JOINT EUROPEAN TORUS

JET–P(86)31

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JET Contributed Papers at the International Workshop on Small Scale Turbulence and Anomalous Transport in Magnetized Plasmas

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Preprint of Paper to be submitted for publication in
Contributed Papers at the International Workshop on Small Scale Turbulence and Anomalous
Transport in Magnetized Plasmas (Cargese, Greece, July 1986)

JET-P(86)31

JET CONTRIBUTED PAPERS AT THE INTERNATIONAL WORKSHOP ON SMALL SCALE TURBULENCE AND ANOMALOUS TRANSPORT IN MAGNETIZED PLASMAS (CARGESE, JULY 1986)

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(Cargese, July 1986)

OBSERVATIONS OF TURBULENCE IN THE JET TOKAMAK

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INTRODUCTION

Anomalous transport and degradation of confinement during additional heating in pinch discharges are widely believed to be associated with fluctuations of random nature /1/. Here we report some measurements of fluctuations in edge magnetic field and visible light emission carried out on the JET Tokamak and discuss the time - space behaviour of the broadband activity.

EDGE MAGNETIC FLUCTUATIONS

The main parameters of the JET machine and of one of its typical discharges (during Neutral Beam Injection) are summarised in Fig 1. Also shown is the location of the edge pick-up coils ($\dot{B}_\theta$) located inside the vacuum vessel. Each of the eight octants of JET is provided with an identical array of 18 coils (although 2 octants are devoted exclusively to feedback current control). The data are collected by digitally sampling at 40kHz over a time interval of ~ 200ms during the flat-top period of a discharge; if additional heating is applied the acquisition starts ~ 1s after that has started, so as always to observe steady state phenomena. Data thus collected from several similar discharges is selected in order to eliminate that influenced by coherent large amplitude MHD fluctuations such as sawteeth, minor disruptions, etc; in this way we can focus our attention on the low amplitude background activity. The total normalised fluctuation amplitude in such conditions is $|\tilde{B}_\theta|/\langle B_\theta\rangle \sim 10^{-4} - 10^{-5}$ and Fig 2 shows the digital spectra obtained for two identical pulses, in one of which ~ 4MW of NBI heating was applied (# 8060).

Mirnov activity is normally observed, under ohmic conditions, up to frequencies of 0.5-1kHz; during NBI this limit can shift to 5kHz, as in the example shown, where a narrow peak at ~ 5.6kHz is representative of some sawtooth precursor activity. For the rest the two spectra are characterised by broad random features. The increase of spectral power density at high frequencies during NBI is a systematic and well reproducible feature (Radio Frequency heated discharges are not yet sufficiently well documented but appear to behave similarly). The protective metal shielding of the pick-up coils has an associated cut-off frequency of ~ 10-15kHz but this effect has not yet been studied in detail and is of little relevance in what follows.

The spatial structure of this broad band activity has been investigated by means of correlation techniques applied to signals from several coils at various toroidal and poloidal angles. The original time histories are first digitally filtered; then a time-space correlation is calculated as follows:

$$R_{xy}(\tau) = \frac{1}{T}\int_{t_0}^{t_0+T} x(t)\, y(t+\tau)\, dt \quad \text{(cross-correlation)}$$

$$\rho_{xy}(\tau) = R_{xy}(\tau) \Big/ R_{xx}(o)\, R_{yy}(o) \quad \text{(cross-covariance)}$$

Figures 3 and 4 show $\rho_{xy}(\tau = 0)$ for various pairs of coil signals x and y (for pulse # 8060) in the frequncy bands 2-5kHz and 15-20kHz. In particular coils 1 to 10 of octant 8 have been correlated with the N° 3 coils of all the available octants, so as to form a 2-D (Θ-ψ) space correlation. The bottom inset in both figures shows the (toroidal) correlation between the N° 3 coils (the gaps being filled by assuming axisymmetry).

