

Measurement of Safety Factor and Poloidal Beta by Design and Fabrication of Emissive Limiter Bias in IR-T1 Tokamak

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Abstract In this paper, The first results of the movable emissive limiter biasing experiments performed on the IR-T1 Tokamak are presented. For this purpose, a moveable emissive limiter system was designed, constructed, and installed on the IR-T1 Tokamak. The emissive biased limiter is positioned at $r/a=1.05$, and the biased voltage which is varied from -350 to 350 V applied between the head of emissive limiter and vacuum chamber. Then, the plasma current, safety factor, poloidal beta and plasma resistance in the absence and presence of the emissive biased limiter in negative polarity were measured and results were compared with the cold limiter biasing in negative polarity. Much more plasma parameters such as the magneto hydrodynamics instability and plasma energy confinement time are determined by using these parameters. Diamagnetic loops and loop voltage can be utilized in measurements of the plasma poloidal beta and plasma resistance. Result are compared and discussed.

Keywords Tokamak, Emissive Limiter Bias, Safety Factor, Poloidal Beta

1. Introduction

Electrostatic polarization of the plasma edge has the capacity initiate an improved energy and particle confinement regime by applying voltage between the head of the limiter and the vessel, so a radial electric field is produced and the consequent force initiates sheared flows which has a suffocating effect on turbulence. The development of the $E \times B$ shear stabilization model, which is utilized to define the formation of transport barriers in magnetic confinement devices, leads to the improvement of the confinement.

The basic physics to be used in transport reduction is the impact of $E \times B$ velocity shear on the growth, radial extent, and phase correlation of turbulence eddies in the plasma. However, it seems that the $E \times B$ velocity shears has an effect on force balance equation

$$E_r = (Z_i e n_i)^{-1} \nabla P_i - V_{\theta i} B_{\phi} + V_{\phi i} B_{\theta} \quad (1)$$

The above equation implies that there is a connection between E_r , the cross field heat and practical transport (∇P_i), cross field angular momentum transport ($V_{\phi i}$) and poloidal flow ($V_{\theta i}$), since sheared $E \times B$ flow also affect turbulence and transport[1]. The control of the shear layer is a crucial tool to modify transport in Tokamak[2-5]. According to experiments done in other Tokamak for negative

bias, no significant modification of either the global or the edge plasma parameters were observed, simply because the current drawn by the limiter was low. Consequently, an emissive limiter has to be used to develop a larger current necessary to modify confinement at negative applied voltage[6]. Measurements of poloidal beta β_p and edge safety factor q_a are important for Tokamak plasma research. Much of the plasma information such as plasma energy, plasma pressure, plasma confinement time and magneto hydrodynamics (MHD) instability can be deduced using these two parameters.

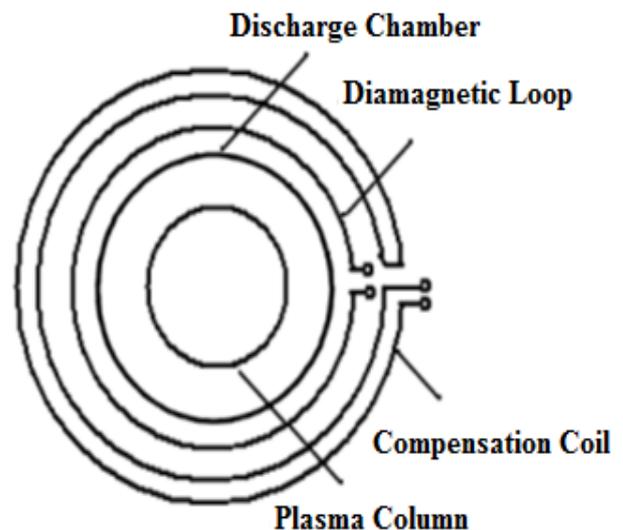


Figure 1. Diamagnetic and Compensating loops

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The relationship between the poloidal beta and the diamagnetic flux $\Delta\phi_D$ is determined as [7,8,11]:

$$\beta_p = 1 - \frac{8\pi B_\phi}{(\mu_0 I_p)^2} \Delta\phi_D \quad (2)$$

$$\Delta\phi_D = \phi_D - \phi_T - \phi_{OH} - \phi_{VF}$$

Where I_p is the plasma current, and B_θ is the toroidal magnetic field, ϕ_D is the diamagnetic signal that is measured by diamagnetic loop as shown in Figure 1. Furthermore, ϕ_T is the toroidal flux due to the toroidal magnetic field that is measured by a compensating loop as illustrate in Figure 1.

