

A Method to Determine the Evolution of the Plasma Column Position from the Analysis of the Mirnov Coils Signals

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Abstract: A fast method for the determination of the temporal evolution of the plasma column transverse position is established through the analysis of the fluctuations on the signals associated with a discrete set of poloidally distributed Mirnov coils. This method is applied to the study of the equilibrium properties of some typical ISTTOK discharges.

1. Introduction

This method is based on the determination of the poloidal variation of the high frequency weighted mean magnetic fluctuations amplitude and on its assumed inverse dependence on the distance between the Mirnov coil axis and the plasma periphery. It assumes that: (i) the plasma rotates with a period shorter than the required resolution time; (ii) localized magnetic fluctuations are carried by the rotating plasma; (iii) the fluctuations spectrum does not change significantly from coil to coil; (iv) for the poloidal angle corresponding to the coil with maximum fluctuations amplitude, the plasma touches the vessel wall.

2. Theoretical considerations

Let us consider the existence, at the edge plasma region, of a single MHD mode represented by its poloidal magnetic field, at the axis of a particular Mirnov coil located at the poloidal angle ϕ_0 , $B(\phi_0, t) = B(\omega, t) \sin(\omega t)$. Then, the Mirnov coil signal may be represented by

$$-S \partial B / \partial t = -\omega S B(\omega, t) \cos(\omega t) - S \partial B(\omega, t) / \partial t \sin(\omega t) \quad (1)$$

where S is the equivalent transverse area of the coil. If the wave amplitude is a slowly varying function of time ($\partial B / \partial t \ll \omega B$), equation (1) may be simplified to

$$-S \partial B / \partial t = -\omega S B(\omega, t) \cos(\omega t) \quad (2)$$

and the slowly varying part of the integral of the square of the Mirnov coil signal is

$$I(t) = \frac{1}{2} S^2 \omega^2 \int B^2(\omega, t) dt \quad (3)$$

For a wide spectrum of magnetic oscillations this equation becomes:

$$I(t) = \frac{1}{2} S^2 \iint \omega^2 b^2(\omega, t) d\omega dt \quad (4)$$

where $b(\omega, t)$ represents their spectral amplitudes.

The ratio $\Delta I(t) / \Delta t$, at $t=t_0$ and at the poloidal angle ϕ_0 , is then proportional to the high frequency weighted mean global wave power, $\langle W_M(\phi_0, t_0) \rangle$,

$$(\Delta I / \Delta t)_{t=t_0} = \frac{1}{2} S^2 \int \omega^2 b^2(\omega, t_0) d\omega \sim S^2 \mu_0 \langle W_M(\phi_0, t_0) \rangle \quad (5)$$

The square root of this ratio may therefore be a measure for the high frequency weighted mean global magnetic fluctuations amplitude, $\langle B(\phi_0, t_0) \rangle$. Given the initial considerations, we may determine the plasma local radial extension, at the poloidal angle ϕ_n , by

$$a(\phi_n, t_0) = c - (c - b) \langle B(\phi_{nmax}, t_0) \rangle / \langle B(\phi_n, t_0) \rangle \quad (6)$$

where c is the Mirnov coil radius, b is the vessel radius and $\langle B(\phi_{nmax}, t_0) \rangle$ is the maximum value of $\langle B(\phi_n, t_0) \rangle$.

The presented method, by avoiding the usual initial integration of the Mirnov coil signals

and by squaring them before further processing, reduces the influence of off-sets and slow changes in the equilibrium external fields from first order perturbations ($\sim 10\%$) to second order ones ($\sim 1\%$).

3. Experimental conditions

The application of this method only requires the knowledge of the evolution of the signals of the eight Mirnov coils. The associated algorithm has the following steps: (i) acquires the Mirnov signals; (ii) squares them; (iii) integrates the squared signals in time; (iv) determines the slope of these averaged integrals and identifies this quantity as $\langle W_M(\phi_n, t_0) \rangle$; (v) takes the square root of these slopes and associates it with $\langle B(\phi_n, t_0) \rangle$; (vi) computes the radial distances between the tokamak geometrical axis and the plasma edge, for the eight poloidal angles; (vii) makes a circular curve fitting through the calculated surface points; (viii) determines the coordinates of the circumference centre (x_0, y_0) , which is associated with the plasma column axis, and the plasma column radius (r_0) . After being tested with simulated Mirnov coil signals, this algorithm was applied to the study of some typical ISTTOK discharges.