In both cases a still significant correlation (error bars are ~ 5-10%) is revealed between signals from coils separated by π in both toroidal and poloidal location. This indicates the presence of global modes (low m, n) and it is very interesting to note that whereas in the first case (2-5kHz) relatively high m and n numbers (m up to 6-8 and n up to 3-4) must be present and dominate the correlation (rapid decrease of ρ when moving in both Θ and ψ directions), in the second case (15-20kHz) correlations are broader and it appears that the dominant mode is m = 2, n = 1. In both cases the correlation in the direction of the average $\vec{B}$ is very good (still ~ 50% when moving by π in ψ) but whereas a poloidal propagation velocity of about 4-6 x 10^3 m/s (in the electron diamagnetic drift direction) is observed (with time-delayed correlations) up to ~ 10kHz (independently of additional heating and of frequency), no propagation is observed in the range 15-20kHz.

VISIBLE LIGHT FLUCTUATIONS

An array of 100 Surface Barrier Diode is available in JET to measure X-ray emission. By removing the absorbtive metal foil at the front of each diode we have observed the emission of visible light radiated by the edge plasmna region. Fig 5 shows in a poloidal cross section, the line of sight of some of the diodes and the contours of emissivity. The total normalised fluctuation amplitude is ~ 10^{-2} (this represents an upper limit for the relative $\tilde{n}_e$ fluctuation level but not for $\tilde{T}_e$).

The digital sampling is at 200kHz over a period of ~ 40ms and the frequency spectrum is shown in Fig 6. The level and shape of the spectrum can vary considerably according to the choice of line of sight (Fig 6 corresponds to diode 63) and also according to the plasma parameters. The case chosen (pulse # 8420) is similar to the previous example, ie., is a standard NBI heated plasma.

The spatial correlation is shown in Fig 7 for two frequency bands (15-20kHz and 40-60kHz). The correlation is dominated by that part of the signal which corresponds to fluctuations in the edge plasma directly facing the diodes (shown by an arrow in Fig 5), due probably to the fact that visible radiation is partly reabsorbed by the plasma and that the separation of lines of sight is larger on the opposite side. Fluctuations are observed to propagate poloidally (when NBI is applied) with a velocity of about $5\text{x}10^3$m/s in the electron diamagnetic drift direction, constant at all frequencies. The latter property implies that m is linearly proportional to the frequency (m ~ 25-35 for 15-20kHz and m~70-100 for 40-60kHz, as in fact shown by Fig 7). As yet, no direct correlation between these fluctuations and fluctuations in B_Θ has been observed above 2-5kHz.

CONCLUSION

The measurements we have presented show that broad band edge magnetic fluctuations at frequenices up to ~ 20 times the normal Mirnov frequency can be dominated by low m, n modes with m/n possibly as low as 2. Broad band fluctuations in visible light emission up to 100 times the Mirnov frequency are also observed in the edge region. In both cases some features seem to indicate waves associated with **edge** drift motions but the lowest m/n magnetic activity shows different properties which are more suggestive of plasma turbulence originated in more central plasma regions. This is particularly important in view of the relationship between magnetic fluctuations and global confinement properties which is investigated in the accompaning paper /2/. Further work is necessary to assess the nature of the modes and the mechanism of enhanced transport.

ACKNOWLEDGEMENTS

We are grateful to A Pochelon and G Tonetti, for assistance and discussions on magnetic data and to R J Granetz and the JET KJ1 group for SBD data.

REFERENCES

/1/ P C Liewer: Nucl. Fusion, 25, (1985) 543.
/2/ P A Duperrex, M Malacarne: contributed paper to this workshop.

