatic probes, magnetic coils, X-Ray; and data acquisition processes, shown squematically in fig. 1.

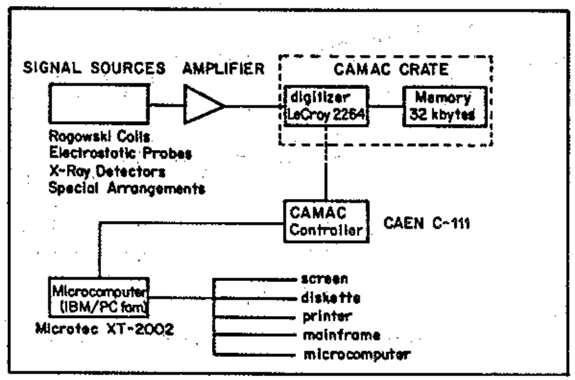

Fig.1 - Data Acquisition System.

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Results about Resonant Helical Fields are reported in another paper (I.L. Caldas et al., "Resonant Fields in TBR-1"), in this Proceedings.

2. WALL CONDITIONING THROUGH MICROWAVE PLASMA

It is well known the necessity of wall conditioning and cleanliness of Tokamaks in order to get more stable plasma pulses. Almost every Tokamak has a discharge cleaning process, most of them based upon Taylor's method [1] of creating a low energy plasma, without equilibrium conditions, that strike the walls with H^+ and H^o. Products formed with atoms of C and O on the surface suffers desorption more easily and are pumped away by the vacuum system. The experiment [2] conducted at TBR-1 was to test an alternative procedure of creation a low energy plasma through Electron Cyclotron Resonance (ECR) using a domestic oven magnetron (f = 2.45 GHz, P = 800 W DC). The main results are in fig. 2, which show the vessel gaseous ambient composition, before and after the discharge cleaning process.

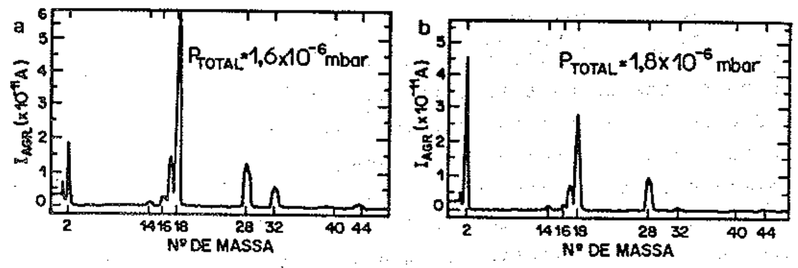


Fig.2 - Ambient Gas composition as seen by the Residual Gas Analyzer. (a) Before Cleaning Process with microwaves and (b) after process.

There is a enhanced peak of Hydrogen and a reduction of all other gases. Final results are that this cleaning process is as efficient as Taylor's method, with a low frequency power oscillator.

3. SHAPE OF PLASMA COLUMN [3]

An circular arrangement of 20 coils of two kinds: one made of 56 turns of wire with diameter 0.13 mm, on a spool of cross section 12.7 mm; the other with 130 turns of the same wire with the same cross section, were fit radially and tangentially side by side into two 180° bent tube as in fig. 3, creating a system sensitive to the radial and poloidal field of plasma.

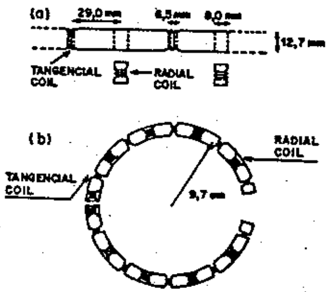


Fig. 3 - Sketch of the tangential and radial pick-up coils and the assembling scheme (a) and the two bent nylon tubes before insertion in the supporting metal tubes (b).

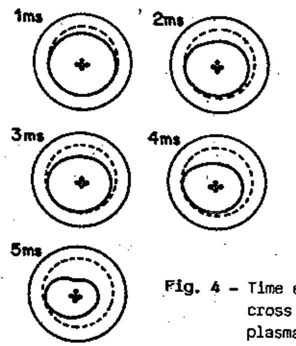


Fig. 4 - Time evolution of the cross section of the plasma column in the 10 kA discharge.

