First Results of Movable Limiter Biasing Experiments on the IR-T1 Tokamak

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Abstract In this contribution we presented the first results of movable limiter biasing experiments on the IR-T1 tokamak. For this purpose we designed, manufactured, and installed a movable localized poloidal limiter and its biasing system on the IR-T1 tokamak. Then, we measured the effects of limiter position and positive biased limiter on the time intervals of plasma parameters. Using a movable biased limiter we have shown that improvement in energy confinement can be obtained for positive biased limiter. The results compared in different circumstance and discussed.

Key Words: Tokamak, Movable Limiter, Biasing, Plasma Parameters.
***PACS*:** 52.55.Fa

Introduction

A limiter plays a number of roles in tokamak operation. It serves primarily to protect the wall from the plasma when there are disruptions, runaway electrons, or other instabilities. For this reason it is commonly made of a refractory material, such as carbon, molybdenum or tungsten, capable of withstanding high heat loads. Secondly, the limiter localizes the plasma-surface interaction. The high power and particle density at the limiter surface causes rapid removal of adsorbed gas, oxide layers and other easily desorbed impurities. When only the clean substrate remains it is possible to maintain plasmas with lower impurity levels. Plasma-surface interaction in tokamaks is important in plasma conditions such as impurities, plasma parameters, and plasma confinement. Thirdly, the limiter localizes the particle recycling. A higher neutral density and more radiation are observed in the region near the limiter, than at other positions around the torus [1-7]. On the other hand, commonly accepted that improvement of both particle and energy confinement regimes can be induced in tokamaks by electrically biasing limiters inserted in the plasma edge region [8-13]. The biased limiter drives a radial current between itself and the vacuum vessel and the resulting force originates sheared flows, which have a suppressing effect on turbulence and related transport. Plasma turbulence is one of the main causes of anomalous transport in toroidal magnetic confinement devices. 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. A velocity shear stabilization mechanism has been proposed to be responsible for an improvement in plasma confinement. A clear correlation between the modifications of radial electric fields induced by biased limiter and the reduction of turbulence has been also observed in several experiments [8]. The control of the shear layer is therefore an important tool to modify transport in tokamaks [9-13]. Biased limiter has been used on IR-T1 tokamak to investigate the possibility of modifying the plasma energy confinement. It has been shown that both positive limiter and limiter bias can modify the plasma behavior. Limiter biasing is more efficient than limiter biasing in modifying the radial electric field and confinement, introducing stronger modification in the plasma potential, probably because it was inserted a few cm inside the

Last Closed Flux Surface (LCFS). However, it has been also shown that for negative limiter and limiter bias no significant modification of either the global or the edge plasma parameters was observed since the limiter drawn current was too low to modify the plasma parameters. In order to obtain the larger current necessary to modify confinement at negative applied voltages, biasing experiments have been performed using the horizontal limiter inserted well inside the fully poloidal limiter position [14-18]. In this contribution, limiter biasing experiments using the movable horizontal localized limiter are presented, emphasizing the influence of the limiter position and bias voltage on plasma parameters. Design, construction and experimental set-up of the movable limiter system on the IR-T1 will be presented in section 2. Experimental results and effects of the limiter position on the plasma parameters and comparison of them will be presented in section 3. Design, construction and experimental set-up of the limiter biasing system on IR-T1 will be presented in section 4. Experimental results and effects of the limiter biasing on the plasma parameters and comparison of them will be presented in section 5. Summary and conclusion will be discussed in section 6.

2. Design, Construction, and Experimental Set-up of the Movable Limiter System

IR-T1 is a low beta, large aspect ratio, and circular cross-section tokamak (see Table (1)), which has two fixed stainless steel grounded fully poloidal limiters with radiuses of 12.5cm. In the experiments described the constructed movable limiter position has been varied between 11.5- 12.5cm. The main diagnostics used in this work are a radially oriented movable Langmuir probe, a poloidal flux loop, and a diamagnetic loop.

The experiments were performed in hydrogen. An average plasma density was in the range $0.7\text{-}1.5\times10^{13}$ cm^{-3}, the toroidal magnetic field induction $B_T \approx 0.8\,\text{T}$, the plasma current $I_p = 25-30\,kA$.

