Effects of Viscosity on Magnetohydrodynamic Behaviour During Limiter Biasing on the CT-6B Tokamak

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Abstract. Effects of viscosity on magnetohydrodynamics behaviour during limiter biasing in the CT-6B Tokamak has been investigated. The results shown that subsequent to the application of a positive bias, a decrease followed by an increase in the frequency of magnetic field fluctuations was observed. With contribution of viscous force effects in the radial force balance equation for *Limiter Biasing*, in terms of the nonstationarity model, it allows us to identify the understanding physics responsible for change in the Mirnov oscillations that could be related to poloidal rotation velocity and radial electric field. It could be seen that the time scale of responses to biasing is important. The response of ∇p_i, decrease of poloidal rotation velocity, the edge electrostatics and magnetic fluctuations to external field have been investigated. The results shown that momentum balance equation with considering viscous force term can be use for modeling of limiter biasing in the tokamak.

1. Introduction

Many experiments have shown the importance of the radial electric field in improved confinement states and several theories can explain the transition mechanism. There are several methods for controlling the radial electric field externally [1,2]. Edge biasing experiments have been found to be important in modifying edge turbulence and transport, but the mechanism of biasing penetration in edge fluctuations and its levels are different with respect to devices operation. Limiter biasing is one of these methods, and is carried out by imposing a voltage directly in the radial direction of tokamak plasmas. In CT-6B, some characteristics are observed in the limiter biasing experiment. One is with respect to the power of the applied voltage, and another is the start time of the voltages. The mechanisms of plasma behavior to applied external field investigated in some models [3]. These models have been considered the momentum equation. In the present research, effects of viscosity on magnetohydrodynamics behavior during limiter biasing on the CT-6B tokamak has been investigated. In addition, the effects of a positive limiter biasing on the plasma floating potential, poloidal magnetic field fluctuation and H_α emission fluctuations are examined.
In the sections to follow a description of the experiment, its findings and conclusion are presented.

2. Experiment Setup

The experiments were conducted on the ohmically heated iron core CT-6B tokamak, with a major radius *R*=0.45m and a minor radius *a*=0.125m defined by a fixed four-block poloidal limiter. The vacuum chamber was a stainless steel welding structure with two toroidal breaks and a minor radius *b*=0.15m. An array of twelve Mirnov coils is used for measuring the poloidal magnetic field oscillations and a segment poloidal limiter made of thin molybdenum plate, with 8cm height and 2cm width, electrically isolated with the chamber positioned at *r*=0.125m on the outer side of the equatorial midplane of the plasma, was employed as the biasing limiter, where *r* is the minor radius. The biasing voltages were continuous. It was applied on the plasma at some moment (starting time) during the plasma current plateau and -

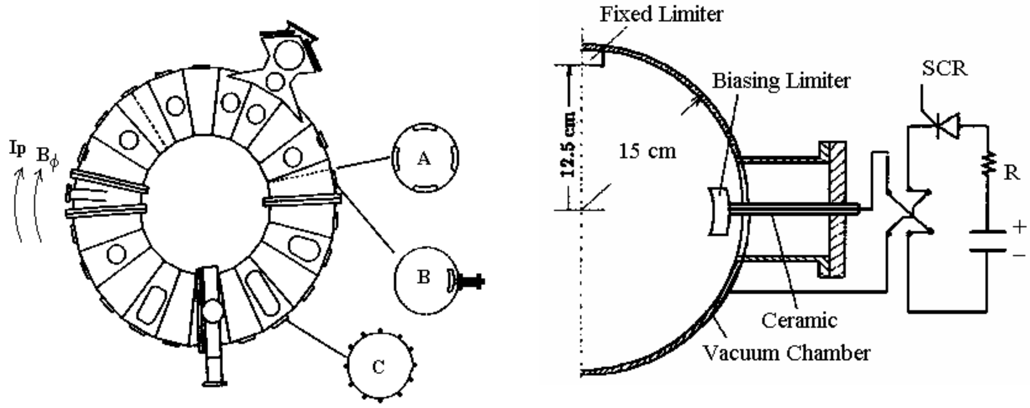

FIG. 1. Schematic drawing of CT-6B (left), locations of Mirnov coils indicated by (c), Limiter biasing position indicated by B and fixed limiters indicated by A, and Limiter Biasing setup (right).

