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Interdependence of Magnetic Islands, Halo Current and Runaway Electrons in T-10 Tokamak

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Abstract. The results of experiments on a modulation of halo current through a rail limiter and of x-ray emission from the limiter under the influence of rotating magnetic islands are presented. The external part of the halo-current circuit connected the rail limiter at one side and the discharge chamber with a circular limiter at the other side. A controllable connector that was switched on at a preprogrammed moment of time during the tokamak discharge was introduced into the circuit. In discharges with MHD activity, oscillations of the halo current were observed. The frequency of the oscillations was equal to the frequency of the dominant mode of the poloidal magnetic field perturbation. In some conditions the switching on of the connector in the halo-current circuit resulted in a shift of the MHD mode frequency. This means that the halo current can influence the rotation velocity of the magnetic islands. In the case of low plasma density, repetitive spikes of hard x-ray emission from the rail limiter were observed. These spikes were coherent with the MHD-activity signal and the halo-current oscillations. It can be concluded that besides an effect of magnetic islands resulting in halo-current and x-ray modulation with the frequency of MHD activity, an influence of halo current on the magnetic island behaviour was observed. This influence can be attributed to a coupling between the magnetic islands and the space-resonant component of the halo-current magnetic field.

1. Introduction

The disruptions in tokamaks (see [1]) are characterised by the development of magnetic islands that leads to an increase of radial transport and variation of space distributions of plasma parameters. During the disruptions in vertically elongated tokamaks, the plasma usually becomes vertically unstable. The development of vertical instability, called a vertical displacement episode (VDE), results in a generation of halo current that flows in the plasma along magnetic field lines that intersect electrically conducting first wall elements - vacuum vessel, divertor, limiter etc. The reconnection of the halo current through the vacuum vessel and in-vessel components produces significant electromagnetic forces.

In an analysis of the MHD instability development and halo current generation, it is natural to suppose that poloidal and toroidal inhomogeneities of magnetic surfaces produced by magnetic islands can influence generation of the halo current and its spatial distribution. In turn, the corresponding space component of the halo-current magnetic field should affect the magnetic island behaviour. The interdependence between the MHD perturbation and halo current can be affected by the development of runaway electrons. The magnetic islands can produce poloidal and toroidal inhomogeneities of radial transport of plasma components including runaway electrons. The inhomogeneity of the runaway electron flux to the first wall should contribute to the formation of the halo current inhomogeneity.

A verification of the assumption about the interdependence of magnetic islands, halo current and runaway electrons was the purpose of our experiment. Since T-10 is a tokamak with a circular plasma cross-section, VDEs followed by halo currents are not observed during disruptions in this tokamak as in tokamaks with elongated plasmas. Therefore our experiment was carried out in modelling conditions: instead of disruption, a steady-state stage of a discharge with m=2 mode MHD activity was used. A halo current between a movable rail limiter and the vacuum vessel with a permanent circular limiter was measured. The rail limiter and vacuum vessel were connected by an external halo-current circuit. This halo current did not exceed 100 A which is much less than halo currents during disruptions in elongated tokamaks.

2. Experimental Arrangement

The major and minor radii of the T-10 vacuum vessel are 1.5 m and 0.39 m, the radius of the permanent circular limiter is 0.33 m. The experiments were carried out in the range of discharge parameters: toroidal magnetic field 2.3 - 2.5 T, discharge current 220 - 280 kA, line-average plasma density $(0.6 - 3)\cdot 10^{19} m^{-3}$. The plasma minor radius determined by the position of the movable rail limiter was 0.26 - 0.28 m.

The structure of the MHD perturbation was measured with magnetic detectors located at the discharge chamber wall. The procedure of processing of the MHD signals included spatial and time Fourier transforms. The measurement of x-ray emission from the rail limiter was performed in the range of quantum energy from 40 to 100 keV.

The external part of the halo-current circuit between the rail limiter and vacuum vessel was provided by a controllable connector that was switched on at a preprogrammed moment of time during the tokamak discharge and by an instrument shunt placed in series. To eliminate effects of the limiter potential when the connector was shut off, a 3 Ohm resistor was placed in parallel with the controllable connector. The resistance of the instrument shunt was 0.015 Ohm.

3. Experimental Results

When the connector was switched on, a current which depended on the tokamak regime arose in the halo-current circuit. In the T-10 discharges with MHD activity, oscillations of the halo-current were observed. The frequency of the oscillations was equal to the frequency of the dominant mode of the poloidal magnetic field perturbation (see Fig.1). In the investigated tokamak regimes, the halo-current oscillations had a 30° phase delay from the poloidal magnetic field oscillations in location of the rail limiter. The amplitude of the halo-current oscillations was approximately proportional to the amplitude of the MHD activity (Fig.2).