The two tubes circles the plasma column. Appropriate buffers conducts the signals to data acquisition systems. After reduction, the data is used in a simulation procedure where it is asked what current, flowing through four circular filaments, concentric to the vessel, would produce the measured results. Minimization techniques, based upon the average square deviation of measured and calculated values of the magnetic field at the position of the arrangement of the coils were used for the determination fo equivalent currents. Once determined the currents, the flux function may be calculated, and, since the plasma boundary has to be a flux surface, the last flux surface is the one that

touches the limiter. Numerical procedures are used to plot this surface. The main results are shown in fig. 4, with the evolution of the plasma shape boundary with time.

4. ELECTRON TEMPERATURE MEASUREMENTS THROUGH THE METHOD OF X-RAYS ABSORBING FOILS [4]

The experimental procedure consists of measuring soft X-Rays emissions from plasma column, with two pairs of surface barrier detectors. Each detector of the pair responds to the same solid angle, as determined by a collimator, but presents different thickness of berillium foils, 2000 Å and 5000 Å to the optical path of X-Rays. The ratio of the signals in the two detectors determines the plasma temperature [5]. Although this method is known not to be accurate, it is useful to monitor directly the time evolution of the electron temperature. Fig. 5 shows the temporal evolution of the electron temperature at the center of the plasma and at $r = 3.8$ cm. In this shot, the maximum temperatures were respectively 200 eV and 100 eV.

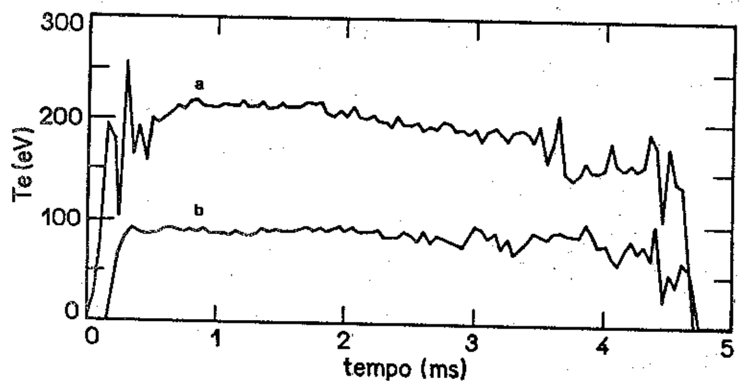


Fig. 5 - Temporal evolution of the electron temperature at the center of plasma column (a) and at $r = 3.8$ cm (b).

5. TEMPORAL AND SPATIAL MEASUREMENTS OF THE EDGE OF ELECTRON TEMPERATURES

A saw-tooth generator was recently designed that make possible to drive a electrostatic probe with adjustable ramp voltage of -100 V to 100 V, with period adjustable from 0.050 ms to 50 ms. The maximum permissible current for the probe is 0.25 A. Incorporating a current transformer, the system allows for the measurement of the electrostatic probe current with a resolution of 0.020 mA (fig. 6).

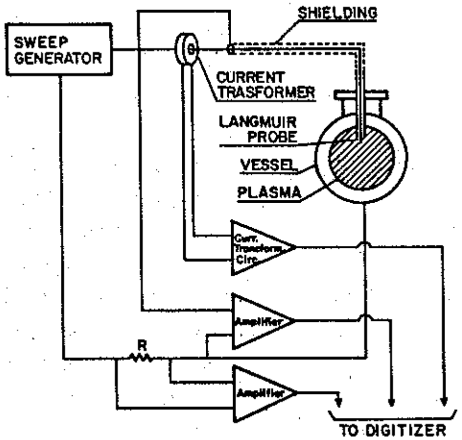
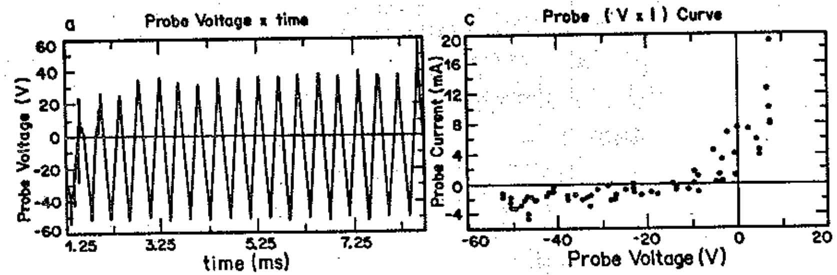


Fig. 6 - Connections for driving Langmuir probes with the saw-tooth generator.