ended after the discharge termination. The biased voltage was restricted to $125V \leq V_{bias} \leq 220V$. The array of Mirnov coils and H_α spectrometer detectors were mounted at toroidally 75° and 90°, respectively, from the limiter-biasing device. The horizontal displacement of the plasma column, Δx, was measured with a set of cosine coils and saddle coils. The value of Δx can be controlled with a feedback system of vertical magnetic field in each discharge. The conditions of the experiment were as follows: The toroidal magnetic field B_t=6.5-7.5kG, plasma current I_p=17-25kA, chord-averaged electron density $\overline{n}_e$=0.5-1.5x$10^{19}m^{-3}$ in hydrogen and the plasma discharge duration ~30ms. The data were digitized at 6.4 μsec resolution using a multi-channel data acquisition system. The locations of Mirnov coils, Limiter biasing setup and a schematic drawing of CT-6B are shown in Fig.1.

3. Results and Discussion

In the biasing experiments, subsequent to the application of a positive bias, a decrease followed by an increase in the main frequency of magnetic field fluctuations was observed [4]. To cite an example, after applying +180V bias voltage in the plasma current plateau at 16.8ms, the main frequency of oscillations decreased by about 10-15%. Then, after a short delay time of about t_d=2-2.5ms from 16.8-18.5ms, it increased by about 20-25% with respect to their values without biasing. Temporal evolution of the magnetic fluctuations spectrum is shown in Fig.2. The result of this experiment for positive bias is different from other tokamaks. For example, the MHD behavior of *negative* bias in the ISTTOK [5] tokamak is similar to *positive* bias in the CT-6B tokamak. The plasma current in CT-6B experiments is about four times higher than in the ISTTOK one, so that, it has been shown that plasma current plays an effective role in MHD activity. Temporal evolution of the main frequency of magnetic fluctuations, H_α emission, horizontal plasma displacement, plasma current, Mirnov oscillations and bias voltage has been illustrated in Fig.3. It is seen that after biasing, H_α emission intensity increases, Mirnov frequency decreases and plasma moves outward. When the limiter is biased, the plasma potential floats to a value close to the bias potential. In Fig.4, it can be seen that the low frequency floating potential fluctuations level <20kHz decreases after a positive bias near the limiter. This reduction is similar to results of the ADITYA[6], KT-5C[7], ATF Torsatron[8] and Thorello[9]. Thus, our results may show that after the biasing, the outward-flowing current based upon the existence of the turbulence is quenched and an inward radial current is recovered. On the other hand, the floating potential fluctuation in TEXTOR [10] and STOR-M [11], through positive biasing, increases near the limiter when outward flow decreases. The difference between results can be due to the conditions of device operation.

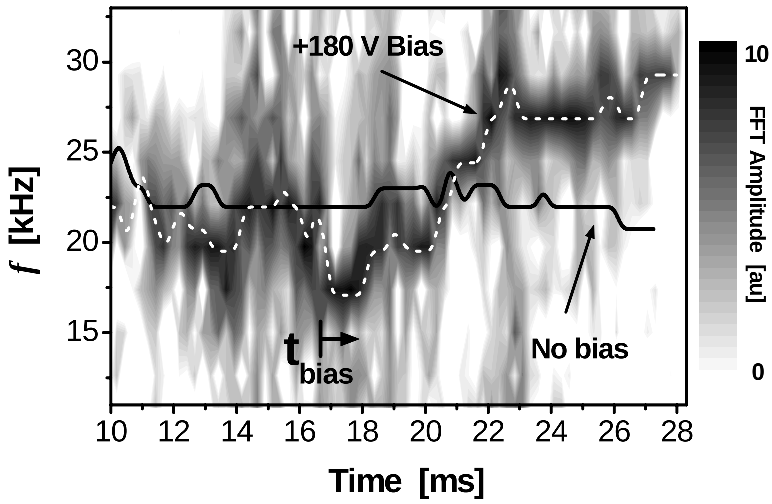

FIG.2. Time evolution of the magnetic oscillation frequency with positive biasing limiter and reference signal without biasing. The biasing start time is indicated at t_{bias}=16.8 ms by an arrow