The switching on of the connector in the halo-current circuit resulted in a downshift of the MHD mode frequency. This means that in some conditions the halo current can influence the rotation velocity of magnetic islands. This result is illustrated in Fig.3 where a variation in time of the m=2 mode frequency and Fourier spectra of this mode before and after the switching on of the connector are presented. In the next figure (Fig.4) one can see that the normalised shift of the MHD frequency increased in cases of higher halo-current oscillation amplitude.

In the case of low plasma density $(0.6\cdot 10^{19}\ m^{-3})$ repetitive spikes of x-ray emission from the rail limiter coherent with the signal of MHD activity were observed. The emergence of these spikes can be presumably attributed to an effect of magnetic islands on the poloidal and toroidal inhomogeneity of runaway electron density. Because of magnetic island rotation, this inhomogeneity results in oscillations of interaction intensity between runaway electrons and the rail limiter. As one can see in Fig.1, the main x-ray signal spikes correspond to the moments of time when both O-point and X-point (small spikes) of the magnetic island are located at the position of the rail limiter.

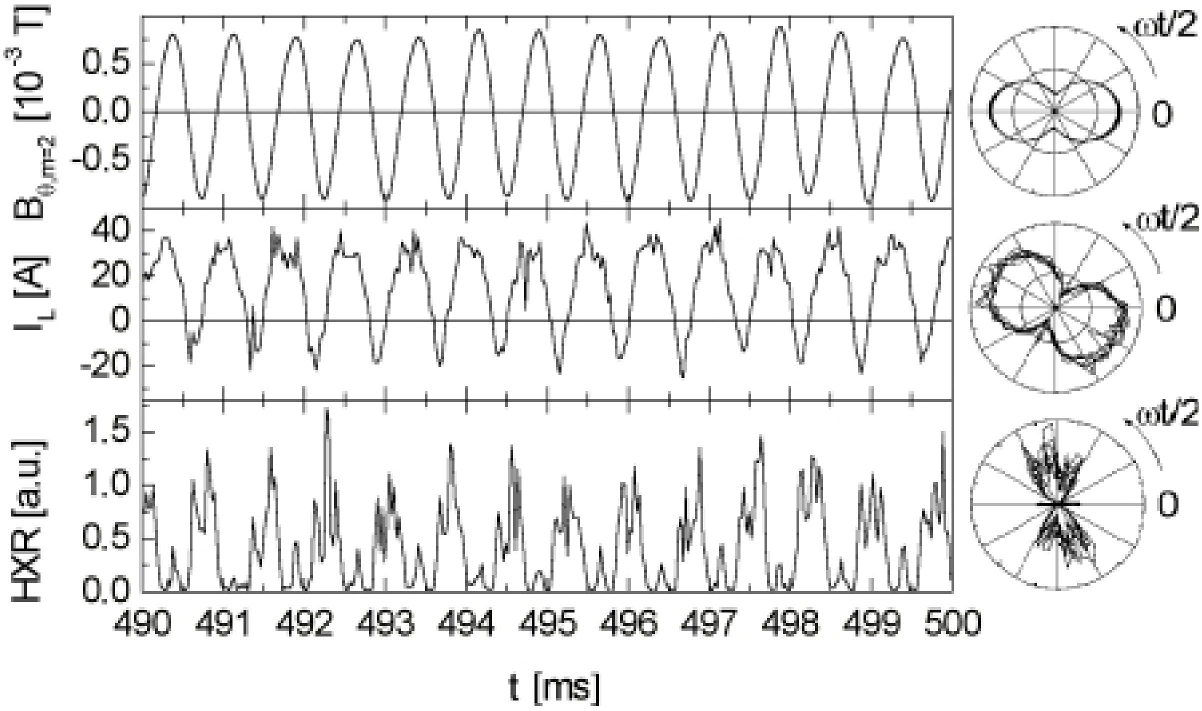

Fig.1. Time traces in the case when the connector was switched on: m=2 poloidal magnetic field perturbation ($B_{\theta,m=2}$), halo current (I_L) and hard x-ray emission (HXR). The $B_{\theta,m=2}$ and HXR signals correspond to the space location of the rail limiter. The same signals in angular coordinates are shown on the right (ω is the m=2 mode frequency, in this case t=0 - time moment when the $B_{\theta,m=2}$ signal comes to its maximum value).