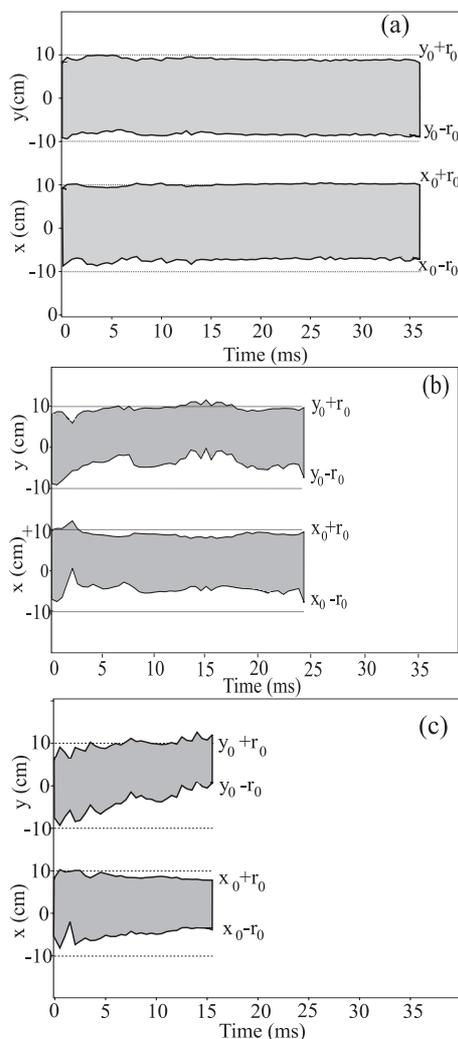


Fig. 1

biasing, t_B and we have arrived to the following results shown in Fig. 2: with positive (negative) bias, in #2454 (#2455) we have observed a slight out and upwards (a) (in and

3.1. – Optimization of the horizontal equilibrium magnetic field

Fig.1 shows the evolutions of both the vertical and the horizontal cuts of the plasma column, obtained in three discharges with the same external parameters, except for the value of the equilibrium horizontal B-field, B_H . Fig.1a shows the behaviour of a flat-top plasma current discharge (#7899). The column diameter remains practically constant and its axis does not shift significantly along time. Fig.1b shows the modifications produced by the removal of the horizontal B-field (#7866). We observe that the lower vertical and the inner horizontal boundaries of the plasma column have become irregular and that the column has shown a diameter reduction. The discharge ended by a disruption. Reversing the direction of B_H (#7872) has led to an unstable situation in which the plasma column is progressively moving up and outwards with a severe diameter reduction leading to an earlier disruption (Fig 1c).

3.2. – Analysis of vertical displacement events under a limiter biasing regime.

In a recent publication [1] we have described experimental results concerning the plasma response to the biasing of the tokamak localised limiters. Positive limiter biasing has caused a significant, transitory, almost vertical displacement of the plasma current axis (#2454). We have now determined the evolution of the plasma column transverse cross-section, around the instant of

downwards (c)) displacement of the column axis, resulting in a reduction (b) (increase (d)) of the column diameter . These results suggest that the current axis, as determined by the sin-cos coils in [1] does not necessarily coincides with the plasma column axis.