Measurements of the plasma parameters were performed using single movable Langmuir probe, poloidal flux loops, and diamagnetic flux loop. The movable limiter consists of a stainless steel poloidal head, 2 cm in radial direction (width) and 10 cm in poloidal direction (diameter). It is inserted approximately 1-2 cm past the fixed poloidal limiter into the plasma through the low field side of the tokamak as it is shown in Figure (1). Movable limiter experiments were performed in regime with ohmic heating.

Parameters	Value
Major Radius	45 cm
Minor Radius	12.5 cm
Toroidal Field	〈 1.0 T
Plasma Current	〈 40 kA
Discharge Time	〈 35 ms
Electron Density	$0.7\text{-}1.5\times10^{13}$ cm^{-3}

Table (1), Characteristics of the IR-T1 Tokamak plasma

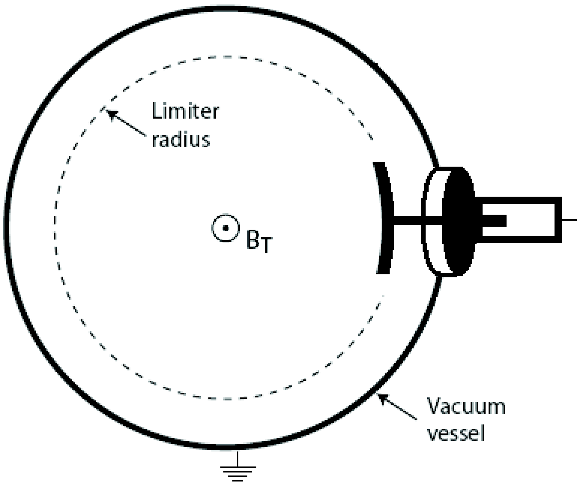

Figure (1), Schematic drawing of the movable limiter system

3. Experimental Results of Measurements of Limiter Position Effects on the Plasma Parameters

In this contribution we reported mainly the effects of the movable limiter position on the plasma parameters. In the Figure (2), the time evolution of the plasma currents for the different positions of the movable limiter are compared. In the Figures (3-5) we have compared the time interval of the electron density, electron temperature, and ion density, respectively, for the different positions of the movable limiter, measured by Langmuir probe (LP) which positioned at r=12cm. As observable, the electron density is larger for the movable limiter which positioned at 11cm. Also, the electron and ion density are larger for the movable limiter which positioned at 10.5cm. It seems that by insertion of limiter 1.5-2cm past the fixed poloidal limiter into the plasma through the low field side of the tokamak, the plasma surface interactions are reduced and then plasma density and temperature increased.

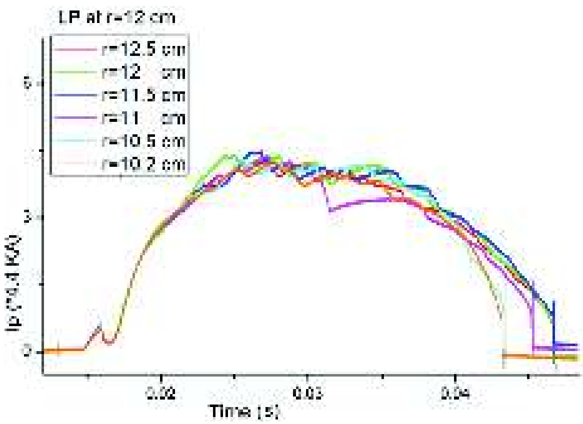

Figure (2), Time interval of the plasma current for the different positions of the movable limiter.