Safety factor q is one of the key parameters describing the stability of the plasma in Tokamak. The meaning of this dimensionless parameter is the number of toroidal turns it **which** takes a magnetic field line to make a single full poloidal turn. For Tokamak with circular cross-section, it is given by following formula:

$$q = \frac{rB_T}{RB_\theta} \quad (3)$$

Where r is radial coordinate along the minor radius, R is major radius, B_T is toroidal magnetic field and B_θ is poloidal magnetic field. As q has clearly a radial dependence, it is convenient to express its value at the boundary of the plasma confinement region called separatrix using the measured quantities as B_T and plasma current I_p

$$q(a) = \frac{2\pi a^2 B_T}{\mu_0 R I_p} \quad (4)$$

Assuming the constant R and B_T , the radial profile of q inside the plasma confinement region is given only by radius r and radial profile of B_θ [9,10].

2. Experimental Setup

IR-T1 Tokamak is a small circular cross-section research Tokamak ($R=0.45\text{m}$, $a_{\text{vessel}}=0.15\text{m}$) which has two stainless steel grounded fully poloidal limiters with a $r_{\text{limiter}}=0.125\text{m}$, located at Plasma Physics Research Center (PPRC). The maximum achieved plasma current is 35KA, toroidal magnetic field induction $B_T=0.8\text{T}$, the discharge time is 35ms, the mean electron density is $1.5 \times 10^{19}\text{m}^{-3}$. The experiments were performed in hydrogen. The average pressure before discharge was $2.2 \times 10^{-5}\text{Torr}$.

In order to do the experiments, an emissive biased limiter was designed and fabricated, the head of which made of an arc-shaped stainless steel with the radius of 12.5cm and the thickness, width and the height are 4mm, 20mm and 30mm, respectively. There is an element inside the limiter which can evenly raise the temperature of limiter using a separate DC power supply. The head of emissive limiter and its horizontal position inside the vessel have been illustrated in the Figure 2.

The position of emissive biased limiter is $r/a=1.05$. The applied biased voltage between head of this limiter and the vacuum chamber is in the range of -350 to 350V and the bias current is between 10 and 40A, the current of limiter heating

is 5A.

3. Experimental Results and Discussion

In this contribution we reported mainly the effect of the emissive biased limiter with negative polarity on the plasma current, poloidal beta β_p , safety factor and plasma resistance. Results compared with the cold limiter biasing in negative polarity. Figure 3 illustrates the time evolution of the plasma current and the current of biased limiter.

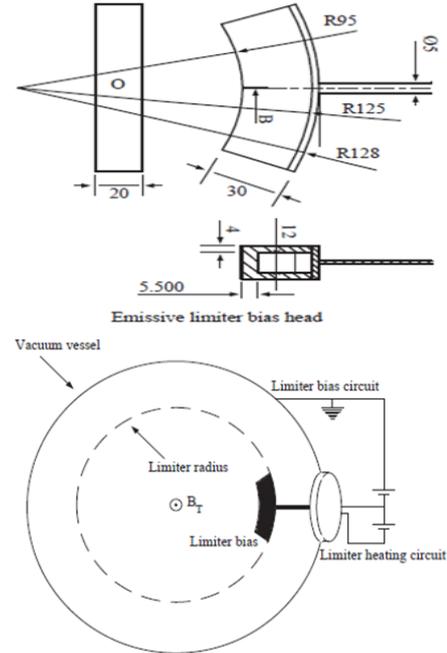


Figure 2. Top: the size of head of emissive limiter, below: schematic illustration of emissive limiter position inside the vessel

