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Coupling of 2/1 and 3/2 Tearing Modes in T-10 Tokamak

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Introduction

Features of rotation of tearing modes in T-10 tokamak have been investigated by analysis of signals from a system of poloidal magnetic field detectors. The system includes an array of sensors distributed uniformly along poloidal direction and a single sensor located at π/2 away from the array of sensors in toroidal direction (fig. 1). It is assumed that poloidal plasma rotation is dumped due to anomalous neoclassical viscosity, so only toroidal rotation takes place. As magnetic island rotates, the signals from magnetic probes have the form of oscillations with frequency $\Omega = n\omega_\varphi$, where ω_φ is angular toroidal rotation velocity, and n is toroidal mode number. Irregularity of island rotation is observed which is attributed to the action of error field [1]. Such action affects the average rotation velocity and sometimes leads to mode-locking [2, 3].

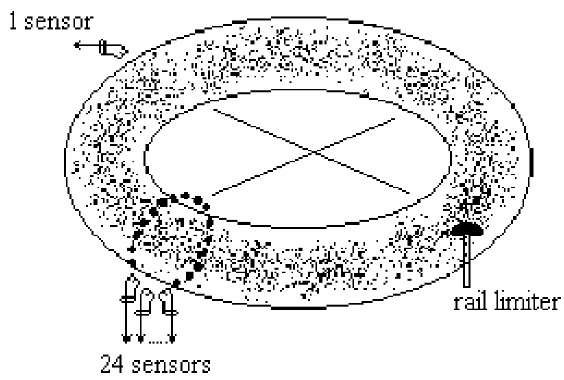

Fig.1. MHD diagnostics layout in T-10.

MHD data processing

Processing of signals from magnetic sensors includes filtering, integrating and decomposing poloidal perturbation field to a set of poloidal Fourier harmonics with different poloidal numbers m. For each harmonic of poloidal perturbation field at the radii of the sensors is equal to $B_m(\theta, t) = B_{C,m}(t)\cos(m\theta) + B_{S,m}(t)\sin(m\theta)$, where $B_{C,m}(t)$ and $B_{S,m}(t)$ are cosine and sine components of the harmonic. The space amplitude of the harmonic is $|B_m(t)| = \sqrt{B^2_{C,m}(t) + B^2_{S,m}(t)}$ and space phase is defined as $\Phi_m(t) = \mathrm{arctg}\left[B_{S,m}(t)/B_{C,m}(t)\right]$.

Due to helical structure of MHD perturbations, the toroidal rotation of magnetic island with toroidal number n, poloidal numbers m and velocity $\omega_{\varphi,m}$ produce appearance of poloidal rotation with velocity $\omega_{\theta,m} = (n/m)\omega_{\varphi,m}$ being measured by the poloidal sensors. This fake angular velocity of poloidal rotation can be determined as $\omega_{\theta,m}(t) = \frac{1}{m}\frac{d\Phi_m}{dt}$. Thus, the actual toroidal rotation velocity equals to $\omega_{\varphi,m}(t) = \frac{1}{n}\frac{d\Phi_m}{dt}$.

Experiments

T-10 is a tokamak with a circular plasma cross-section. The major and minor radii of the vacuum vessel are $R = 1.5$ m and $b = 0.42$ m. The plasma minor radius determined by the position of the movable rail limiter was $a = 0.27$ m. The experiments were carried out at the discharge parameters: toroidal magnetic field $B_T = 2.42$ T, discharge current $I_P = 240$ kA, line-average density $<n_e> = 0.9\cdot10^{19}$ m^{-3}, $q(a)$=2.75. Simultaneous evolution of MHD modes with $m = 2$ and $m = 3$ were observed. Ratio of oscillation frequencies of the modes were $\Omega_{m=3} / \Omega_{m=2} = 2$. Phase relations between the signals from the array of sensors and the single sensor located away in toroidal direction allow to interpret the MHD modes as superposition of magnetic islands with $m/n = 2/1$, $m/n = 3/2$ which rotate in toroidal direction. In some experiments the error field was amplified by magnetic field of halo-current introduced in SOL by applying EMF source between the rail limiter and vacuum vessel [4]. Fig. 2 presents distribution of additional poloidal magnetic field at sensors location, normalized by the amplitude of halo-current, and its space spectrum.

