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MHD DECOMPOSITION OF MEASURED MAGNETIC FLUCTUATION SIGNALS IN TBR-1 TOKAMAK

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ABSTRACT

To determine the MHD components associated with the disruptive instabilities observed during a TBR-1 plasma pulse, a computer program was developed to Fourier decompose the experimental magnetic fluctuation signals detected by a set of poloidal magnetic coils. The program considered the fact that the coils were not all uniformly distributed and, therefore, a correction factor had to be properly introduced.

I - Introduction and Experimental Set-up

The detection of magnetic field fluctuations has already proved to be an important tool for investigating the disruptive instabilities in tokamaks. These instabilities commonly lead to undesirable energy losses, deteriorate the confinement and can even cause the complete destruction of the plasma column [1]. Therefore, the mechanisms that lead the plasma to a disruption must be unerstood so it can be controlled and, possibly, avoided.

Plasma instabilities are usually preceded by MHD modes, which are commonly accepted to be the direct responsible for the disruptions triggering mechanisms. Hence, the identification of the perturbed magnetic field components, through a Fourier analysis of the experimental data, is very important. Early experimental investigations have already indicated, for example, that the $m = 2$ mode plays an important role on the ocurrence of major disruptions in tokamaks [2,3].

In the TBR-1 tokamak, the detection of the perturbed poloidal magnetic field was done with a set of ten air-refrigerated magnetic coils that have been installed inside two very thin (0.15 mm) stainless steel tubes. Each tube has a semi-circular geometry and was placed inside the vacuum vessel, in a fixed toroidal position, protected by the limiter from directly interacting with the plasma [4]. The output signal from each coil was digitalised in CAMAC modules at 400 kHz sampling rate and recorded in a PC AT-386 microcomputer. As showed in fig. 1, the coils angular position, along the poloidal direction, are not all equally spaced. Therefore modifications had to be made in the usual way of Fourier analyzing the experimental data. The TBR-1 is a small tokamak with major radius R_0 = 0.30 m, limiter radius a = 0.08 m and maximum plasma current pulses $I_p \cong 12$ kA, lasting up to 10 ms.

II - Fourier Decomposition

Basically, the magnetic field perturbations detected by the magnetic coils can be described by the equation:

$$\dot{\tilde{B}} = \dot{B}_0\, e^{i(wt+m\theta-n\phi)} \qquad (1)$$

where θ and ϕ are the poloidal and toroidal angles, and m and n are the poloidal and toroidal mode numbers, respectively.

In TBR-1 discharges, the analysis of the output signals from two others magnetic coils, located in two opposite toroidal positions, have always showed that the toroidal mode number of the observed perturbations corresponds to n = 1. In order to determine the temporal evolution of each m component, however, the output signals from the set of ten poloidal magnetic coils had to be Fourier analyzed.

Basically, the perturbed poloidal magnetic field amplitude $\dot{\tilde{B}}_\theta(\theta)$ measured by each coil can be written [5]:

$$\dot{\tilde{B}}_\theta(\theta) = A_0/2 + \sum_{m=1}^{4}\left[A_m \cos(m\theta) + B_m \sin(m\theta) \right] + A_5/2 \cos(5\theta), \qquad (2)$$

were:

$$A_m = 2/N \left\{ \sum_{K=0}^{N-1} \dot{\tilde{B}}(k) \cos\left[k(sm + f)\right] \right\} \qquad (3)$$

and

$$B_m = 2/N \left\{ \sum_{K=0}^{N-1} \dot{\tilde{B}}(k) \sin\left[k(sm + f)\right] \right\} \qquad (4)$$

In equations (3) and (4), N represents the number of coils used in the experiment (N=10) and s takes the value 0.5979 rad, representing the average poloidal angular spacing between the coils in each tube. The parameter f = 0.1521 rad is inserted in order to provide an adjustment of the existing poloidal asymmetry between the pairs of coils 5 - 6 and 1 - 10 (Fig. 1). Tests performed without considering the geometric asymmetry of the coils resulted in decomposed signal that, when reconstructed, showed no similarity with the corresponding experimental data.