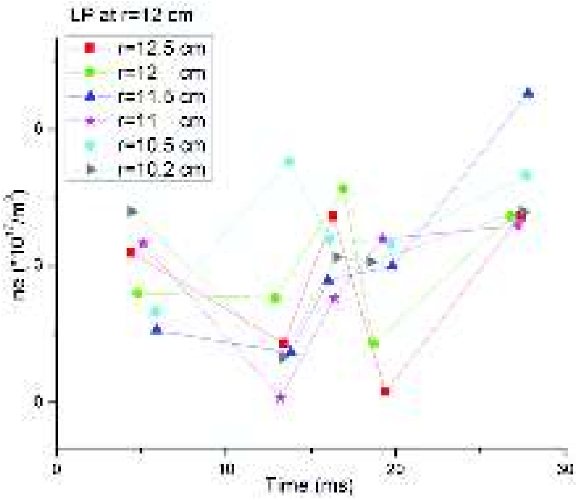

Figure (3), Time interval of the electron density for the different positions of the movable limiter, measured by Langmuir probe (LP) which positioned at r=12cm.

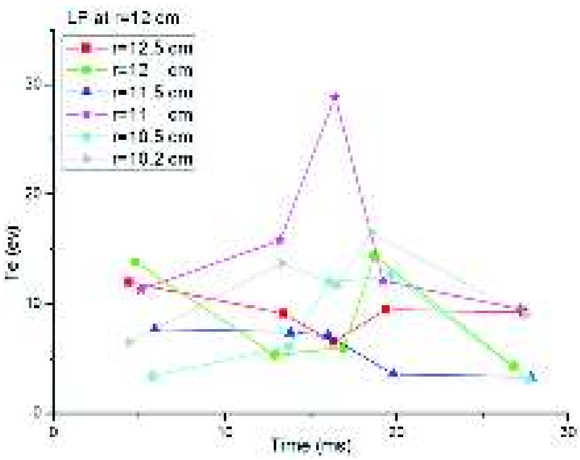

Figure (4), Time interval of the electron temperature for the different positions of the movable limiter, measured by Langmuir probe (LP) which positioned at r=12cm.

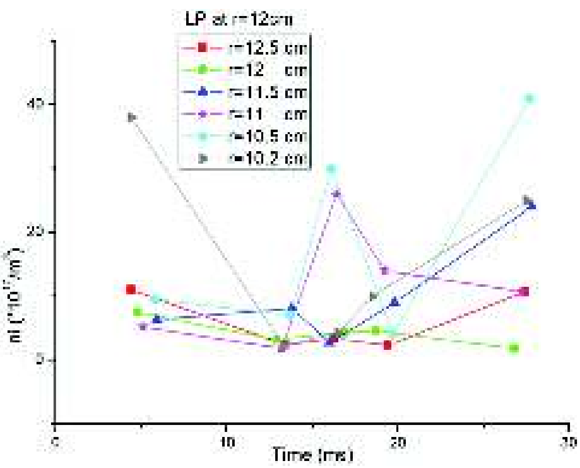

Figure (5), Time interval of the ion density for the different positions of the movable limiter, measured by Langmuir probe (LP) which positioned at r=12cm.

4. Design, Construction, and Experimental Set-up of the Movable Limiter Biasing System

IR-T1 is a low beta, large aspect ratio, and circular cross-section tokamak (see Table (1)), which has two stainless steel grounded fully poloidal limiters with radiuses of 12.5cm. In the experiments described the biased limiter position has been varied between 11.5-12.5cm, and the bias applied between the limiter and the vessel. The main diagnostics used in this work are a poloidally and radially oriented magnetic probes, a poloidal flux loop, and a diamagnetic loop.

The experiments were performed in hydrogen. An average plasma density was in the range 0.7-1.5×10^{13} cm^{-3}, the toroidal magnetic field induction $B_T \approx 0.8$ T, the plasma current $I_p = 25 - 30\ kA$.

Measurements of the plasma parameters were performed using single Langmuir probe, triple magnetic probes, poloidal flux loops, and diamagnetic flux loop. The localized limiter consists of a section of a poloidal limiter 2 mm thick, covering a poloidal extension of 90°. It is inserted approximately 1 cm past the fixed poloidal limiter into the plasma through the low field side of the tokamak as it is shown in Figure (6). Also the electric circuit of limiter biasing system used in IR-T1 is shown in Figure (7). A capacitor bank biases the limiter positive or negative with respect to the grounded wall. The applied limiter voltage V_{bias} is in the range −400 to +400 Volts, and the bias current I_{bias} is in the range -40 to +40 Amperes. Biasing experiments were performed in regime with ohmic heating.