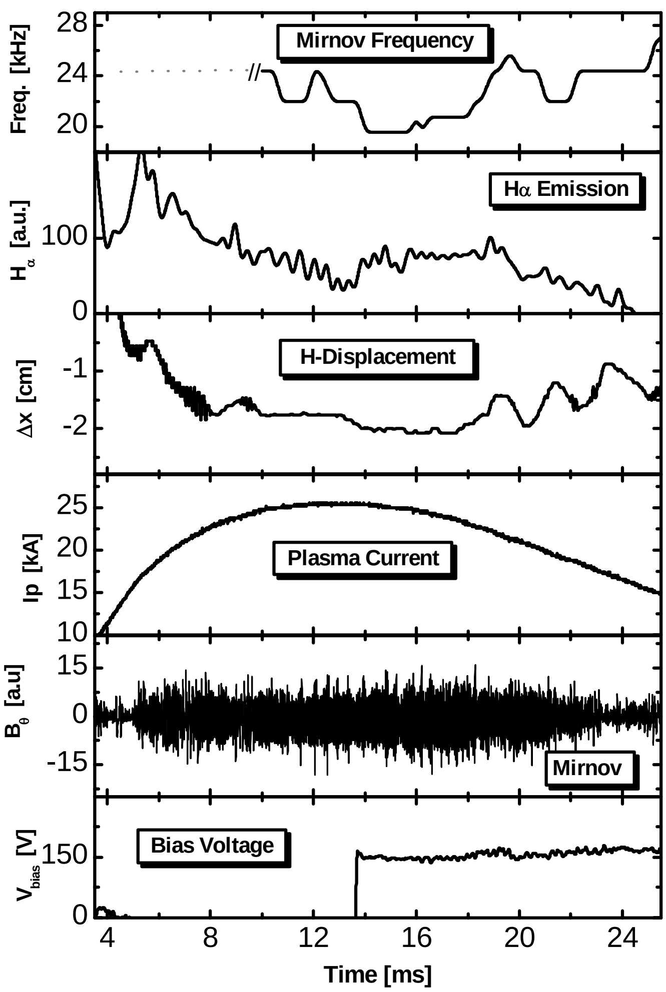

FIG. 3. Temporal evolution of the main frequency of poloidal magnetic field fluctuations, H_α emission, horizontal plasma displacement, plasma current, Mirnov oscillations and bias voltage

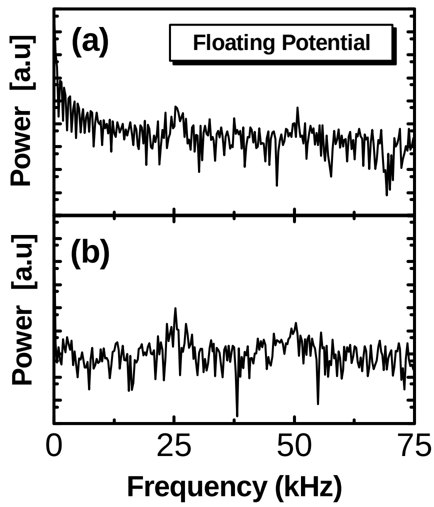

FIG. 4. Frequency floating potential fluctuations, a) Before biasing, b) After positive biasing.

