Limiter Biasing Effects on the Magnetohydrodynamic Behavior of the CT-6B Tokamak

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Abstract. Magnetohydrodynamic phenomena in the CT-6B Tokamak based on Mirnov oscillations have been investigated by applying the limiter biasing potentials. The results show that setting up a radial electric field at the plasma edge could drive electromagnetic instabilities in the tokamak plasma. Magnetic oscillation frequency upon application of a positive biasing voltage decreases by about 10%-15% and then after a delay time, t=2.5-3 ms, increases by about 20%-25% with respect to their value without biasing. In the negative biasing regime, the oscillation frequency increases by about 10% in 1ms after the application of the biasing pulse. The plasma poloidal rotation changes during two steps are related to its link with the radial electric field and the timescale of the density gradient change. Microinstability impression by limiter biasing observed. During positive biasing it is seen that before, after and during biasing the high frequency amplitude decreases upon positive biasing that means the Microinstability is suppressed.

1. Introduction

The biasing experiments on tokamak limiter, electrode or divertor [1-12] and some plasma devices [13] have been considered to improve the global confinement by setting up an electric field at the plasma edge. The main attention has given to the role of radial electric field (E_r) and its control to modify edge plasma turbulence, plasma rotation, transport, and L-H transition. It has theoretically shown that a strong shear of the **E**×**B** velocity can drive electromagnetic instabilities in tokamak plasma [14]. It suggests the existence of a close link between the electrostatic and magnetic behavior of plasma turbulence. It is the purpose of this work to study the relation between magnetic perturbations and radial electric field by investigating the Magnetohydrodynamic (MHD) activity based on Mirnov oscillations on the CT-6B Tokamak through the application of external limiter biasing potentials and changing the chamber gas pressure, P_{gas}, and plasma displacement, Dx. In section 2 we will describe some experiments to observe MHD behavior for a better understanding of magnetic field fluctuations and mode structure. Section 3 will be in detail on study and experiment of main aim of this work means Limiter Biasing, and then a conclusion will be presented in last section.

2. MHD Experiments

The experiments were conducted on the ohmically heated iron core tokamak CT-6B with a major radius R=0.450 m and a minor radius a=0.125 m defined by a set of fixed four block poloidal limiters. The vacuum chamber is a stainless steel structure with two toroidal breaks and a minor radius b=0.150 m. The toroidal magnetic field B_t=7-7.5 kG, plasma current I_p=30 kA, chord-averaged electron density of 1 10^{-19} m^{-3} in hydrogen and the plasma discharge duration ~30ms. An array of twelve Mirnov coils is used. At the beginning of the experiments, we selected a typical discharge condition for observing the typical behavior of sinusoidal magnetic perturbation with clear and large MHD activity. Two arrays of magnetic coils mounted on CT-6B are used to study the fluctuations of the poloidal magnetic field. There are 24 coils in each array. These coils are uniformly separated by $2\pi/n$, where n is the number of coils in the array. Only one array has been used in this run of experiments. The locations of the Mirnov coils of the array and a schematic drawing of CT-6B are shown in Figure 1.

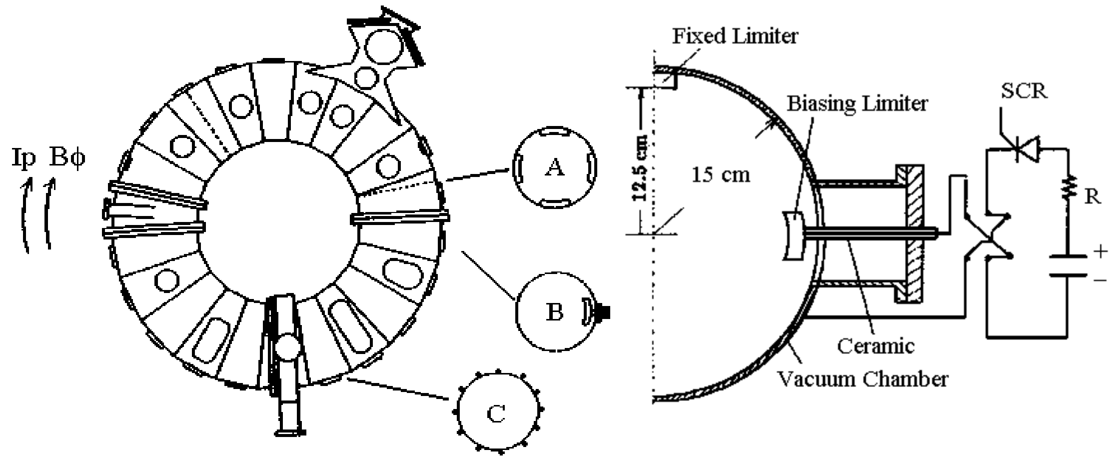

FIG. 1. Schematic drawing of the CT-6B Tokamak (left) and the A) location of fixed limiter, B) Scheme of the limiter biasing experiment (right) and C) The location of Mirnov coils.