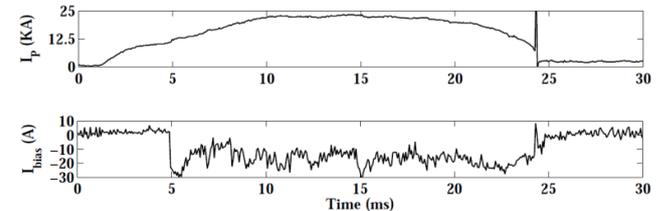


Figure 3. Time evolution of the plasma current and the biased limiter current

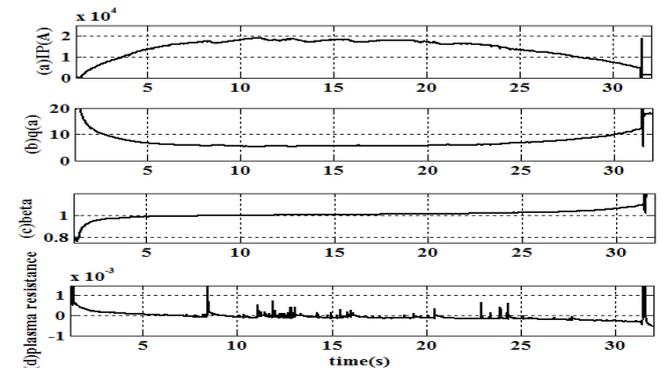


Figure 4. (a) Time evolution of the plasma current, (b) safety factor, (c) the poloidal beta β_p , (d) plasma resistance in absence of the biasing.

In Figure 4 the time evolution of the plasma current, safety factor, poloidal beta β_p and plasma resistance in absence of the biasing have been calculated and are shown.

In Figures 5 and 6, the time evolution of the plasma current, safety factor, the poloidal beta β_p and plasma resistance in the presence of the cold biased limiter and emissive biased limiter for negative applied voltage $V_{bias} = -350V$ were presented respectively. In our experiments the bias voltage is applied at 12.5 ms.

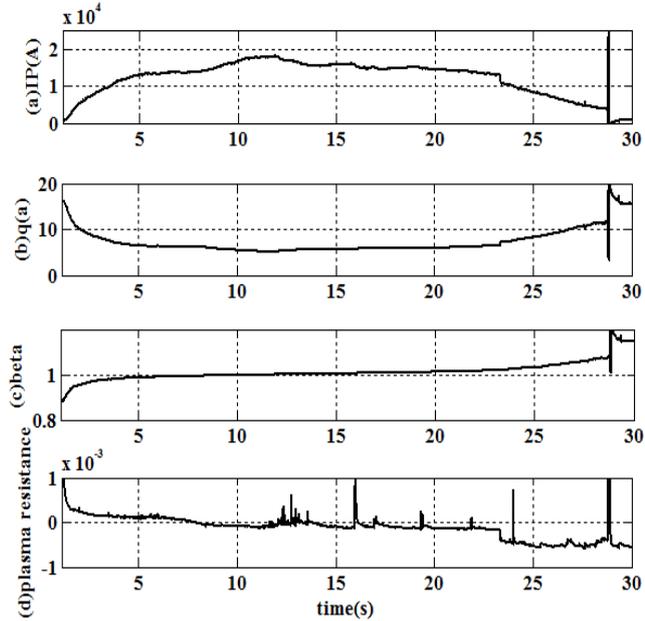


Figure 5. (a) Time evolution of the plasma current, (b)safety factor, (c) poloidal beta β_p , (d) plasma resistance in presence of negative cold biased limiter for $r/a=1.05$.