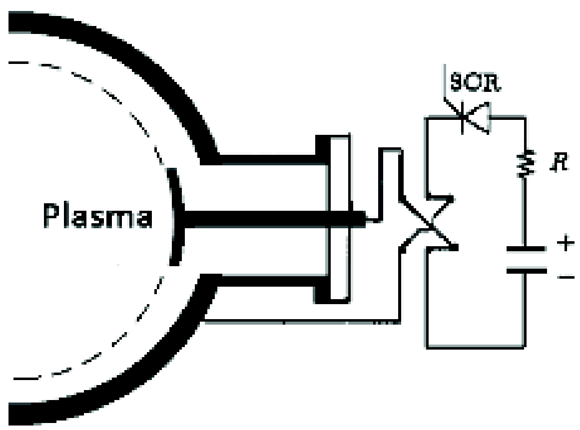

Figure (6), Schematic drawing of the limiter biasing system in the IR-T1

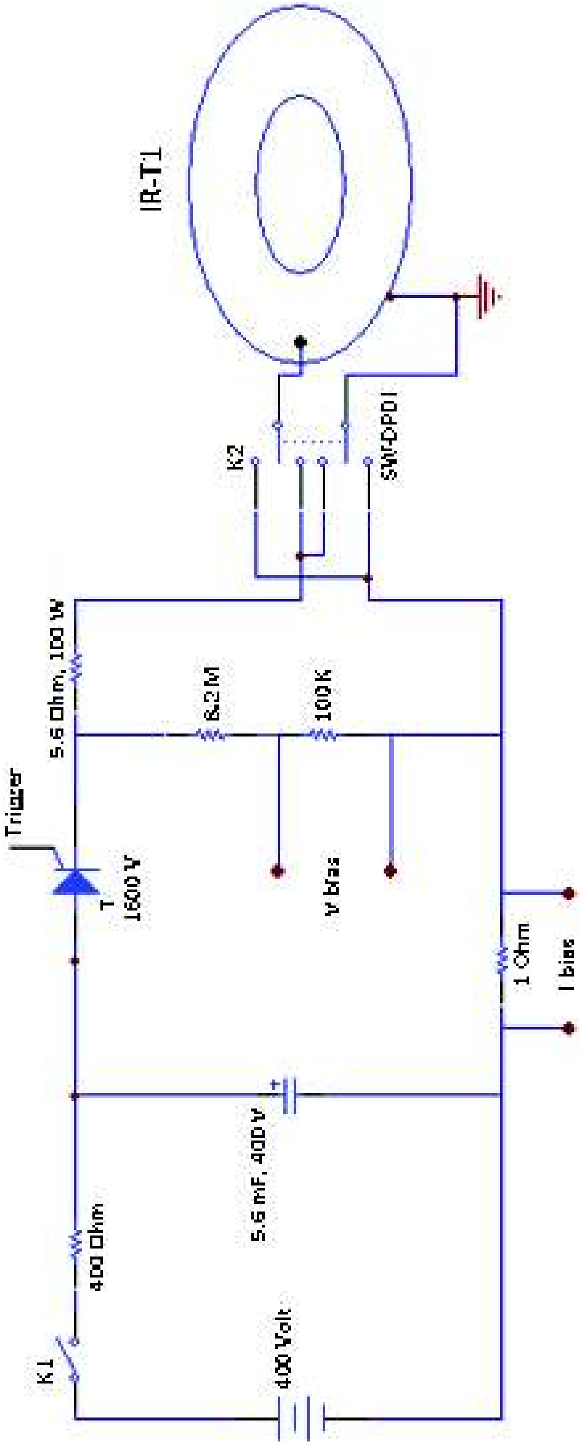

Figure (7), Electric circuit of the limiter biasing system used on the IR-T1

5. Experimental Results and Effects of the Movable Limiter biasing on the Plasma Parameters

In this contribution we report mainly the effects of the limiter biased with positive voltage on the plasma behavior. Alternating bias voltages (50-200 Hz, 400 peak voltage) provided by a transformer have been used to determine the limiter voltage-current characteristic in a single shot. This is illustrated in the Figure (8), which shows the variation of the limiter current and voltage for 1cm inserted limiter. In the Figures (9-11), the time evolution of the plasma current, loop voltage, and diamagnetic flux for positive and no limiter bias are compared for $r_{Limiter} = 11.5\,\text{cm}$. In the Figures (12-13) we have compared the plasma resistance and the plasma energy confinement time for positive limiter bias and no bias for $r_{Limiter} = 11.5\,\text{cm}$. Positive bias has been applied to the limiter at t=12.5ms during 14.5ms. For this biasing an