*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-4.065 (2005)*

Investigation of Tokamak Plasmas as Non-Rigid Body Plasma

M. Ghoranneviss[1], P. Khorshid[1, 2], L. Wang[3], A.H. Sari[1], M.K. Salem[1], A. Hojabri[4]

[1] *Plasma Physics Research Center, Islamic Azad University, Tehran, Iran*

[2] *Physics Dept., Islamic Azad University, Mashhad, Iran*

[3] *Institute of Physics, Chinese Academy of Sciences, Beijing, China*

[4] *Physics Dept., Islamic Azad University, Karaj, Iran*

The effect of magnetic fields on tokamak plasmas is one of most studies on small and large devices. The balance between plasma pressure and magnetic fields leads to a plasma equilibrium in a tokamak. In addition, the balance between the radial flows of positive and negative charges leads to an equilibrium radial electric field with axial symmetry. Due to the resulting E×B drift, electrons and ions drift both in the same direction at the same velocity, leading to an azimuthally convection of the whole plasma. In the past experiments, rigid plasma models have been used for linear stability and shape control design such as soft X-ray tomography and some spectroscopy measurement with Doppler shift method. In a rigid model, the plasma current profile is considered fixed and moves rigidly in response to control coils to maintain radial and vertical force balance. In a non-rigid model, however, changes in the plasma shape and current profile are taken into account. Such models are expected to be important for future advanced tokamak control design. The present work describes a non-rigid plasma base on Mirnov oscillations in a MHD Behavior.

Evidence of magnetic islands in tokamak plasma is given by the external magnetic field fluctuations that Mirnov coils detect. Correlating the phase from an array of Mirnov coils yields useful information about the geometry of a mode's magnetic perturbations. A poloidal array of 24 Mirnov coil used for detecting poloidal magnetic field oscillations. A set of typical discharge of CT-6B Tokamak (R=45 cm, a=12.5 cm, τ_d=30-45msec with I_p=30kA, B_t=6-8 kG, $n_e=(1\text{-}3)\times10^{13}$ cm^{-3} and T_e=200 eV) has been selected. Fig.1b shows the time evolution of plasma current, loop voltage and Mirnov coil oscillations. The locations of the Mirnov coils in CT-6B are given in fig.1. The coils are located 170cm from the vacuum vessel center and are oriented in order to detect $\widetilde{B}_\theta$.

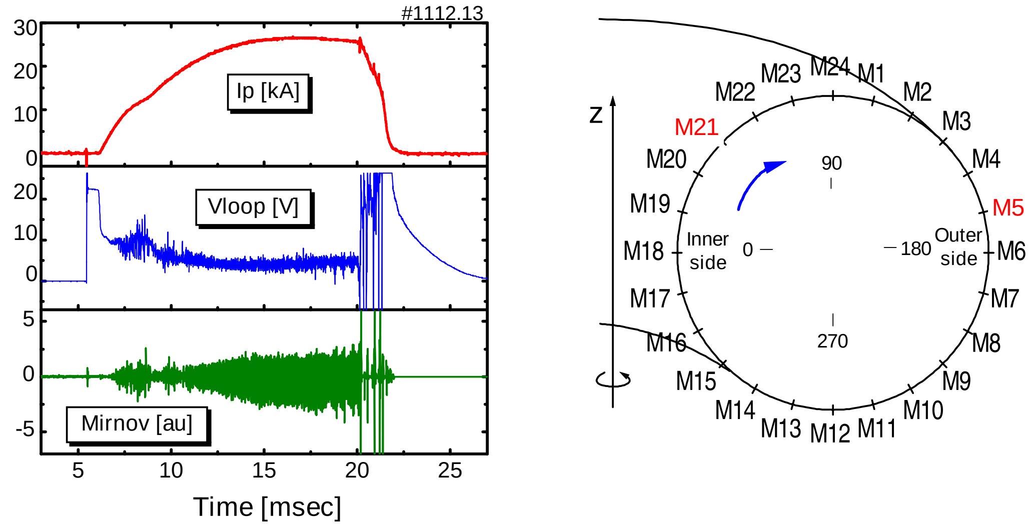

Fig.1- a) The Mirnov coils array and their positions, b) The time evolution of plasma current, loop voltage and Mirnov coil oscillations.