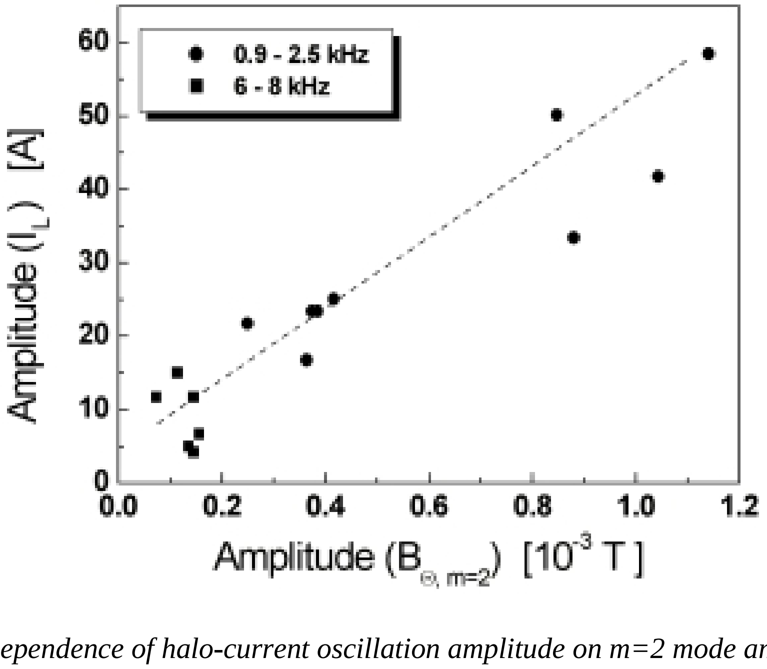

Fig.2. Dependence of halo-current oscillation amplitude on m=2 mode amplitude.