We changed conditions of plasma, such as plasma current I_p, plasma displacement Δx and vacuum vessel pressure. By changing these parameters, the start of MHD activity changed, too. These experiments are done in two pressure, 7×10^{-5} torr and 8.5×10^{-5} torr, two positions of plasma centre 2.5cm outward and 3.5cm outward. Figure 2 (left) shows the relationship between plasma current and plasma displacement in two conditions when MHD activity is started.

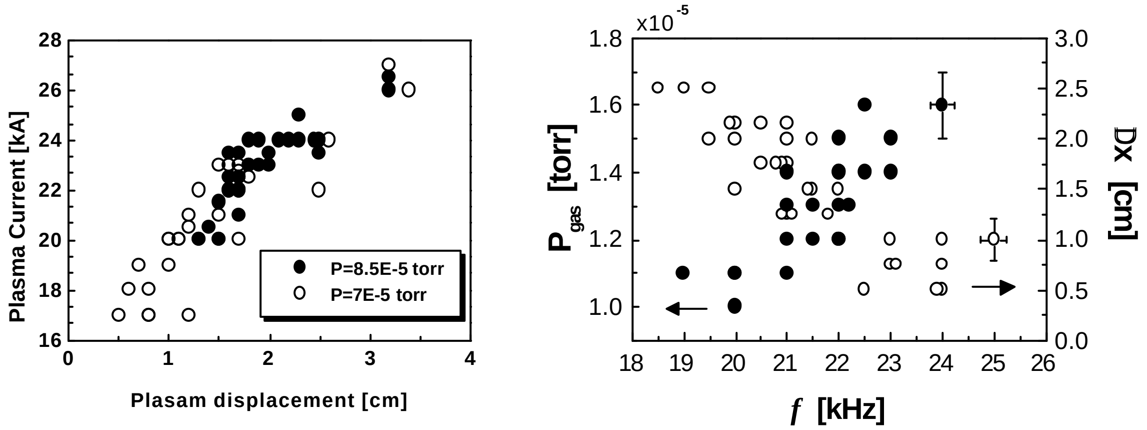

FIG. 2. Relationship between plasma current and plasma displacement when MHD activity is beginning, points are from many shuts (left). The frequency dependence of MHD oscillations shown by changing chamber gas pressure and plasma displacement (outward) shut by shut (right).

The poloidal magnetic field fluctuations have been detected through shot to shot by varying chamber gas pressure P_{gas}=1.0×10^{-5} torr to P_{gas}=1.6×10^{-5} torr on a fixed plasma displacement. After taking Fast Fourier Transform (FFT) from Mirnov signals, we observe that the frequency of oscillations increase along with the increase of the gas pressure because of increase in electron density. Furthermore we fix chamber gas pressure and change the plasma displacement from Dx=-0.5 cm to Dx=-2.5 cm. The frequency spectrum of the Mirnov signals at this condition shows that by increasing plasma displacement to outer side, the frequency of oscillations decreases. The results of these experiments are shown in Figure 2 (right). Since the edge magnetic coils give the mode number m of the instability, B_θ polar plot are made in which the radial distance from the circle is proportional to B_θ at that angle θ. This plot gives a graphic representation of the mode number. Figure 3 shows the detailed time evolution of poloidal variations of poloidal amplitude dependence of magnetic field perturbation signals at 13.7 msec; the samples are separated by 12.8 μsec intervals. So that is seen, rotation of mode *m*=3 is clear, the inside of torus with toroidal effects, the shape of plots are unsymmetrical so that, the number of mode inner side is more than outer side of machine. Infact it is clear that the plasma column can not be as a rigid body.