Techniques for analyzing data from these signals are known. The dominant mode number can be found by counting the number of lobes, even though the shape of polar diagrams is distorted by the presence of noise and multiple modes. A detailed time evolution of poloidal variations of m=3 mode diagram has been shown in Fig.2. So, the non-rigid behavior can be seen as a non-uniform lobe of plasma column inner side with the outboard side. In this case, the perturbation magnetic field contains harmonics of the form $cos(n\varphi - m\theta)$, where φ and θ are the angle variables along the major and minor circumferences of the torus. The magnetic islands twist their way around the plasma and have their own set of nested flux surfaces and local magnetic axis. The whole structure of each island closes upon itself after continuing around the torus one or more times.

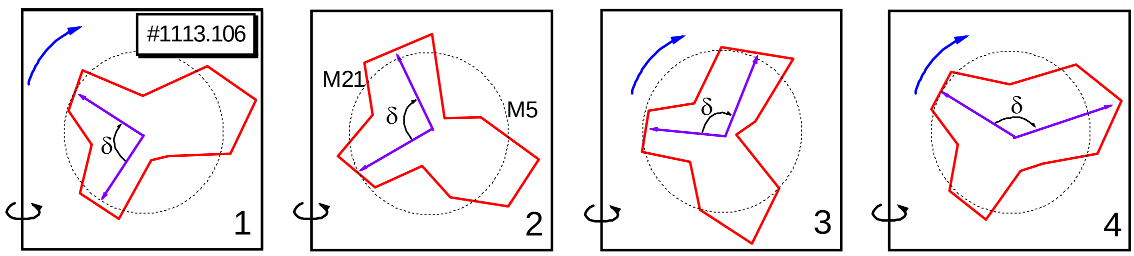

Fig.2- The detailed time evolution of poloidal variations of m=3 mode diagram. The M21 and M5 indicate the Mirnov coils position according to fig.1. The angle of δ indicates the lobe angle of mode diagram which changes during rotation.

The spatiotemporal structure of a coherent m=3 mode was recorded using two lobes. One lobe is the reference that its coordinate twist with plasma column. The other lobe have a rotation frequency of $\omega=\omega_0+d\delta/dt$. Two fixed Mirnov coils M5 and M21 positioned on inner and outer side of torus respectively, detect the frequency of lobe (magnetic island) oscillations. The fig.3-(a,b) shows an arbitrary time selection of magnetic oscillations detected by M5 and M21. It is seen that the frequency of oscillations are not same and it seems the whole plasma column have different frequency. One can see that the shape of plasma in fig.2 changes during plasma rotation. Fig.3-c) shows the signals of magnetic oscillations detected from M5 and M21, and Fig.3-d) shows the relative amplitude of B_θ signals at just time with respect to angle position.