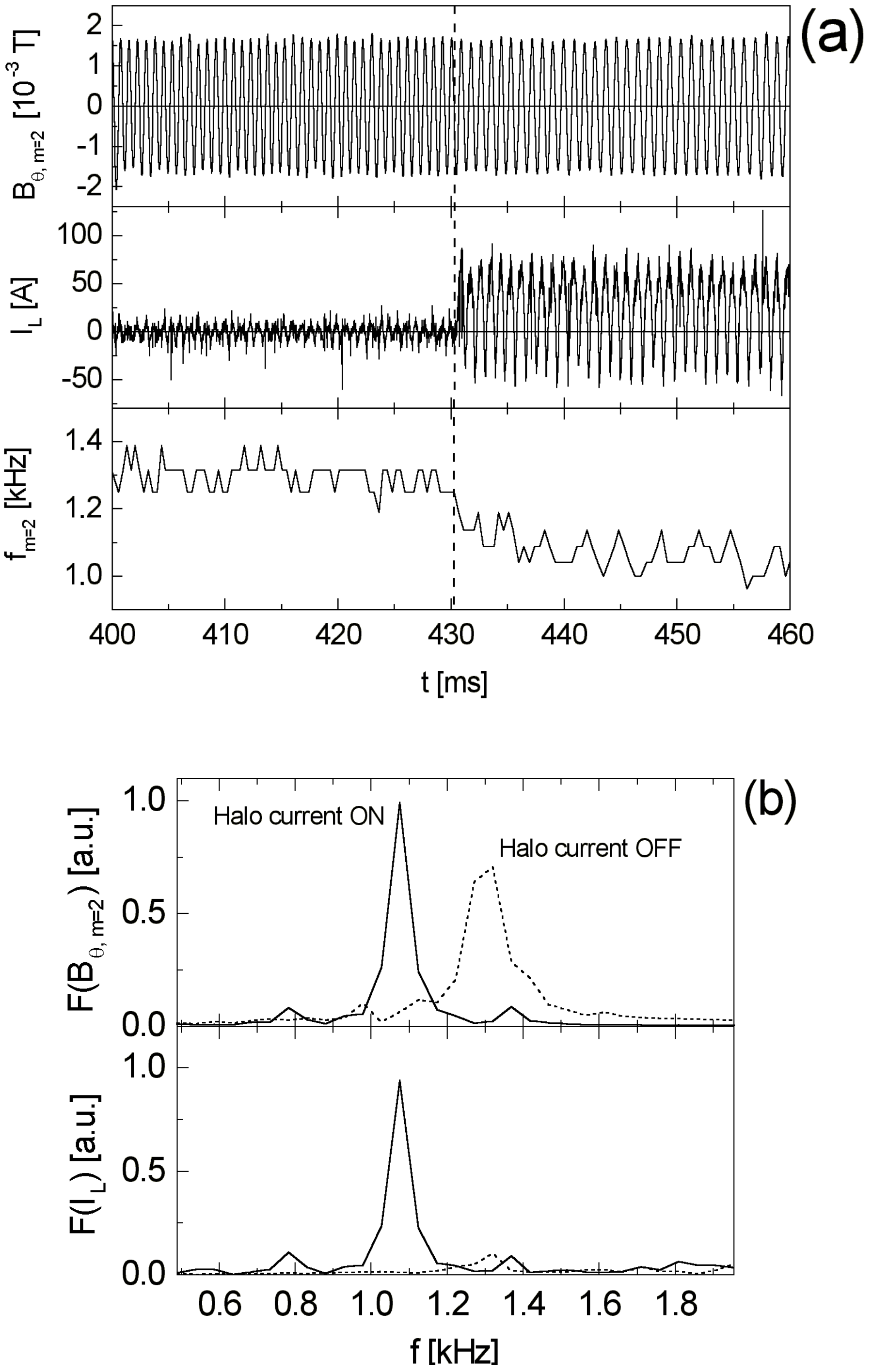

Fig.3. (a) Time traces of m=2 poloidal magnetic field perturbation ($B_{\theta,m=2}$), halo current (I_L) and instantaneous value of m=2 mode frequency ($f_{m=2}$). The moment when the connector is switched on is shown with a vertical dashed line.

(b) Fourier transforms of $B_{\theta,m=2}$ and I_L signals before (dotted line) and after (solid line) the switching on of the connector.

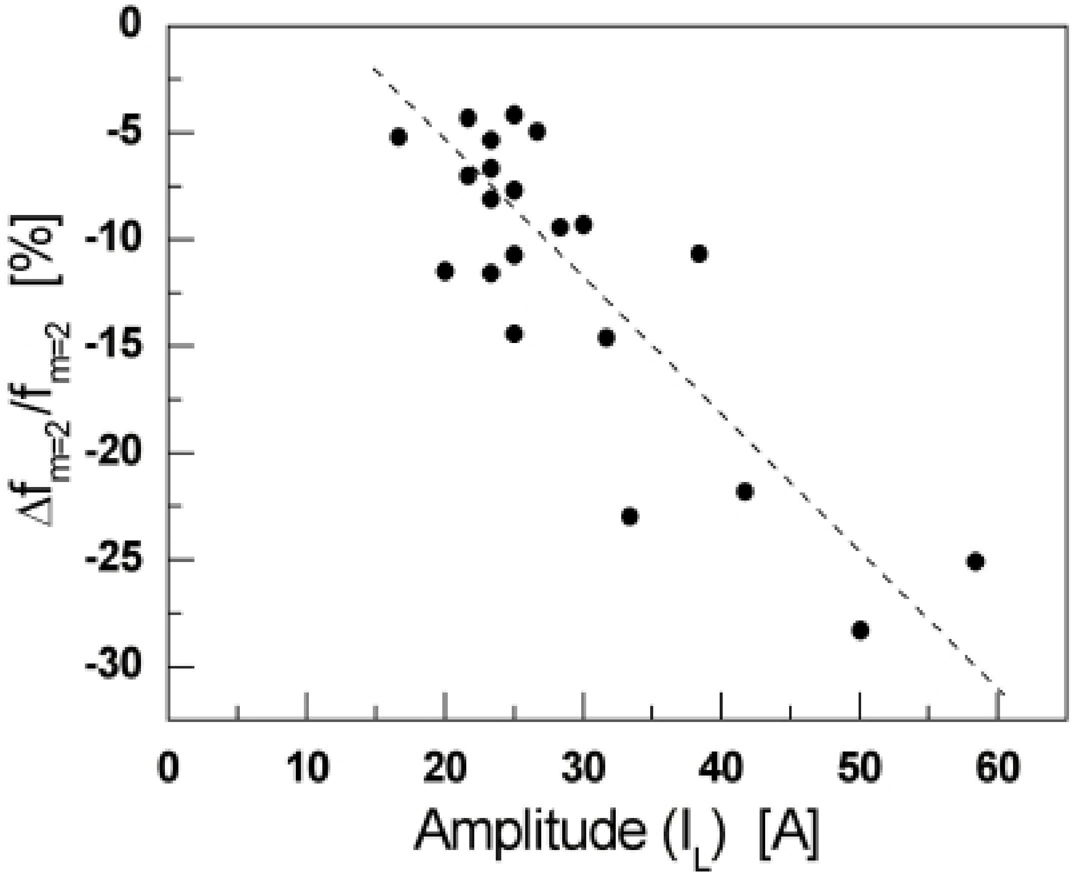

Fig.4. Dependence of normalised shift of m=2 mode frequency on halo-current oscillation amplitude.

4. Conclusion

It can be concluded that an interdependence between magnetic islands, halo currents and runaway electrons is observed in some conditions. It is natural to suppose that this interdependence can be stronger and should be taken into account for disruption conditions in tokamaks with elongated plasmas. In these conditions the value of the halo current is much higher than the halo current in the case of our T-10 experiment. This result should be taken into account in theoretical analysis and numerical modelling of disruption scenarios, especially for next step tokamaks like ITER.

5. Reference

[1] ITER Joint Central Team, ITER Home Teams, “ITER Physics Basis”, Nuclear Fusion **39** (1999) 2137-2664.