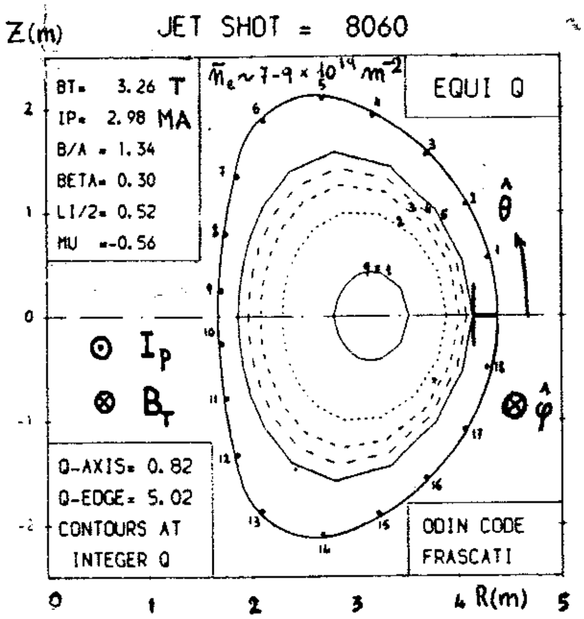

Fig 1: Poloidal cross-section of a JET discharge (flat-top); the location of the $\dot{B}_\theta$ coils is also shown.

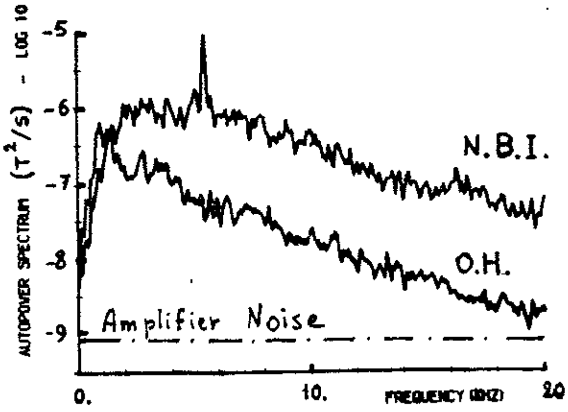

Fig 2: Frequency spectrum of $\dot{B}_\theta$ in the conditions of Fig 1 (NBI) and during an identical pulse without additional heating (OH).

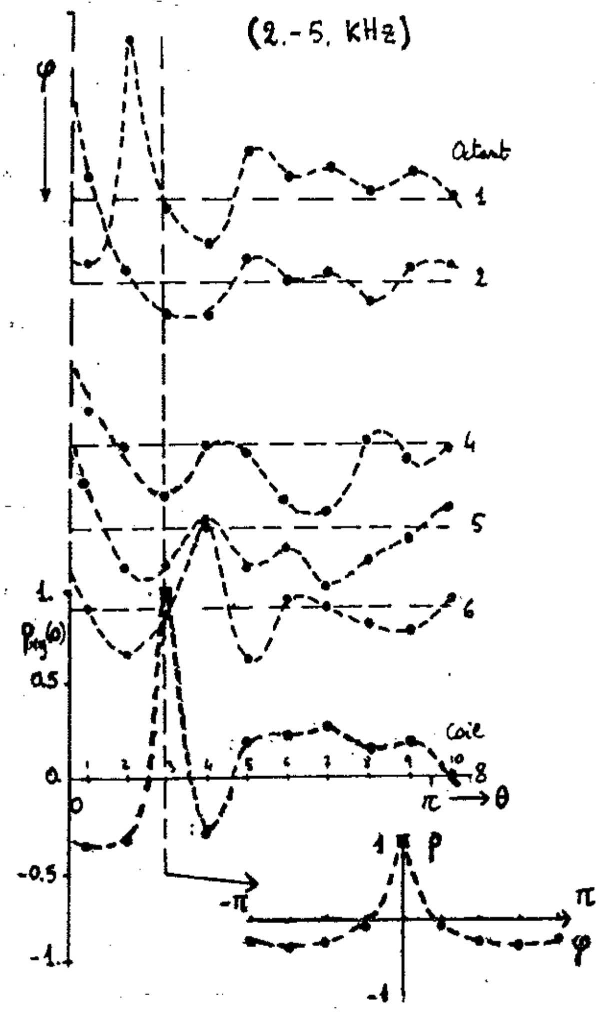

Fig 3: 2-D (θ-φ) covariance for $\dot{B}_\theta$ (2-5kHz) (# 8060) obtained by correlating coils 1 to 10 of octant 8 with the N° 3 coils in 6 of the eight octants (the bottom inset shows the toroidal correlation).