increase in the plasma resistance is observed. Due to the increase in plasma resistance, the plasma temperature also increases, leading to the increase of the plasma energy confinement time. On the other hand, this observed improvement in energy confinement time may because of modification in the edge radial electric field E_r profile. Therefore, positive bias increases significantly the magnitude of the radial electric field in the region inside the fixed limiters. In the Figure (14) we have compared the plasma Horizontal Displacement (H.D.) for positive limiter bias and no bias for $r_{Limiter} = 11.5\,\text{cm}$. As observable, the plasma displacement is decreased, which lead to the improvement of the particle and energy confinement.

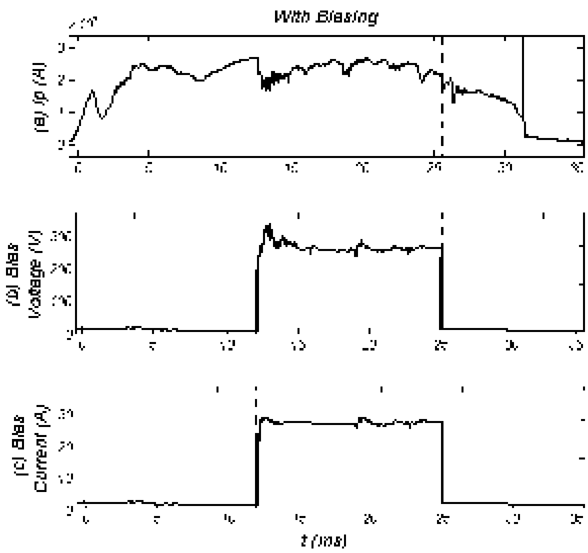

Figure (8), (a) The time evolution of the plasma current in presence of the biasing, (b) time evolution of the bias voltage, and (c) time evolution of the bias current.

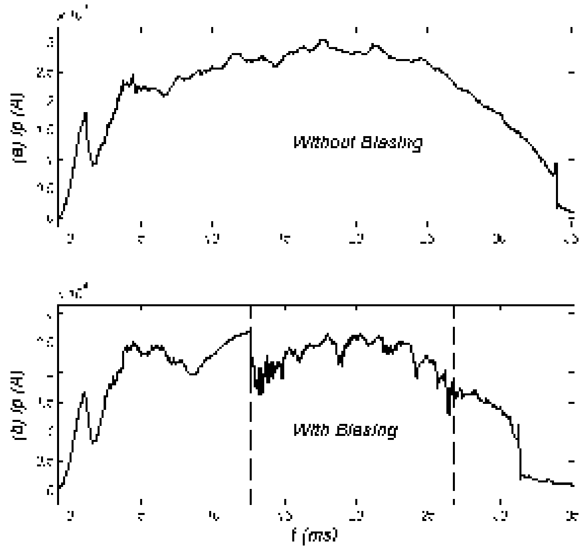

Figure (9), (a) The time evolution of the plasma current in absence of the biasing, and (b) the plasma current in presence of the positive biased limiter for $r_{Limiter} = 11.5\ \text{cm}$.