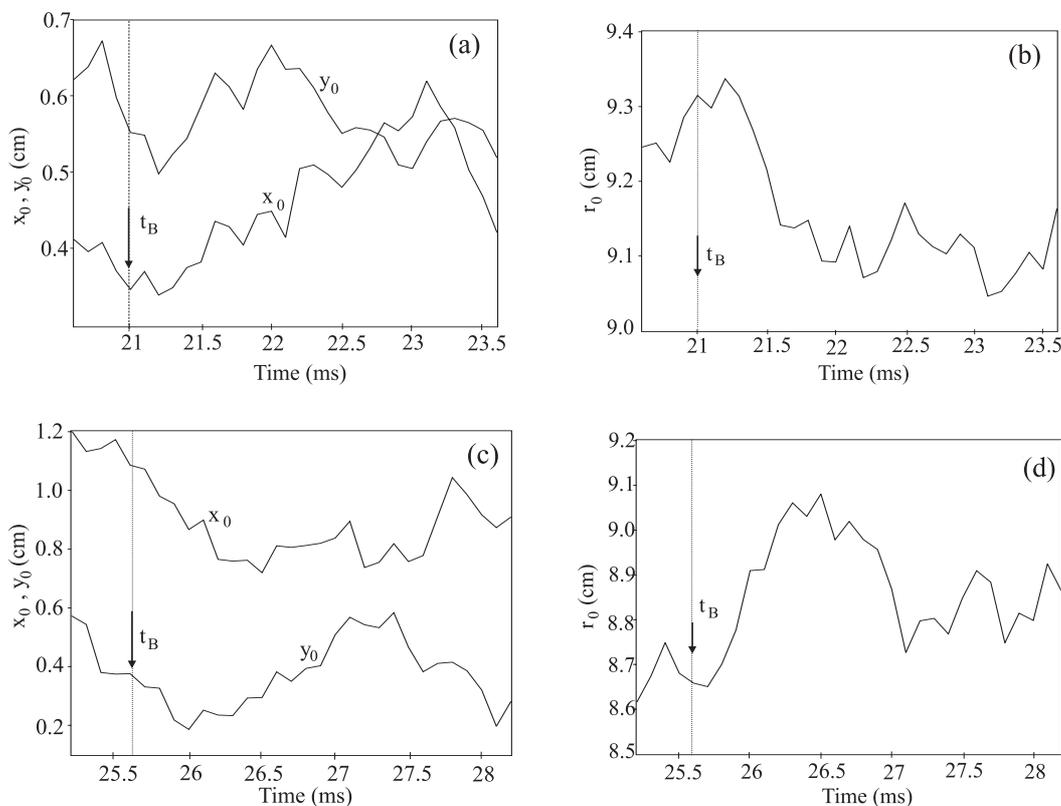


Fig. 2

3.3. - Analysis of the column movement during a sawtooth crash

In a former publication [2] we have described the temporal evolution of the major internal plasma parameters during a complete sawtooth cycle of the tokamak ISTTOK discharges. After the crash, sudden reductions of plasma density and temperature were observed, associated with the rapid plasma movement towards the tokamak wall. We have now analysed the plasma column surface movement during these rapid events.

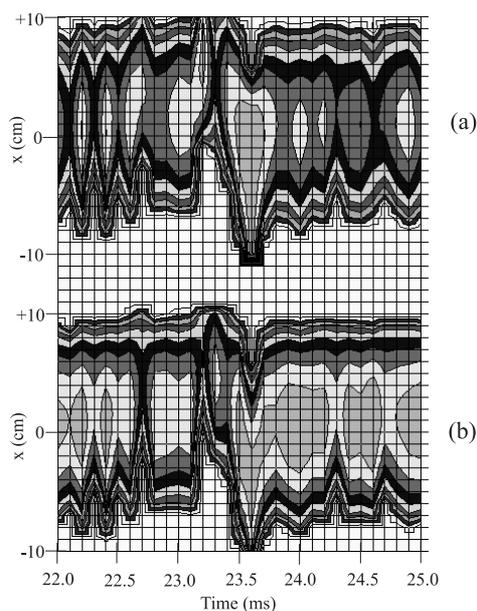


Fig. 3

Fig. 3 presents, in a topographical level chart, the evolution of the lower (a) and the upper (b) halves of the plasma column, during a sawtooth crash (#2457). We observe, before the onset of the sawtooth activity ($t=23,1$ ms), the existence of a precursor with $f\sim 5$ kHz, also noticeable in the plasma current. During the crash, which is seen to occur in less than $100 \mu s$, we witness a very strong diameter reduction, from 18 to 13 cm, resulting from the sudden ejection of core plasma particles along the up and outward directions. $300 \mu s$ latter, the low density column has been pushed inwards,

clearly separated from the external horizontal limiter and attaining a diameter of about 19 cm. After a phase in which we observe lower frequency postcursor oscillations, the plasma column has regained an equilibrium position with the initial ($t=22$ ms) dimensions and location.