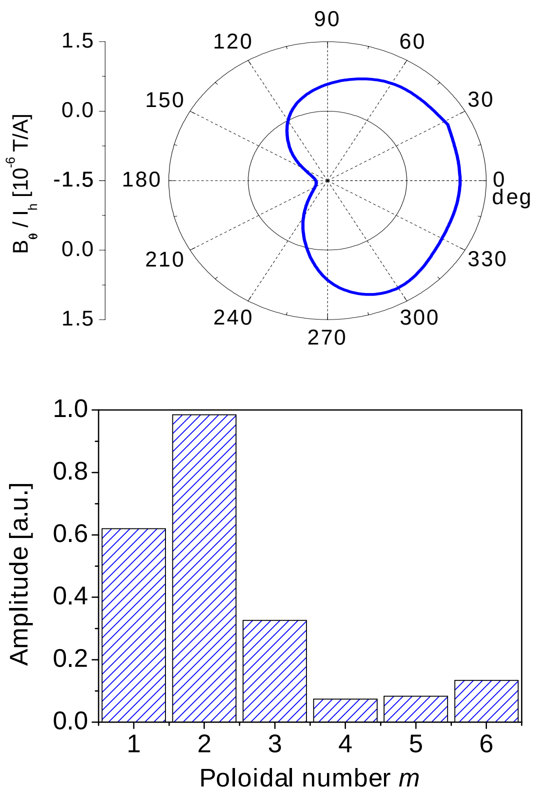

Fig.2. Poloidal distribution of halo-current field and its spectrum.

Cosine and sine components of perturbed field of magnetic islands with $m/n = 2/1$, $m/n = 3/2$ and their instantaneous angular velocities of toroidal rotation $\omega_{\varphi,2/1}$, $\omega_{\varphi,3/2}$ are shown in Fig.3. Rotation velocities varies coherently with a period of $m/n = 2/1$ mode oscillation, there is phase shift between $\omega_{\varphi,3/2}$ and $\omega_{\varphi,2/1}$. One can see that $\omega_{\varphi,3/2}$ also includes component oscillating with a period of $m/n = 3/2$ MHD mode oscillation. In the experiments with generation of halo-current I_h simultaneous

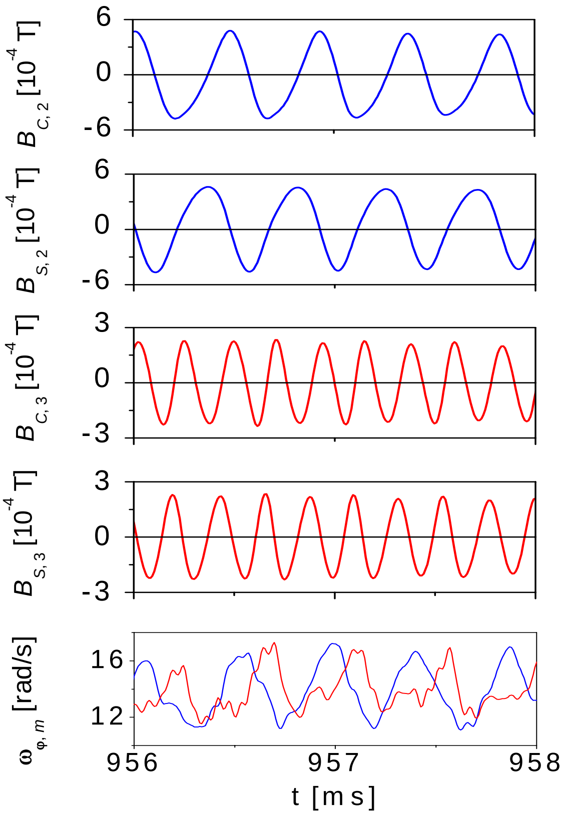

Fig.3. Cosine and sine components and rotation velocity of the modes m/n = 2/1 and m/n = 3/2.