Once the A_m and B_m coeficients are obtained then the program allows, for each instant of the time interval considered, the determination of the poloidal components m = 0, m = 1, m = 2, m = 3, m = 4 and the cosine term of the m = 5, accordingly to the expression:

$$\dot{\tilde{B}}_{\theta m} = A_m \cos(m\theta) + B_m \sin(m\theta) \qquad (4)$$

Therefore, the characteristic frequencies and the power spectra of these oscillations can also be calculated. This is done through a fast Fourier transform (FFT) analysis over a short time interval of the discharge:

$$P(m,f) = \mathrm{FFT}\left[\dot{\tilde{B}}_{\theta m}(\Delta t)\right] \times \mathrm{FFT}^{*}\left[\dot{\tilde{B}}_{\theta m}(\Delta t)\right], \qquad (6)$$

where FFT^{*} is the corresponding complex conjugate.

After P(m,f) is obtained, for all possible m values, a 3D mode intensity plot can be constructed in order to allow the identification of the precursors that would be the main responsible for triggering the observed disruptive instabilities. The time-interval chosen for the analysis done always corresponded to Δt = 0.64 ms (256 data points).

III - Experimental Results

An example of a pulse which ended due to a major disruption, while the plasma was under the influence of an externally applyed resonant magnetic field [6], is showed in fig. 2a. It corresponds to a 8 kA plasma discharge, approximately, which disrupted at t ≅ 2.7 ms. The loop voltage and the output signal of a given magnetic coil are showed in figs. 2b and 2c, respectively.

After the experimental magnetic coils signals were conveniently Fourier analysed, according to what has been discussed previously, the m = 0 to m = 4 poloidal magnetic fields

components were thus obtained and the results are presented in fig. 3, along with the typical output signal of a given coil. In fig. 4, both the reconstructed and the original signals are compared to each other. The similarity between them is visible, demonstrating that the adopted signal decomposition method is acceptable, even though the Fourier series had to be truncated at the m = 5 term, due to the existence of only ten magnetic coils.

In fig. 5 the corresponding spectral power, related to the time interval just prior to the end of this discharge, is showed. Clearly, m = 2 and m = 1 are the dominant modes in almost all frequency range. Therefore, a possible interaction between them could be the main mechanism that triggered the observed major disruption for this discharge.

IV - Conclusions

The disruptive instabilities in TBR-1 tokamak have been investigated by Fourier analyzing the magnetic fluctuation signals detected by a set of ten poloidal magnetic coils. The m = 2 MHD mode was identified as playing an important role in the disruption triggering process. Since the coils were not uniformly distributed, a correction factor had to be introduced in the expressions that give the Fourier coefficients. Comparing the original signal to the reconstructed one, for a given coil, it was shown that the method used for correcting the coils distribution asymmetry is reliable.

Acknowledgements

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Figure Captions

Fig. 1. Magnetic coils experimental set-up. The coils, which are placed inside two stainless steel tubes that go inside the tokamak vacuum chamber, are not equally distributed along the poloidal direction.

Fig. 2. Plasma current (a), loop voltage (b) and fluctuating poloidal magnetic field of a pulse that disrupted while external resonant magnetic fields were applied.

Fig. 3. The signal at the top corresponds to the experimental output of a given magnetic coil. The signals bellow correspond to the intensity of each MHD mode, along the time, as obtained from the described Fourier decomposition.

Fig. 4. The MHD components are here recomposed and compared to the experimental signal of a given poloidal magnetic coil. The good similarity between them indicates that the method described is reliable.

Fig. 5. Spectral power analysis over the time range that just precedes the major disruption show the dominant presence of the modes $m = 2$ and $m = 1$.