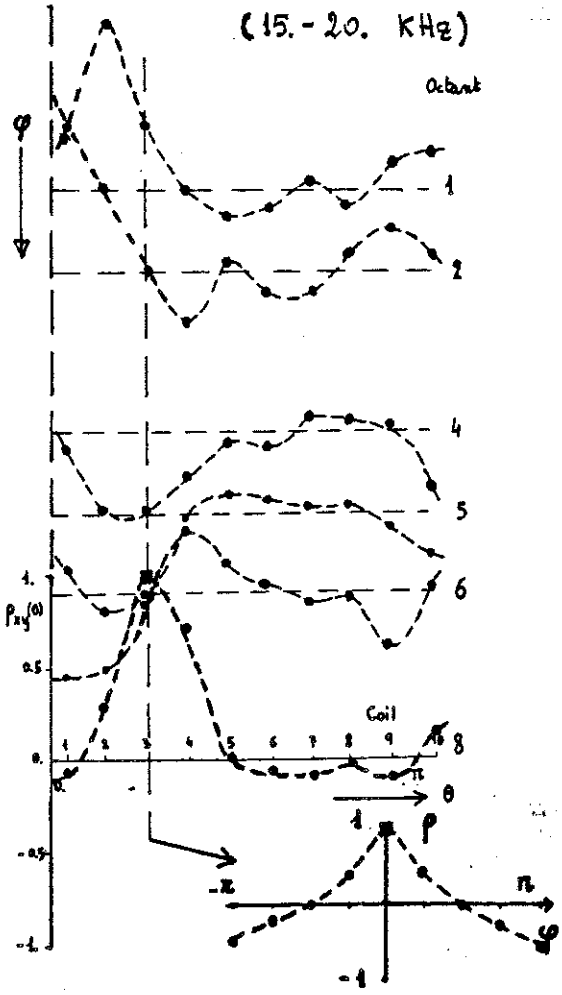

Fig 4: As in Fig 3 but for 15-20kHz.

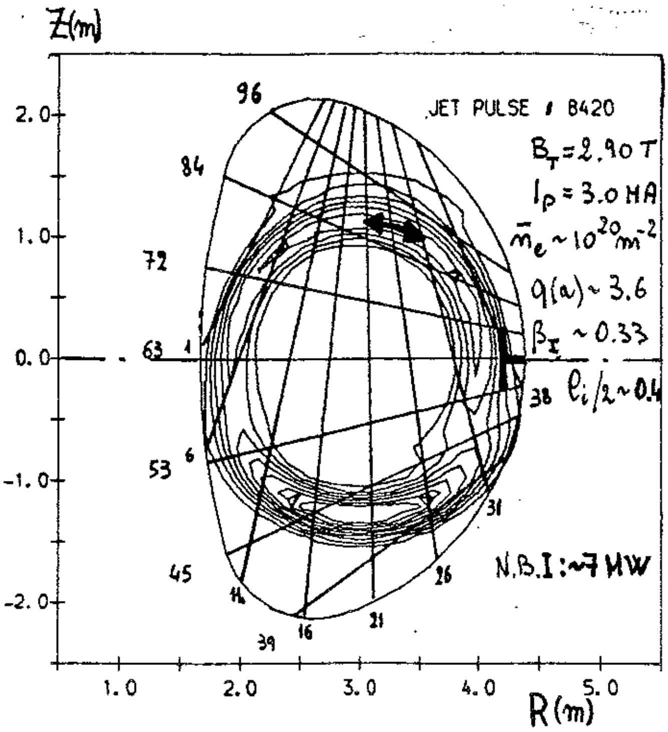

Fig 5: Contours of (visible light) emissivity as measured by an array of 100 SB Diodes (also shown are the lines of sight of some diodes).