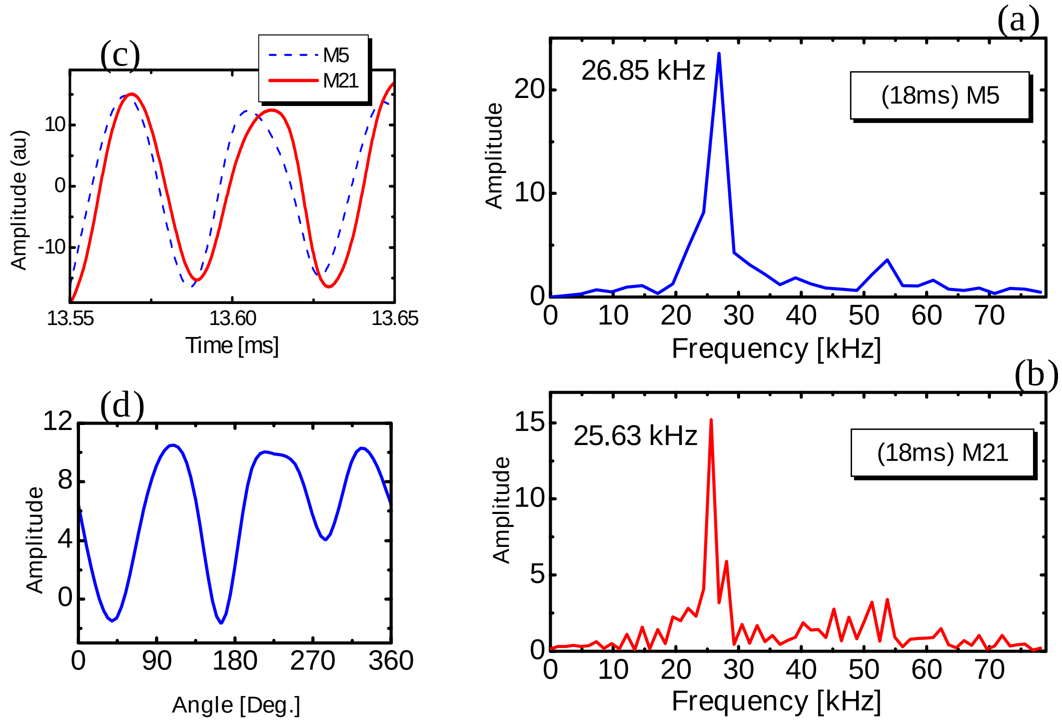

Fig.3-(a, b) The arbitrary time selection of magnetic oscillations frequency detected by M5 and M21 Mirnov coil positioned according to fig.1. (c) Signals of magnetic coils oscillations. (d) A spline fit of the amplitude data taken from each coil at the same time, the poloidal angular dependence of Mirnov coil signals from shut no.1112.13

A calculation from change in lobes angle,δ, illustrated in fig.4. The results shown that the frequency of plasma rotation, ω, outer side of torus because of toroidal magnetic effects is greater than inner-side of torus. It deduced that the plasma column rotates as non-rigid body, so that the angle φ_0 of a rotating island does not rotate in a constant frequency. The angle is calculated from the rotation frequency assuming non-rigid body rotation as:

$$\varphi=\varphi_0+(\omega_0+d\delta/dt)t$$

where δ is the angle between island lobes and $d\delta/dt$ is a periodic function that depends on time, mode number of oscillations.

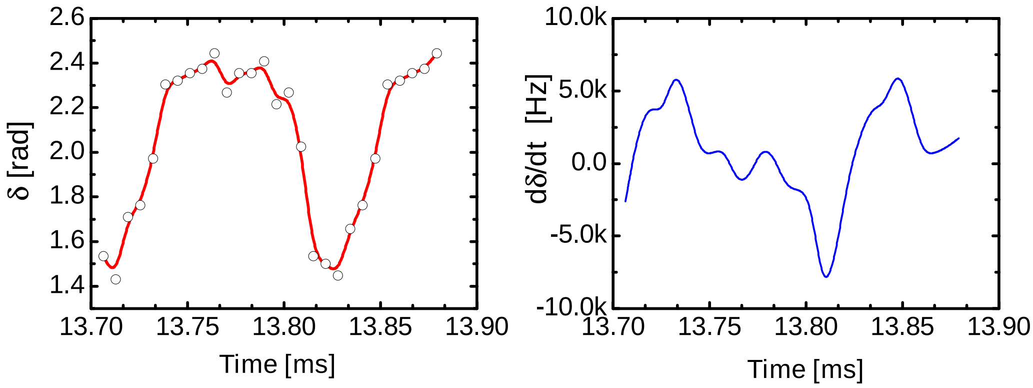

Fig.4- The variation of angle island lobes during plasma rotation according to data on fig.2.

In conclusion, in this study we have investigated the bulk of plasma behavior during plasma column rotation as non-rigid body tokamak plasma. The mode number measurement of magnetohydrodynamics activity has been carried out using Mirnov coils oscillations. We found that mode number and rotation frequency of plasma column are different in angle position, so that the phase data detected from Mirnov coils array located in poloidal angle on the inner-side of torus is more than outer-side which it can be because of toroidal magnetic field effects. It shows that plasma column behaves as Non-Rigid body plasma.

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