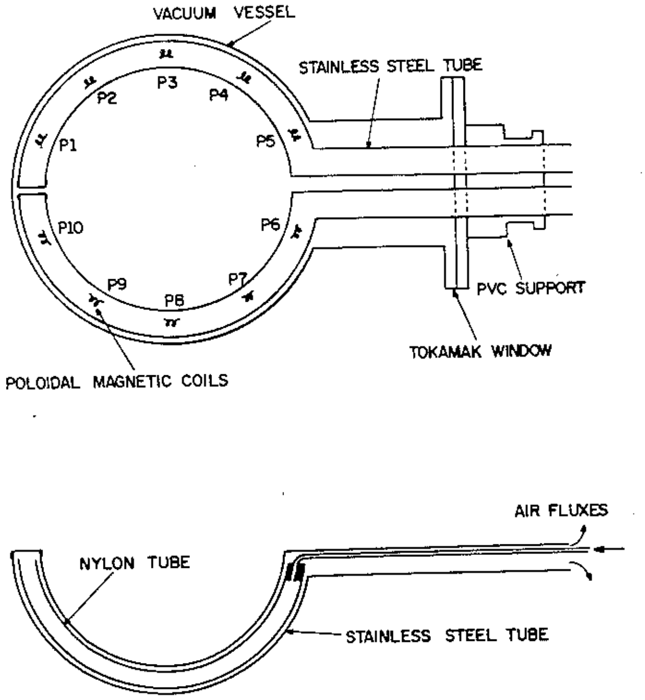

Fig. 1

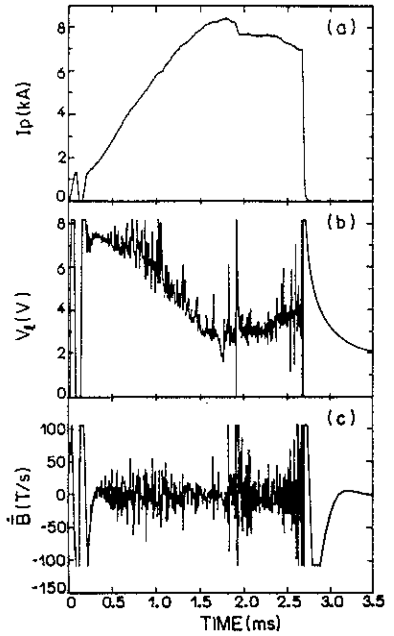

Fig. 2

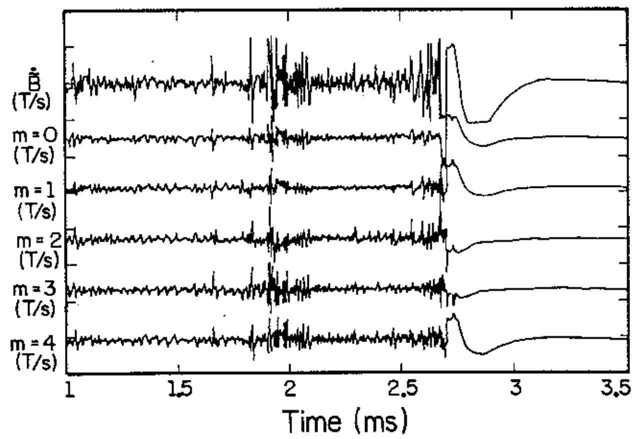

Fig. 3

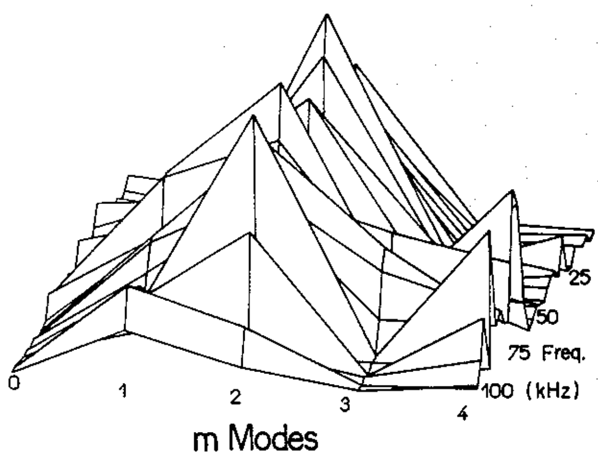

Fig. 5

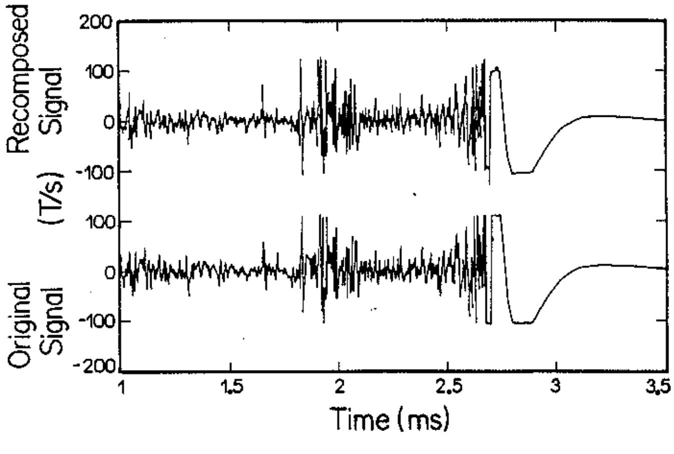

Fig. 4