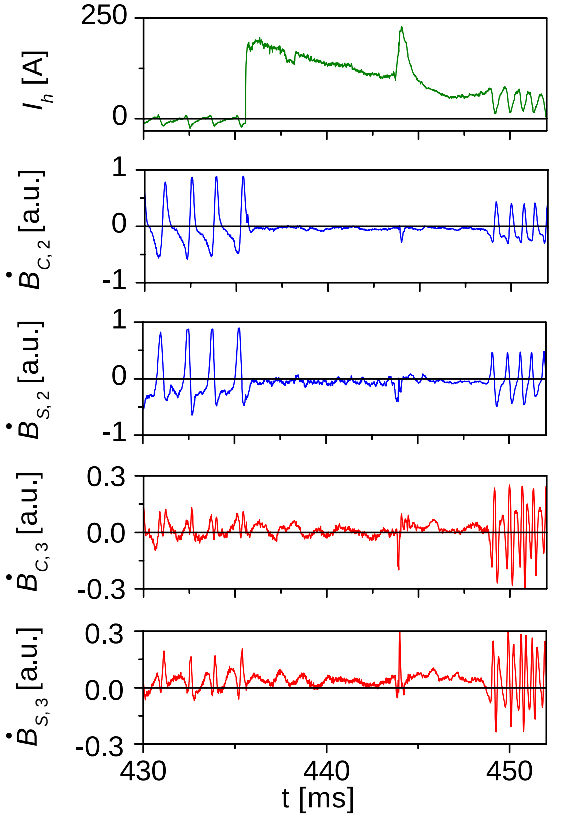

Fig.4. Halo-current I_h and time derivatives of Fourier components of the modes m/n = 2/1 and m/n = 3/2.

mode-locking of the modes *m/n*= 2/1 and *m/n* = 3/2 was observed (Fig. 4). One can see that mode-unlocking also happens simultaneously for both of the modes.

Discussions

Within the framework of mechanic equations, magnetic island rotation is determined by electromagnetic force produced by action of external magnetic field on perturbed plasma current near the resonant surface, viscous force of plasma surrounding the island and inertia of plasma within the island [5]. The electromagnetic force is calculated as a reaction to the force applied to the conductors with the external helical currents from the radial component of magnetic field perturbation of the tearing mode. The effect of error field on dynamics of magnetic islands rotation becomes stronger with the increase of MHD perturbation amplitude.

In our experiments error field produces irregularity of rotation of magnetic islands *m/n* = 2/1 and *m/n* = 3/2, that is identified by oscillation of instantaneous angular frequencies of modes rotation $\omega_{\varphi,2/1}$ and $\omega_{\varphi,3/2}$. As expected, the period of oscillation of $\omega_{\varphi,2/1}$ is equal to the period of oscillation of the perturbed field of m/n=2/1 mode. At the same time, the plot of $\omega_{\varphi,2/1}$ contains two oscillating components. The period of the smallest one corresponds to the period of perturbed field oscillation of m/n=3/2 mode. The period of the dominant component equals to the period of perturbed field oscillation of m/n=2/1 mode. This fact points to the coupling of the modes m/n=2/1 and m/n=3/2 whereas in tokamak these modes are space orthogonal and should not interact with each other.

Possible explanation of space orthogonal modes coupling is torque transfer by viscous forces from plasma layer inside the one magnetic island to the layer occupied with another island. In this case variation of angular rotation velocity of the first plasma layer affected by external helical magnetic field leads to variation of rotation velocity of the second layer that is presented in Fig. 3.

It is shown in Fig. 4 that rotation of magnetic islands m/n = 2/1 and m/n = 3/2 starts simultaneously while it should happens at different time because electromagnetic force is proportional to the product of island perturbed field and amplitude of corresponding error field harmonic. In the experiment the electromagnetic forces of two modes were different, so the simultaneous start of rotation of the modes observed can be explained as the effect of viscous forces.

Conclusions

Coupling of space orthogonal tearing modes is observed in experiments in T-10 tokamak. The coupling can lead to locking of all of the modes if one of them is locked. Interaction of the modes can be explained by torque transfer from one magnetic island to another through separating plasma layer by viscous forces.

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