The diameter of the probe is 0.2 mm and its length 5.0 mm. Sequence in fig. 7 shows respectively the triangular wave applied to the probe and the current response; details of 1.0 ms interval at 3.25 ms and finally the curve (current) vs. (voltage), through which may be calculated the electron temperature, by the use of known techniques of electrostatic probes. Measurements with the system show that the edge of plasma column in TBR-1 has electron densities ranging in the interval 10^{16} - 10^{18} m^{-3} and electron temperatures 20 - 30 eV.



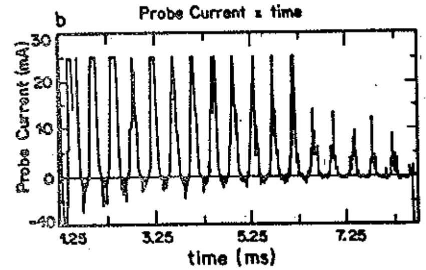


Fig. 7(a) Triangular voltage applied to probe.
(b) Electric current in the probe.
(c) The resultant curve for a single ramp, positive going, at 4 ms, with current vs. voltage.

6. ELETROSTATIC ION PROBE FOR THE DIAGNOSTICS OF THE EDGE OF TOKAMAK PRODUCED PLASMAS [6]

This is a diagnostic technique based upon the different Larmor radius of electrons and ions in a magnetized plasma. The working principle of the probe is shown in fig. 8, where a central collector responds mainly to ions; electrons are prevented from reaching the collector by hollow cylindrical metallic guard involving the central collector. To our knowledge this is the first time an electrostatic ion probe is successfully applied to a Tokamak plasma. Fig. 9 shows the curve (current) vs. (retraction length h), evidencing the optimum working point at h = 0.2 mm(a) with a typical probe curve(b). In this case, the measured ion temperature is 23 eV.

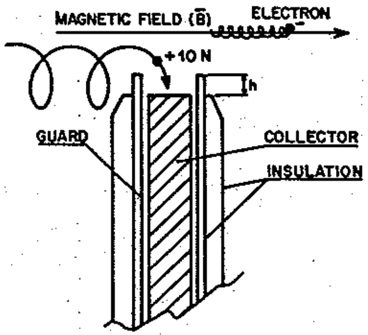


Fig. 8 - Working principle of the ion sensitive probe.

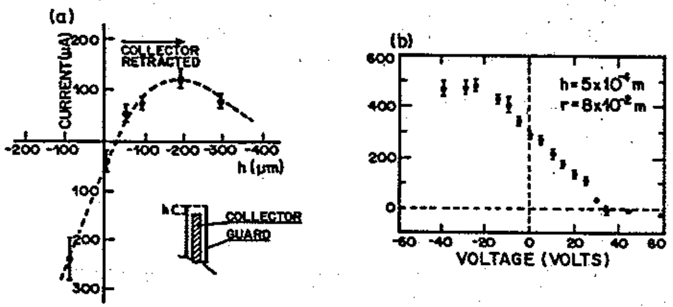


Fig. 9 (a) Collector current vs. collector retraction h. (b) Ion probe characteristic curve.

7. PLASMA EDGE TURBULENCE

The characteristics of the spectrum of electrostatic fluctuations at the edge of the plasma column have been investigated at TBR-1 using electrostatic probes. The signals are digitalized and stored using the data acquisition system shown in fig. 1 and later processed using the FFT technique [7]. The spectrum is limited to a range between 3 and 500 kHz by a band-pass filter. Two sets, of three probes each, are used; one set, S2, is located at the top and the other, S5, at the equatorial plane, on the low-

field side of the device. The probes can be inserted up to 1.0 cm beyond the limiter border, into the plasma, without affecting the global characteristics of the discharge. The limiter is a circular metal ring around the plasma column at $r = 8.0$ cm.

The toroidal magnetic field in TBR-1 has a strong ripple, with the relative well depth δ varying from approximately 4% at the magnetic axis to 12% at the limiter [8]. In order to investigate the effect of the magnetic ripple on the characteristics of the turbulent spectrum, the equatorial probe set S5 is inserted at the position of the bottom of the magnetic ripple well. Thus, although the probes S2 and S5 are at the same toroidal location, the value of δ at the position of the former is approximately three times smaller than the value at the position of the latter.