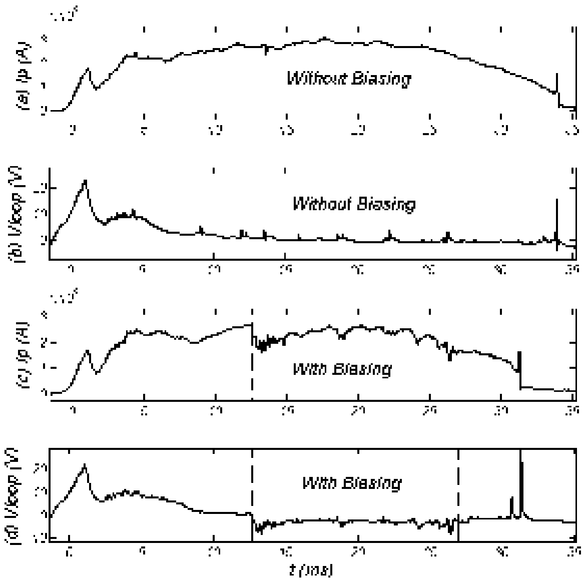

Figure (10), (a) The time evolution of the plasma current in absence of the biasing, (b) time evolution of the loop voltage in absence of the biasing, (c) the plasma current in presence of the positive biased limiter between 12.5ms-27ms, and (d) time evolution of the loop voltage in presence of the positive biased limiter between 12.5ms-27ms for $r_{Limiter} = 11.5\ \text{cm}$.

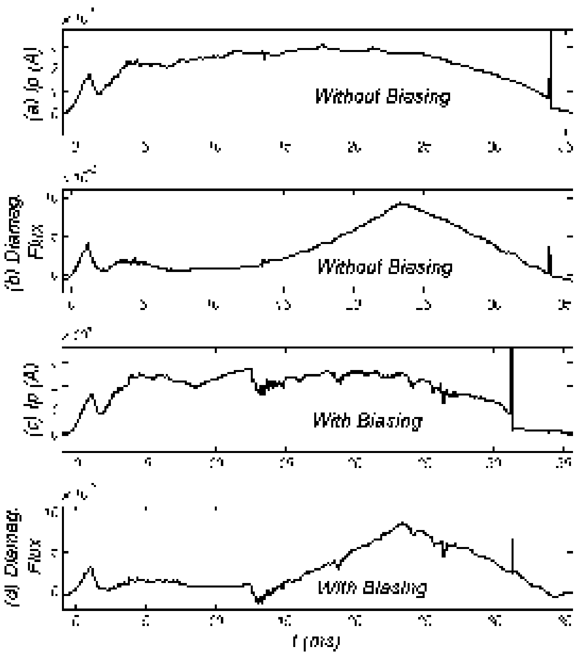

Figure (11), (a) The time evolution of the plasma current in absence of the biasing, (b) time evolution of the diamagnetic flux in absence of the biasing, (c) the plasma current in presence of the positive biased limiter between 12.5ms-27ms, and (d) time evolution of the diamagnetic flux in presence of the positive biasing between 12.5ms-27ms.

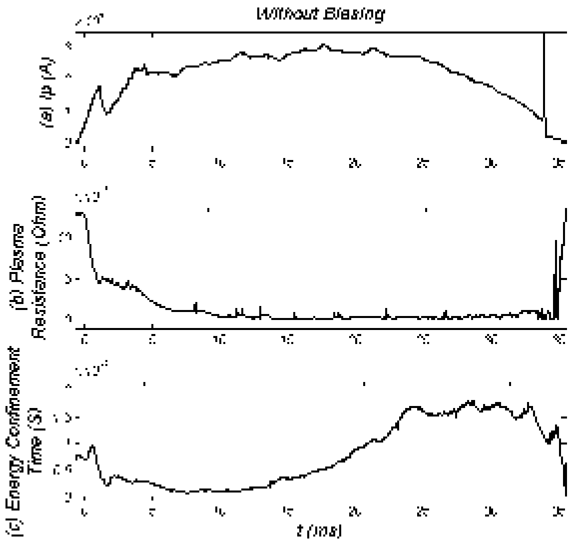

Figure (12), (a) The time evolution of the plasma current in absence of the biasing, (b) time evolution of the plasma resistance in absence of the biasing, and (c) time evolution of the plasma energy confinement time in absence of the biasing.