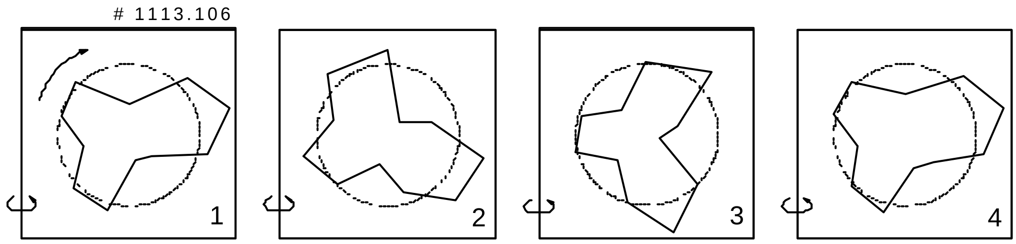

FIG. 3. Time evolution of poloidal variations of the amplitude of magnetic field perturbation at 13.7msec, the samples are separated by 12.8msec intervals. The spatial variations of mode number on the inner side of the Tokamak by reason of toroidal effects are more than outer side. A circle arrow in plots indicates the location of the inner side of the machine.

3. Biasing Limiter Experiments

The experimental setup is schematically shown in Figure 1. The radius of aperture of the fixed limiters is 12.5 cm. A moveable segment of poloidal limiter made of thin molybdenum plate is located at the equatorial midplane positioned in the r=12.5 cm. The limiter is electrically isolated from the vacuum chamber and can be charged by a 36 mF capacitor bank with a silicone controlled rectifier (SCR) switch. The biasing experiments are performed under a pulsed biasing voltage regime, usually at the plateau regime and to the end of discharge. The biased voltage was restricted to the range of $-125V \leq V_{Lim} \leq 220V$. We divide the Mirnov signals to part time segments with a time interval of 0.256ms for FFT analysis.

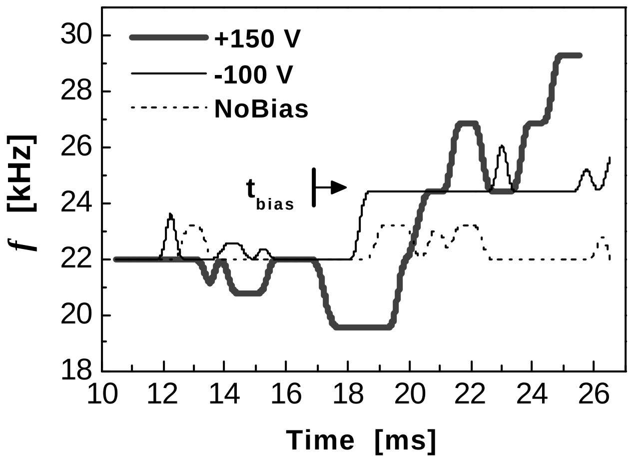

FIG. 4. Time evolution of the magnetic oscillation frequency with positive, negative biasing limiter and reference signal without biasing. The biasing start time is indicated at t_{bias}=16.8 ms by an arrow.

In all experiments, after applying a positive bias, we observe a decrease and then an increase in the frequency of magnetic field oscillations. For example, after applying a +150V bias voltage in the plateau regime at 16.8 ms, the frequency of oscillations decreases by about 10%-15%. Then, after a delay time of about τ_d=2.5-3 ms, it increases by about 20%-25% with respect to their values without biasing, as is shown by the thick solid line in Figure 4. In the negative biasing regime, the magnetic oscillation frequency increases by about 10% by a retardation time ≥1ms after applying a bias pulse as shown by the thin solid line in Figure 4.

The time evolution of the magnetic oscillation frequency with different applied positive and negative bias voltages is illustrated in Figure 5. The magnetic oscillations are more prominent with stronger positive and negative biased voltages so that, after the positive biasing at 16.8ms, the frequency decreases for all voltages while the drop duration for high positive voltages is shorter. Also, for negative bias voltages, the response to the external field has a time retard and after a few milliseconds the frequency of oscillations in low-voltage regimes returns to that without bias.

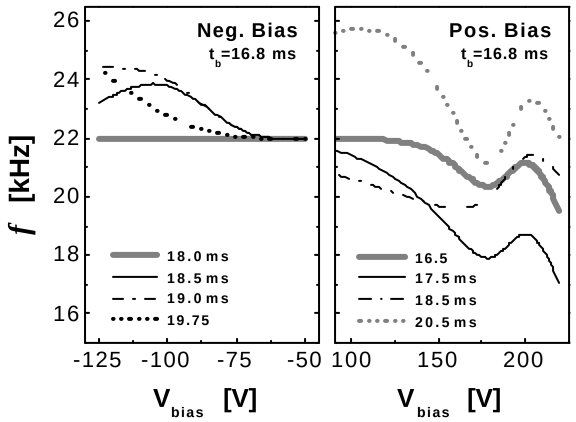

FIG. 5. Dependence of the magnetic oscillation frequency f, with respect to positive (right) and negative (left) bias voltages, before and during biasing.