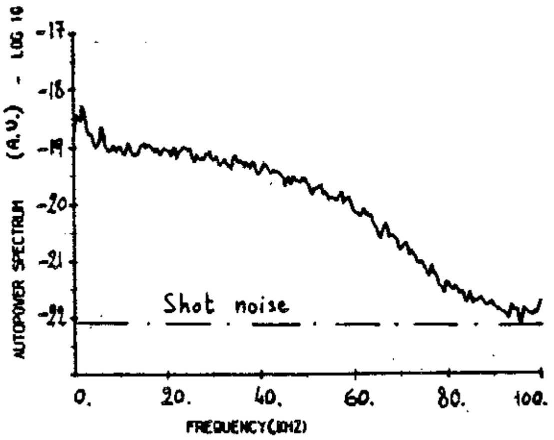

Fig 6: Frequency spectrum for fluctuations in emissivity in the conditions of Fig 5 (diode 63).

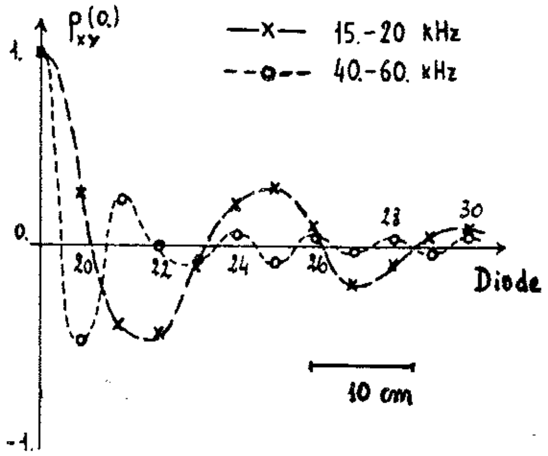

Fig 7: Cross-covariance versus distance between lines of sight for emissivity fluctuations in the frequency bands shown.

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(Cargese, July 1986)

MAGNETIC FLUCTUATIONS AND CONFINEMENT IN JET

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INTRODUCTION

Turbulence can account for anomalous transport observed in tokamaks. Experimental results in ohmic (TCA) [1-2] and neutral beam (D III[3], ISX-B[4]) heated plasmas have already shown a correlation between magnetic fluctuations and the electron energy confinement time. Density fluctuations measurements in TFR indicate a similar correlation [5]. We report here measurements of poloidal magnetic field fluctuations ($\tilde{b}_\Theta$) in JET and a comparison with plasma parameters as well as the energy confinement time τ_E.

MAGNETIC ACTIVITY IN JET

Typical magnetic activity in JET consists of a broadband spectrum (measured from a few khz to 80 khz), the so-called Mirnov oscillations (0.5-2.0 khz typically in ohmic conditions) and perturbations related to the internal $q_\psi=1$ instability (sawtooth). Here we concentrate on broadband activity.

Magnetic microinstabilities can produce anomalous transport by parallel conduction and field line radial motion. We have analysed a number of shots in different conditions to point out the effect of plasma parameters (I_p,B_T etc) and if there is any correlation with τ_E (ratio plasma energy/input power). Parallel studies are in progress to identify the nature of the instabilities responsible for the observed magnetic broadband spectrum [6].

APPARATUS

Measurements of the poloidal magnetic fluctuations are performed using pick-up coils located in the scrape-off layer. Eight band-pass filters (from 5khz to 56khz) analyse the frequency characteristics from a pick-up coil situated near the low field equatorial plan. This technique allows us to measure the time evolution of the magnetic fluctuations for this range of frequencies during the whole shot.

EXPERIMENTAL RESULTS AND DISCUSSION

Time evolution of the different filter signals indicate the following trends:

(a) the behaviour of the different filters is similar but the filters at 5khz and at 7khz are sometimes sensitive to the Mirnov activity.