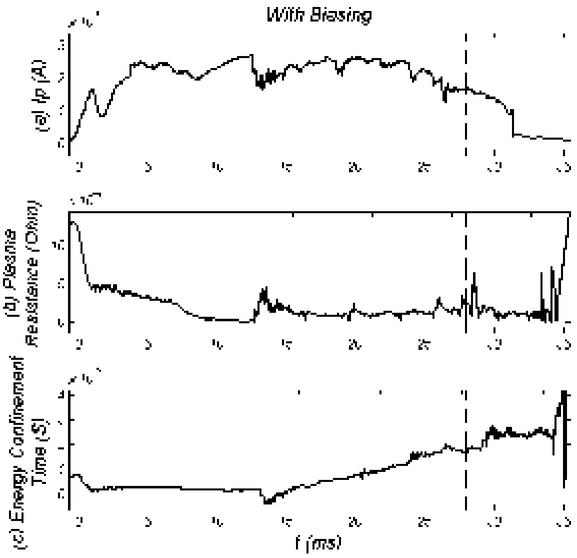

Figure (13), (a) The time evolution of the plasma current in presence of the biasing, (b) time evolution of the plasma resistance in presence of the biasing, and (c) time evolution of the plasma energy confinement time in presence of the positive biased limiter between 12.5ms-27ms for $r_{Limiter} = 11.5\ \text{cm}$.

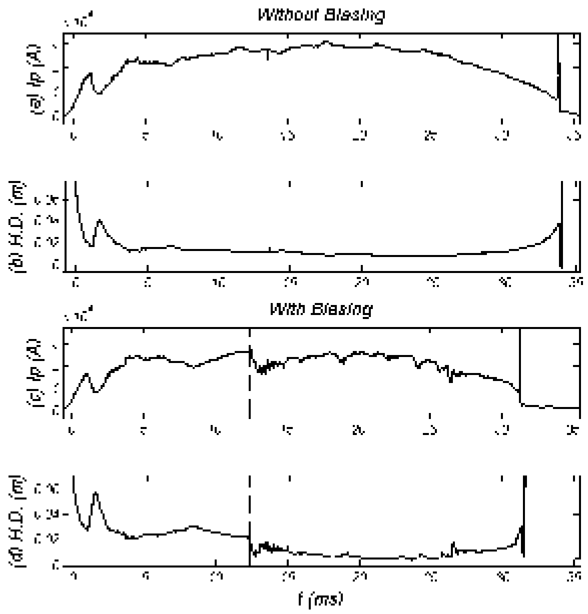

Figure (14), (a) The time evolution of the plasma current in absence of the biasing, (b) time evolution of the plasma Horizontal Displacement (H.D.) in absence of the biasing, (c) the plasma current in presence of the positive biased limiter between 12.5ms-27ms, and (d) time evolution of the of the plasma Horizontal Displacement (H.D.) in presence of the positive biasing between 12.5ms-27ms.

6. Summary and Conclusions

We presented the first results of movable limiter experiments on the IR-T1 tokamak. For this purpose we designed, constructed, and installed a movable localized poloidal limiter on the IR-T1 tokamak. Then, we measured the effects of limiter position on the time intervals of plasma parameters such as: plasma density and temperature. It is observed that by insertion of limiter 1.5-2cm past the fixed poloidal limiter into the plasma through the low field side of the tokamak, the plasma surface interactions are reduced and then plasma density and temperature increased. Also, we reported the first results of the movable limiter biasing experiments performed on the IR-T1 tokamak. For this purpose, a movable limiter biasing system was designed, constructed, and installed on the IR-T1 tokamak, and then the positive voltage applied to an limiter inserted inside the tokamak limiter and the plasma current, poloidal and radial components of the magnetic fields, loop voltage, and diamagnetic flux in the absence and presence of the biased limiter were measured. Using a movable biased limiter we have shown that improvement in energy confinement can be obtained for positive biased limiter. For this biasing an increase in the plasma resistance is observed. Due to the increase in plasma resistance, the plasma temperature also increases, leading to the increase of the plasma energy confinement time. On the other hand, this observed improvement in energy confinement time may because of modification in the edge radial electric field E_r profile. Therefore, positive bias increases significantly the magnitude of the radial electric field in the region inside the fixed limiters. Also, one of the results of improvement of particle and energy confinement is the plasma displacement which is decreased.

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