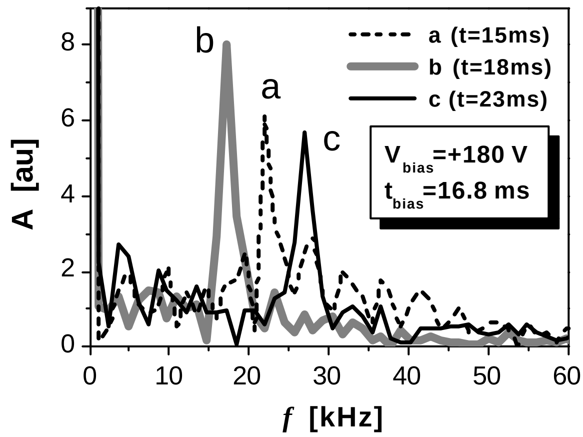

FIG. 6. The spectrum of magnetic oscillations, for a 0.48 ms partial time interval;
a) before biasing at t=15 ms,
b) 1ms after biasing at t~18 ms
c) ramp down of discharge t=23ms

Also, Microinstability effects by limiter biasing observed. During positive biasing it is seen that before, after and during biasing the high frequency amplitude (>20 kHz) decreases upon positive biasing as on the KT-5C[10], ISTTOK[12], and DIII-D[16] tokamaks that for last one the MHD fluctuations (≥10 kHz) show reduction during transition so that it means the Microinstability is suppressed as illustrated in figure 6.

4. Discussion and Conclusion

Now, we try to identify the underlying physics responsible for changes in the Mirnov oscillations that could be related to poloidal rotation velocity and radial electric field. In the CT-6B when the bias voltage is applied, the electron density n_e will experience a change of ~0.5ms later, while the H_α emission measurements show a quicker response than n_e (at a timescale of 100-200 μs) to the biasing [7]. Also, In the STOR-M [3], HT-6M [17], DIII-D[15] tokamaks and the TU-Heliac [13] results show that n_e and main ion pressure gradient term change as slower time scale (0.5-1.0 ms) with respect to H_α emission. In the CT-6B after applying positive bias voltage the H_α emission amplitude first increased and after a delay time decreases.

The measurement of magnetic island rotation velocity v_θ in the CT-6B on the positive biasing regime by mode rotation velocity analysis, shows a rapid decrease for about 0.5 ms and then starts to increase. In HT-6M [17], the results show that v_θ increases just after the transition for r/a<1 and the results of ISTTOK [12] show that v_θ increases immediately after positive biasing for a low plasma current regime so that the results for the first 2ms are different from those in the CT-6B. In all the above experiments, the timescale of the phenomena is important. The decrease of magnetic oscillation frequency in the CT-6B may be explained as follows. Since the response of the pressure gradient ∇p_i to the external field is slower than the timescale of the change in the edge density fluctuation and poloidal flow velocity, therefore for a timescale of <0.5ms the link between the E_r and poloidal rotation velocity v_θ plays a key role in the poloidal flow behavior. The first response of plasma to positive biasing is a decrease of plasma poloidal rotation. During this reduction, in a matter of less than 0.5 ms, the edge electrostatic and magnetic fluctuations are strongly suppressed and the pressure gradient increases. In this step, v_θ increases in with great speed because of suppressed turbulence and increased transport.

In our experiments during biasing regime as an electrostatic phenomenon we investigated magnetic instabilities in CT-6B tokamak that it found a relationship between them. Positive biasing reduces MHD oscillations frequency at first but after a short delay time, the frequency of oscillations increases, that it seems be because of difference in the time scales of the poloidal rotation reduction and the density gradient. Negative biasing has not response just after pulse voltage, it causes increase of MHD oscillations about 1ms later, so that for high negative voltages the frequency remains high while for low negative voltages almost it returns to without bias level. The poloidal rotation velocity changes during two steps refer to its link with radial electric field and the time scale of density gradient. The frequency of oscillations increases by increasing chamber gas pressure and decreases with increasing plasma displacement to outer side. Microinstability affects by limiter biasing so that during positive biasing it is seen that before, after and during biasing the high frequency amplitude decreases upon positive biasing that means the Microinstability is suppressed.

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