(b) high sensitivity to the radial position of the plasma. Comparison between different shots has to be done at the same radial position.

(c) the level of fluctuations increases with the plasma current. This indicates the need to normalise the fluctuations by the averaged field at the probe location.

(d) the level of fluctuations decreases with increasing toroidal magnetic field. The multiplication by B_T for comparison of data with different fields will be introduced.

(e) increase of the magnetic fluctuations during Neutral Beam Injection (Fig 1). This increase affects the whole spectrum (Fig 2).

(f) similar behaviour during ICRH heating (Fig 3).

(g) the frequency dependence of the spectrum: $f^{-1.6 \pm 0.2}$ (cf Fig 2-3). This is in agreement with earlier measurements performed with a spectrum analyser [7].

A database analysis has been undertaken to study the dependence of $\tilde{b}_\Theta$ with τ_E. The data considered were taken during stationary states defined by the condition that the loop voltage on axis be close to the loop voltage at the edge ($\Delta V < 0.2$ volts) insuring the complete diffusion of the electrical field. The plasma position and the elongation are the same for all the shots. The values for the plasma current are 2MA, 3MA, 4MA. The main toroidal field is 2.5T, 2.8T, 3.4T. The database contains values for ohmic and neutral beam heated plasmas.

The direct effect of I_p and B_T is taken into account by normalising the level of magnetic fluctuations: $\tilde{b}_{\Theta N} = \tilde{b}_\Theta \cdot B_T/B_\Theta$. Figure 4 shows τ_E^{-1} versus $\tilde{b}_{\Theta N}^2$ at 40khz for the different conditions. Using a linear regression the straight line crosses the Y axis above the origin. This can be explained by the effect of the other losses: $W/\tau_E = P(\tilde{b}_{\Theta N}^2) + P_{\text{other losses}}$. Similar results are obtained with the other filters.

A good correlation between τ_E and magnetic fluctuations might be surprising because the pick-up coil is located at the edge. But it is not clear whether the energy confinement is sensitive to the transport between the q=1 and q=2 surfaces [8] or to the boundary transport [9]. Moreover magnetic fluctuations may be originated from the inside of the plasma (as suggested by our companion paper [6]) although they are measured at the edge. A typical example is the magnetic perturbation associated with the q=1 internal disruption, which is measured at the edge but is related to phenomena which occur in the core [7].

The level of magnetic fluctuations measured at the edge might also be sensitive to any change of the current profile. A modulation experiment has been carried out to observe any correlation between the current profile and the level of magnetic fluctuations. An RF pulse (total duration: 9s) was modulated with a frequency of 25Hz. The current profile (calculated with the ODIN code) was not affected by this modulation. However $\tilde{b}_\Theta$ was modulated (modulation observed on all the filters) at the same frequency: $\tilde{b}_\Theta$ was larger during the phase when the RF was on (Fig 5), which also corresponds to the usual loss of energy confinement.

CONCLUSION

Magnetic fluctuations (measured at the edge within the range (5khz → 56khz) has been compared with the characteristics of the discharge. The effect of the current profile has been investigated by a modulation of the RF heating: The normalised magnetic fluctuations are well correlated with τ_E^{-1} for different conditions. These results show that magnetic fluctuations may be a fundamental process for the confinement of the energy in the tokamaks.

ACKNOWLEDGEMENTS

We are grateful to Dr A Pochelon for stimulating discussions. Drs L C de Kock, G Tonetti and Mr A Stevens ae also acknowledged for their help in making the measurements possible. Thanks are due to J Thompson for providing support in the analysis of the modulation experiment.

REFERENCES

[1] P A Duperrex et al., Phys Lett 106A (1984) 133.

[2] C Hollenstein et al., Proc 13th EPS Conf on Controlled Fusion and Plasma Phys, Schliersee 1986.

[3] B A Carreras et al., Phys Rev Lett 50 (1983) 503.

[4] E J Strait et al., Proc 11th EPS Conf on Controlled Fusion and Plasma Phys, Aachen Vol I, A09 (1983) 59.