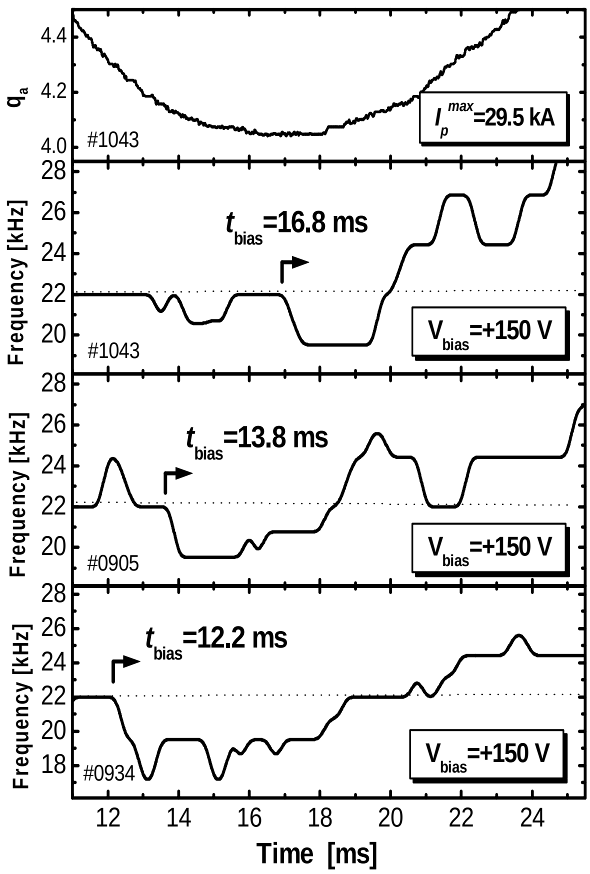

FIG.5. The bias voltage applied on the plasma at some moments (starting time) during the plasma current plateau. V_{bias}= +150V.

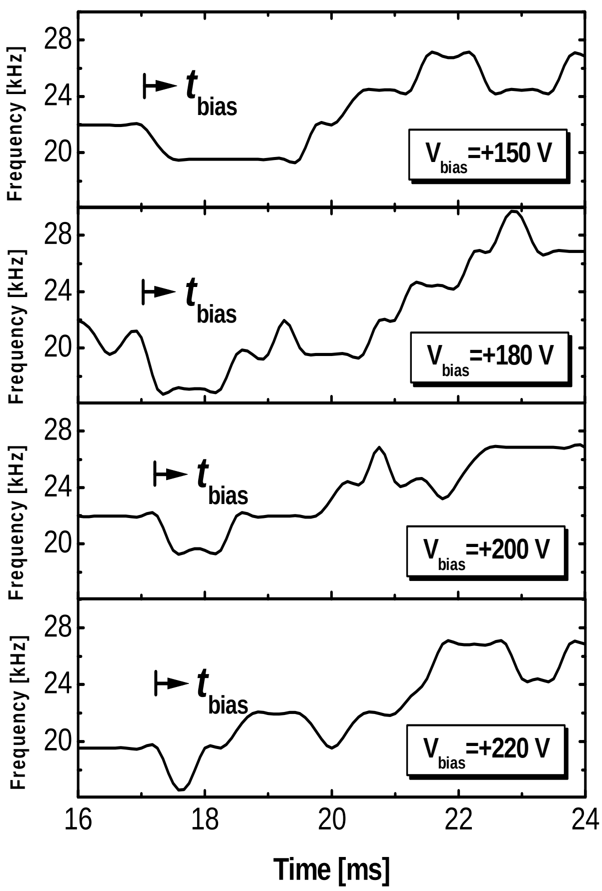

FIG.6. The time evolution of the magnetic oscillation frequency with different applied positive bias voltages.

When the bias voltage is applied on the plasma at some moments (starting time) during the plasma current plateau, the drop duration becomes longer so that it is relative in the higher q factor at the beginning of the high MHD activity, as shown in Fig.5. The time evolution of the magnetic oscillation frequency with different applied positive bias voltages is illustrated in Fig.6. The magnetic oscillations are more prominent with stronger positive biased voltages so that, after the positive biasing at ~17ms, the frequency decreases for all voltages while the drop duration for high positive voltages is shorter.