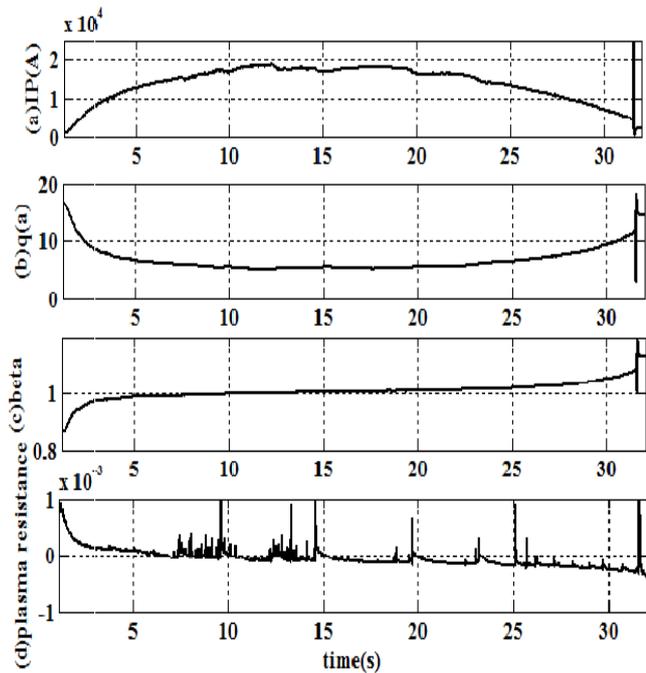


Figure 6. (a) Time evolution of the plasma current, (b)safety factor, (c)the poloidal beta β_p , (d)plasma resistance in presence of the negative emissive biased limiter for $r/a=1.05$

4. Summary and Conclutions

The first results of the moveable emissive limiter biasing experiments performed on the IR-T1 Tokamak are presented. For this purpose, a moveable emissive limiter system was designed, constructed, and installed on the IR-T1 Tokamak. Then, the negative voltage applied to an emissive limiter inserted inside the Tokamak fixed limiter and the plasma current, safety factor, poloidal beta β and plasma resistance in absence and presence of emissive limiter biased for negative polarity, were measured. Results compared with the cold limiter biasing in negative polarity. The position of emissive biased limiter is $r/a=1.05$.

As we expected and the results of IR-T1 Tokamak show, in emissive negative polarity, time duration of plasma current increased. Besides, plasma current in this polarity is more uniform compared to no bias polarity. Comparison of 7-8-9 figures that are related to the expansion of q profile in flat region of plasma current, for no bias, cold negative, emissive negative polarities, respectively, show that q increased to 5.8 in cold negative polarity and decreased to 5.2 in emissive negative polarity.

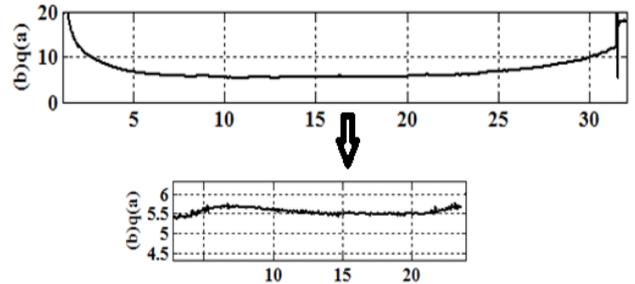


Figure 7. expanded of safety factor profile in absence of the biasing

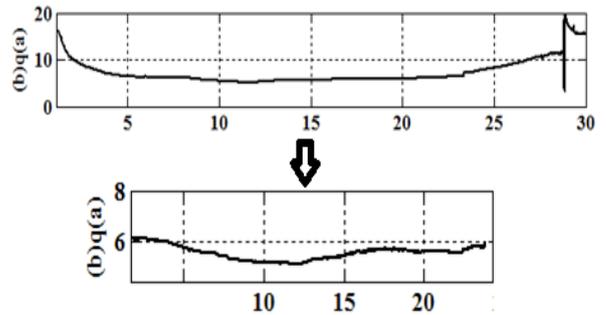


Figure 8. expanded of safety factor profile for cold limiter biased in negative polarity

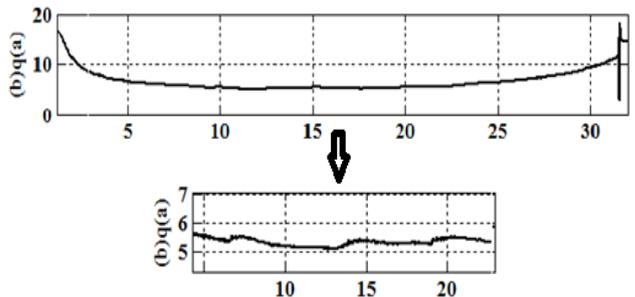


Figure 9. expanded of safety factor profile for emissive limiter biased in negative polarity