[5] TFR group and A Truc, Plasma Phys and Controlled Fusion 27 (1985) 1057.

[6] M Malacarne, P A Duperrex, contributed paper this conference.

[7] P A Duperrex, R Keller, M Malacarne, A Pochelon, Proc 12th EPS Conf on Controlled Fusion and Plasma Phys, Budapest Vol I (1985) 126.

[8] B Coppi, Comments Plasma Phys Cont Fusion 5 (1980) 261; F W Perkins Proc 3rd Int Symp on Heating in Toroidal Plasma, Rome (1984); W M Tang et al, Proc 10th Int Conf London 1984.

[9] N Ohyabu, K J Lee, G A Technologies Report GA-A17890 (Nov 1985).

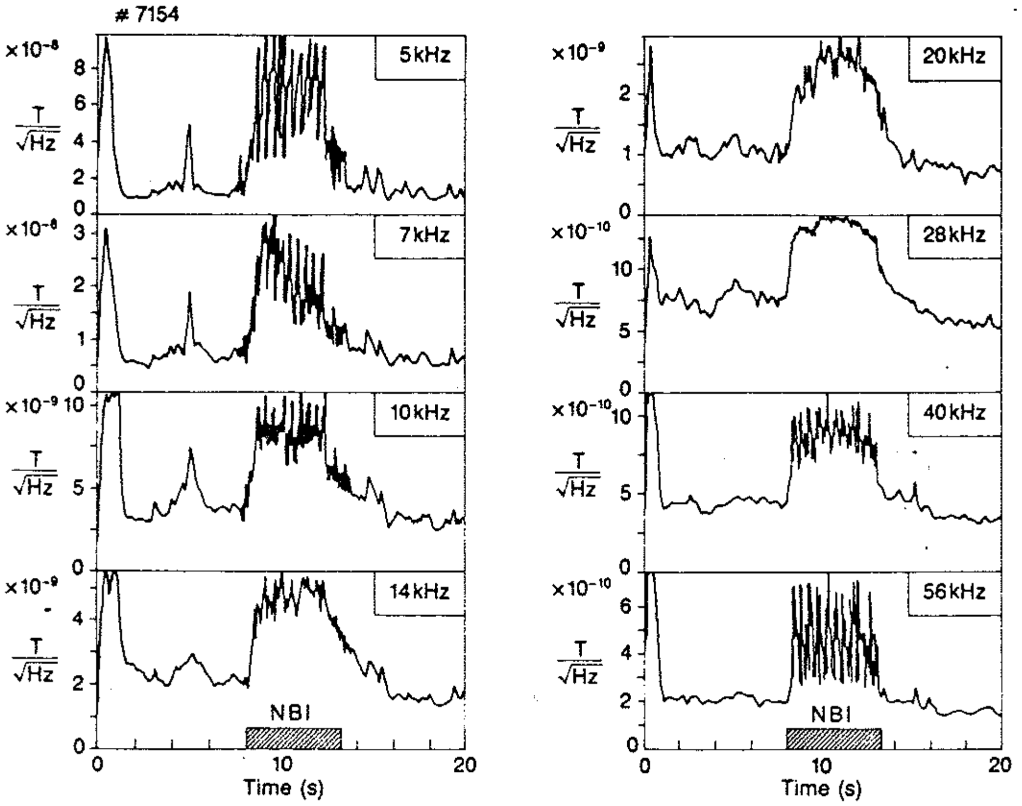

Fig. 1: Filters: time evolution during a discharge with NB injection.