3.4. Plasma column behaviour in an alternating plasma current regime

In a recent article [3], we have reported the operation of the tokamak ISTTOK in a multi-cycle alternating square wave plasma current regime.

In Fig.4 we present a 3-D view of respectively the upper (b) and the lower (a) half of the plasma surface, around a current transition (#5672). We may conclude that the plasma column is most of the time touching both the vertical up and the horizontal external limiters and that the lower as well as the inner surface limits are simply determined by the amount of scraping-off made by them, due the changing transverse equilibrium forces.

Analysis of this current transition shows that the plasma column in the negative current half period ($t < 68,2$ ms) is narrow ($r_o = 6.83$ cm) and is shifted up ($y_o = 0.65$ cm) and outwards ($x_o = 3.81$ cm). Between the instant of loop voltage reversal ($t = 67,5$) and that of zero plasma current ($t = 68,2$ ms) the column reduces its density and gradually fills almost the entire vessel cross section ($r_o = 9$ cm, $x_o = 0.38$ cm, $y_o = 0.03$ cm). While the plasma current is increasing, now in the forward direction, the column reduces diameter. When the column attains its maximum forward current ($t = 73.2$ ms), it shows again a broad and practically centered surface ($r_o = 8.3$ cm, $x_o = 1.84$ cm, $y_o = 0.23$ cm). From this moment on we observe a slight drop in current and the column finally stabilizes with a radius larger than that it had in the reversed current half-cycle. Further we have noticed that the values of the plasma current in different half-cycles scale with those of the square of the plasma column radius.

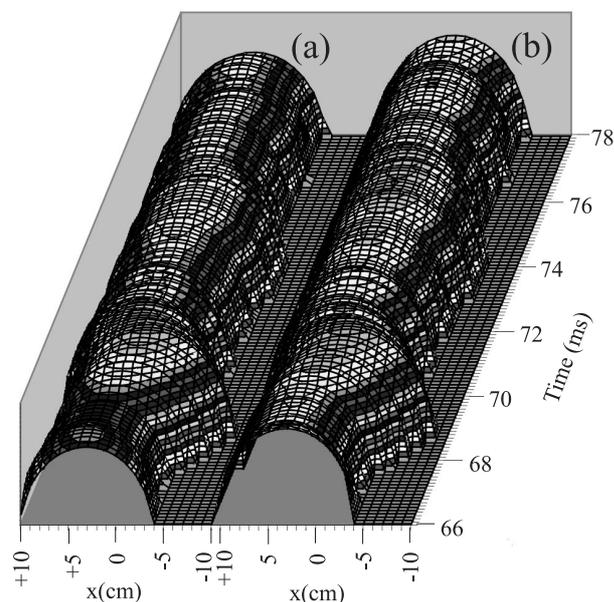


Fig. 4

4. Conclusions

The results so far obtained with the presented method have properly described the typical behaviour of the plasma column under well know discharge regimes, such as those with sawtooth activity, a limiter biasing process and an alternating plasma current.

This algorithm has also been useful in the search for the most adequate external magnetic equilibrium fields, in order to attain a dense, well-centred, broad and stable plasma column.

Concluding, we stress that the described method may be easily extended to the analysis of the plasma column stability in non-circular cross-section

machines, such as those found in torsatrons, stellarators and D-shaped plasma tokamaks.

References:

- [1] – Cabral, J.A.C. et al, Plasma Phys. Control. Fusion 40, 1001, 1998
- [2] – Cabral, J.A.C. et al, Plasma Phys. Control. Fusion 38, 51, 1996
- [3] - Cabral, J.A.C. et al, Nuclear Fusion 37, 1575, 1997