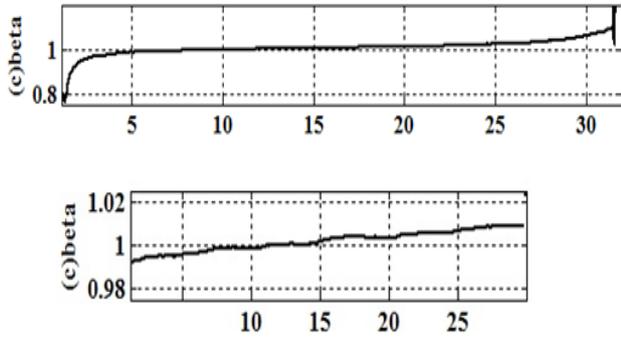


Figure 10. expanded of beta profile in absence of the biasing

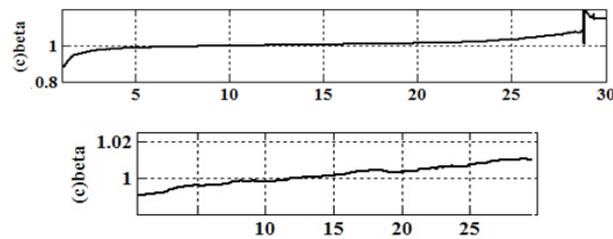


Figure 11. expanded of beta profile for cold limiter biased in negative polarity

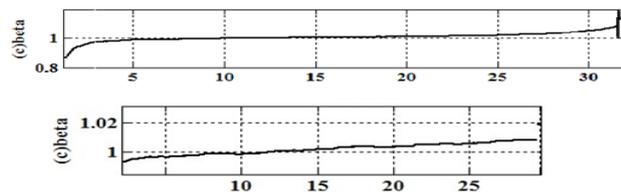


Figure 12. expanded of beta profile for emissive limiter biased in negative polarity

Figures 10-11-12 that are related to expanded of β profile in flat region of plasma current, for no bias, cold negative, emissive negative polarities, respectively, show that cold and emissive limiter biasing for negative polarity have no effect on it.

Figures 13-14-15 that are related to expanded of plasma resistance (R) in flat region of plasma current, for no bias, cold negative, emissive negative polarities, respectively, show that amplitude and fluctuation of this parameter, decreased in cold negative polarity and increased in emissive negative polarity compared to no bias polarity.

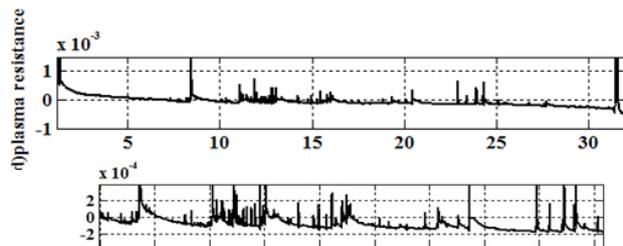


Figure 13. expanded of plasma resistance in absence of the biasing

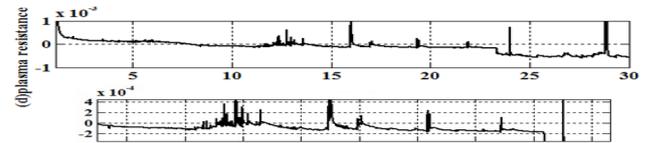


Figure 14. expanded of plasma resistance for cold limiter biased in negative polarity

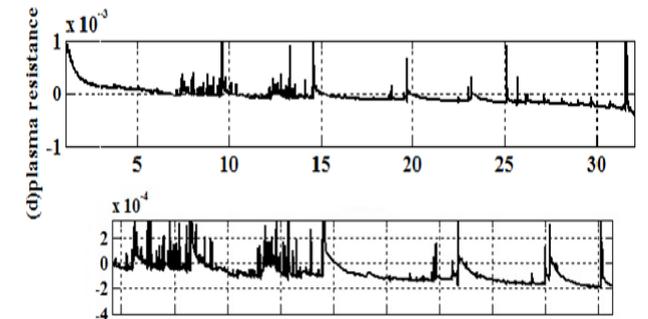


Figure 15. expanded of plasma resistance for emissive limiter biased in negative polarity

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