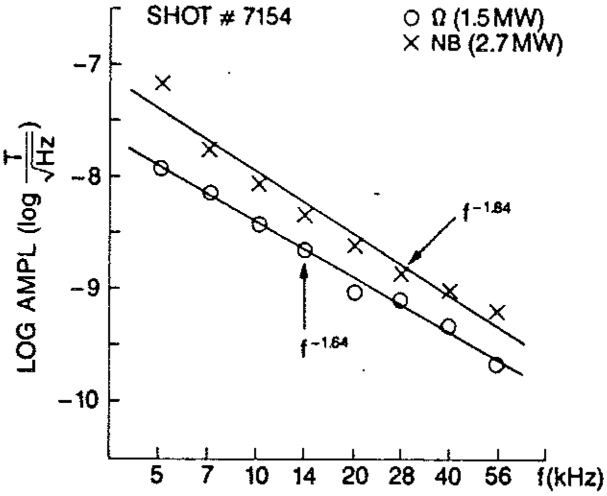

Fig. 2: Level of $\tilde{b}_\theta$: before and during the NB heating.

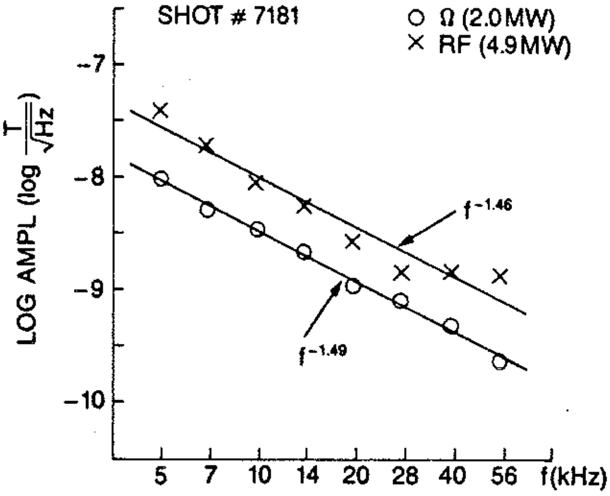

Fig. 3: Level of $\tilde{b}_\theta$: before and during the RF heating.

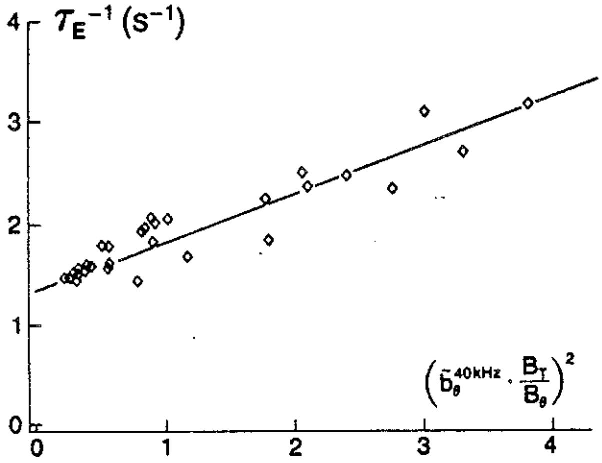

Fig. 4: τ_E^{-1} versus $(\tilde{b}_{\theta N})^2$. I_p = 2, 3, 4MA. B_T = 2.5, 2.8, 3.4T.

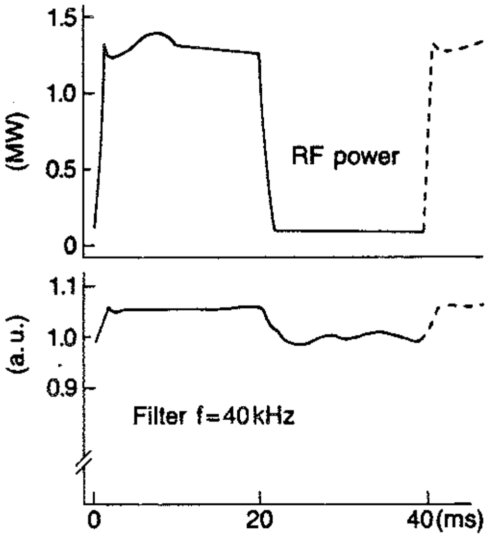

Fig. 5: RF power and $\tilde{b}_\theta$ level during the modulation experiment. (results averaged on 216 periods).