For the measurements reported here, the global parameters are the following: Plasma current $I_p = 10$ kA, Toroidal field $B_T = 3.6$ kG, central electron temperature $T_{CO} \approx 150$ eV, and average electron density $\bar{n} = 4.3 \times 10^{18}\,m^{-3}$. The local edge conditions are roughly the same, both at the same equatorial and top positions, i.e., electron temperature $T \approx 20$ eV and electron density $\bar{n} \approx 1.5 \times 10^{18}\,m^{-3}$. The temperature and density profiles decay towards the limiter with typical characteristics lengths $T/(dT/dr) = 0.45$ m and $n/(dn/dr) = 0.55$ m. For these parameters we find that the electron bounce frequency in a ripple well is $f_b = 1.3$ MHz whereas the effective detrapping frequency $\nu_{eff} = \nu_{ei}/\delta = 0.7$ MHz. Thus the conditions for ripple trapping of electrons is well satisfied. The electron diamagnetic frequency, on the other hand, is given by $f^* = 9.0$ kHz. Consequently, because of the band-pass filter used in the measurements, we are unable to detect any coherent mode with frequency close to the electron bounce frequency and only marginally detect coherent modes with frequencies close to the electron diamagnetic frequency.

The auto-power spectra measured at the edge of the limiter by probes S2 and S5 are shown in fig. 10 a and b respectively.

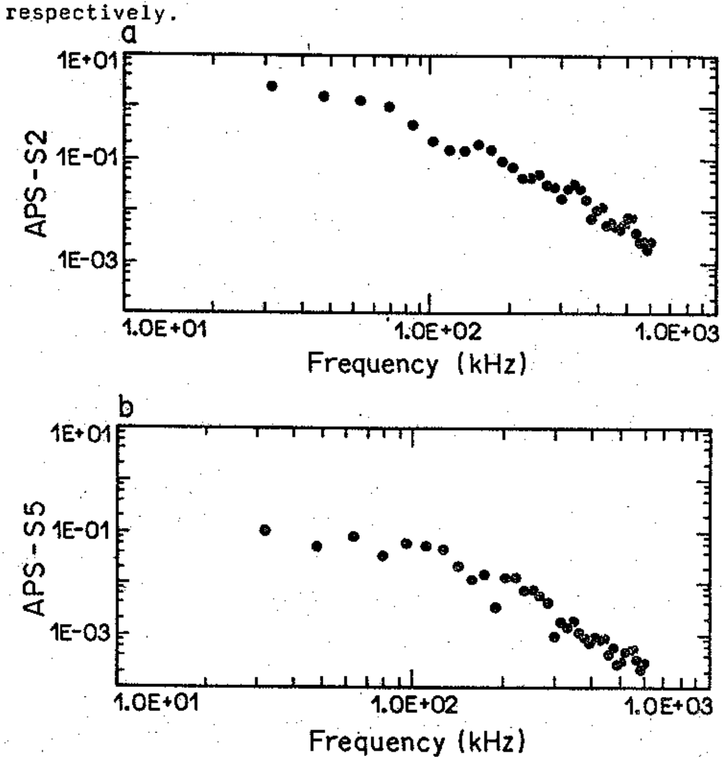


Fig. 10 - Auto-Power spectra measured by probe S2(a,top) and S5(b,equator.) at the edge of the limiter, r= 8,0 cm. The spectral index is 3.0 in (a) and 2.6 in (b).

The spectral point at $f \approx 15{,}6$ kHz is due to a pick-up noise that exists even in the absence of plasma and which we were unable to eliminate. We see that the spectra are typically characterized by a plateau with a decaying tail beyond $f \approx 100$ kHz, as observed in other devices [9]. The spectral index α, $P(f) \sim f^{-\alpha}$, varies typically from 2.5 to 3.0, in qualitative agreement with measurements in other devices and some theoretical models [10]. There is sometimes a

difference, not systematic, between the indices of the spectra measured by the two sets of probes.
A distinctive feature of our results is the radial scaling of the turbulence level. In fig. 11 we show the average ion saturation current $\bar{I}$ and the fluctuation level $\langle\tilde{I}\rangle/\bar{I}$ as a function of minor radius. The fluctuation level is averaged over 0.1 ms time intervals.