In the negative limiter biasing, the magnetic oscillation frequency increases by about <10% by a retardation time ~1ms and after a few milliseconds, the frequency of oscillations in low-voltage regimes returns to that without bias. Since the effects of negative biasing are rather thin on the magnetic fluctuation, no more experiments have been done.

The model for determining the radial electric field structure with a biasing voltage in the plasma edge is considered here. A voltage is applied between limiter and wall. The physics that influences E_r is in terms of the radial force balance equation,

$$E_r = (Z_i e n_i)^{-1} \nabla p_i - v_{\theta i} B_\phi + v_{\phi i} B_\theta - (en)^{-1} f_{viscous}$$

where p_i is the ion pressure, $Z_i e$ is the ion charge, n_i is the ion density, $v_{\theta i}(v_{\phi i})$ is poloidal (toroidal) velocity, $B_{\theta i}(B_{\phi i})$ is the poloidal (toroidal) magnetic field and $f_{viscous}$ is the viscous force opposing the plasma rotation. This equation applies separately to each ion species and is valid at each point on a flux surface. Changes in the E_r at the plasma edge are associated with changes in the main ion pressure gradient and the main ion poloidal rotation (at ohmic heating regime $v_{\phi i} \ll v_{\theta i}$ and $v_{\phi i}$ is almost constant during transition). Almost the $v_{\theta i}$ gives a positive (outward) contribution to E_r because it is in the ion diamagnetic drift direction, and ∇p_i gives the dominant, negative contribution to E_r at the plasma edge [12]. With contribution of viscous force effects in the radial force balance equation, in terms of the nonstationarity model [13], it allows us to identify the understanding physics responsible for change in the Mirnov oscillations that could be related to poloidal rotation velocity and radial electric field. In the CT-6B the n_e changes ~0.5 ms after the bias voltage application, while the H_α emission measurements show a more fast time scale than n_e (at a time scale of 100-200 μs), also, in the STOR-M, HT-6M [14], DIII-D [15] tokamaks 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.

When a potential is applied to the limiter, the plasma becomes biased and a radial electric field is generated. The radial electric field causes change in poloidal velocity so that viscous forces emerge in the direction of the drift velocity. These forces in their turn produce drift of ions in the direction of the initial electric field, thus creating a transverse ion current in the direction of electric field. Since the response of ∇p_i to external field is more slower than time scale of the change in the edge density fluctuation and poloidal flow velocity, therefore, for a time scale of <0.5 ms the link between the E_r and v_θ plays a key role in the poloidal flow behavior. In addition, the poloidal rotation shows a concomitant change with the radial electric field, therefore, the first response of plasma to positive biasing is a decrease of v_θ and then increasing viscous force, during this reduction that is less than 0.5 ms the edge electrostatics and magnetic fluctuations are strongly suppressed and the pressure gradient is increases. In this step, the v_θ because of suppressing turbulence and increasing the transport increases with a faster speed. Therefore, the results shown that momentum balance equation with considering viscous force term can be use for modeling of limiter biasing in the tokamak.

4. Conclusion

Effects of viscosity on magnetohydrodynamics behaviour during limiter biasing on the CT-6B tokamak has been investigated. The results shown that subsequent to the application of a positive bias, a decrease followed by an increase in the frequency of magnetic field fluctuations is observed. The magnetic oscillations are more prominent with stronger positive biased voltages, so that, after the positive biasing, the frequency decreases for all voltages while the drop duration for high positive voltages is shorter. When the bias voltage is applied on the plasma at some moments (starting time) during the plasma current plateau, the drop duration of frequency reduction becomes longer so that it is relative the higher q factor at the beginning of the high MHD activity. The low frequency floating potential fluctuations level <20kHz decreases after a positive bias near the limiter. With contribution of viscous force effects in the radial force balance equation for limiter biasing, in terms of the nonstationarity model close to the edge plasma, it allows us to identify the understanding physics responsible for change in the Mirnov oscillations that could be related to poloidal rotation velocity and radial electric field. It could be seen that the time scale of responses to biasing is important. The results shown that momentum balance equation with considering viscous force term can be use for modeling of limiter biasing in the tokamak.

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