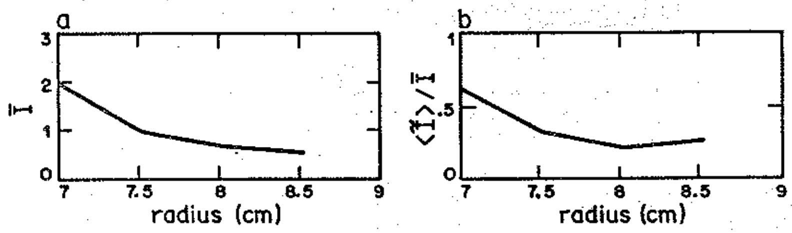


Fig. 11 - Ion saturation $\bar{I}$ (a) and average fluctuation level $\langle\tilde{I}\rangle/\bar{I}$ measured by probes S2 as a function of radius approximately 1 ms after the initiation of the discharge.

We see that the fluctuation level decreases with radius, as opposed to most of the results obtained in other devices. Only at Alcator similar results have been obtained, in low density discharges [11].
The radial dependence can be clearly seen in situations where the plasma column has an outward displacement during the discharge. In fig. 12 we show the loop voltage V_L, the radial position (in-out), the plasma current I_P and the hard X-Ray emission signals for a typical 10 kA discharge. We see that the column undergoes a substantial outward displacement reaching a maximum displacement at $t \approx 3$ ms. The temporal evolution of the ion saturation current I and of the fluctuation level $\langle\tilde{I}\rangle/\bar{I}$ measured by probes S2 and S5 in this discharge is shownin fig. 13. While there is no systematic variation in the fluctuation level measured by probe S2, there is a substantial increase in the fluctuation

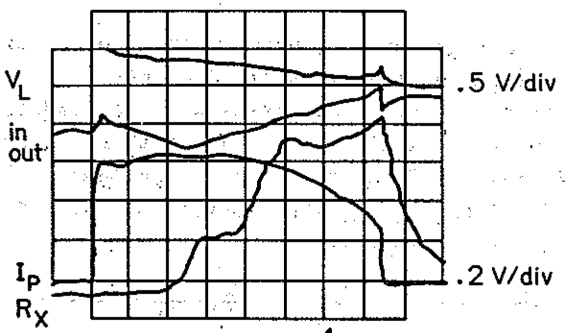


Fig. 12 - Loop voltage, L_p, in-out radial position signal, plasma current I_p, and hard X-ray emission for a 10 kA discharge.

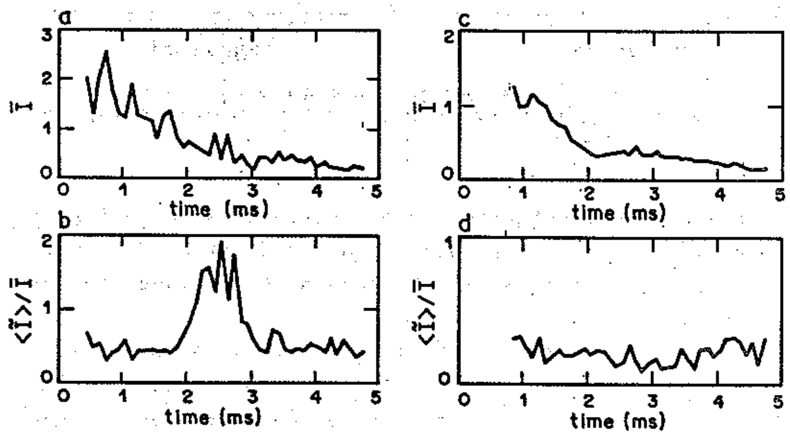


Fig. 13 - Temporal evolution of the average ion saturation current $\bar{I}$ and fluctuation $\langle\tilde{I}\rangle/\bar{I}$ measured as a function of time by probes S5(a and b) and S2(c and d). The probes are located at a fixed radial position r = 7.5 cm.

level measured by probes S5 as the plasma column moves towards them. When the column recedes, the fluctuation level returns to the levels before the displacement while the average density keeps decreasing with time.

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