Dual-Electrode Biasing Experiments in KT-5C Device

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ABSTRACT

Based on the single biasing electrode experiments to optimize the confinement of plasma in the device of KT-5C tokamak, dual-biasing electrodes were inserted into the KT5C plasma for the first time to explore the enhancement of the effects of biasing and the mechanisms of the biasing. By means of applying different combinations of biasing voltages to the dual electrodes, the changes in E_r, which is the key factor for boosting up the Er×B flow shear, were observed. The time evolution showed the inner electrode played a major role in dual-biasing, for it always drew a larger current than the outer one. The outer electrode made little influence. It turned out that the dual-biasing electrodes were as effective as a single one, in improving plasma confinement, for the mechanism of biasing was essentially an edge effect.

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Introduction

The Er×B shear flow stabilization model to explain the formation of edge transport barrier in the tokamak plasma has been developed and proved very successful since the last decade .[1] By shear decorrelation, the sheared poloidal $\mathbf{E_r} \times \mathbf{B}$ flow can effectively suppress the plasma turbulence and improve the confinement.[2] Many mechanisms in the generation of the poloidal sheared flow have been proposed, including Reynolds stress,[3-5] external biasing,[6-9] and others [12-16]. The relationship between the poloidal $\mathbf{E_r} \times \mathbf{B}$ sheared flow and all these mechanisms is given by

$$m_i n_i \left(\frac{\partial \bar{u}_i}{\partial_t} + \bar{u}_i \cdot \nabla \bar{u}_i\right) - \frac{1}{n_i}(\bar{J} \times \bar{B}) = -\frac{\nabla \cdot \vec{p}_\alpha}{n_i} - m_e n_e \left(\frac{\partial \bar{u}_e}{\partial_t} + \bar{u}_e \cdot \nabla \bar{u}_e\right)$$

For example, the external biasing can be put into the second term of the equation. The development of methods to control the sheared $\mathbf{E_r} \times \mathbf{B}$ flows is considered to be a key issue in the control of plasma turbulence and the optimization of plasma confinement. Therefore in such experiments, the radius electrical field $\mathbf{E_r}$ is an essential factor for the $\mathbf{E_r} \times \mathbf{B}$ flow shear effects to be observed.

The first biasing experiment was reported by Taylor in 1989.[7] We also have reported our single biasing work on our tokamak KT-5C.[9-11] Of all these experiments only one electrode was used.[6,17,18] However, how would the Er have been changed if two electrodes were used? What differences might dual electrodes make? Could there be a stronger influence?

Let us first show some typical results of the single biasing on KT5C with the following parameters: R=32.5cm , a=8.5cm, I_p=10kA, B_ϕ=0.45T. Several sets of triple Langmuir probes are used to provide simultaneous and local measurements of the plasma conditions. A RFEA (Retarding field energy analyzer) is also used for getting the ion temperature. Figure 2 shows the radial profiles of the measured electron density n_e, electron temperature T_e and plasma potential f_p as well as of the radial electric field E_r derived from the f_p profile before and during the single positive biasing. In Fig.2 (a) and (b), one can see that the biasing causes a decrease in n_e and T_e over a broad edge region, and steepens their profiles in a narrow layer inside the limiter. The gradient of the radial ion temperature is also enlarged at the edge due to the biasing as shown in Fig 3. The biasing also induces a pronounced change in the plasma potential profile as shown in Fig.2(c) and (d), the plasma potential before the biasing peaks in the proximity of the limiter radius, which leads to a naturally spontaneous occurring E_r gradient layer where a small E_r well occurs which can been explained by ion-orbit loss. With the biasing, the plasma potential rises significantly over a wide edge region and its radial variation changes so that a modest E_r hill is developed. Fig.4 shows the radial profiles of the fluctuation levels given by the root-mean-square values. It exhibits the absolute fluctuation levels of n_e and T_e are reduced during the biasing, which indicates that the $\mathbf{E_r \times B}$ flow shear is effective in fluctuation suppressing.

The floating potential fluctuations could increase at the edge region, which indicates that the absolute potential fluctuation level could have different behavior in responding to the biasing induced change in E_r, as compared with the response of $\tilde{n}_e\ and\ \tilde{T}_e$. So for simplicity, in the following experiments, we will emphasize the change of the key parameter E_r.

Dual-biasing experiments and the results

We began our work using dual-electrode biasing in the ohmically heated H_2 plasma in the KT-5C tokamak with parameters shown above. The two electrodes (stainless steel discs, 2cm in diameter and 0.4cm in thickness) were positioned at the place of r=3cm and r=7cm from the bottom of the device(Figure 1). The biasing voltages were supplied by two charged capacitor banks of 220uf×100 each through the thyristor switches. All the data were sampled at 1MHz by a multichannel 12-bit digitizer.

We performed several sets of dual-biasing experiments with different biasing voltage combinations to the two electrodes (Table 1).

Figure 5 shows the probe floating potential V_f profiles for set B, whose biasing configurations prove to be most effective in dual-biasing. It could be noted that there is only a little difference between inner electrode negative biasing (I_N), and inner electrode negative biasing together with outer electrode positive biasing (I_N_O_P).

Moreover, while the two electrodes are biased as I_N_O_P or I_P_O_N, the profiles of V_f between the two electrodes do not show much difference. The outer electrode seems to be shielded and has very little effect when the inner one is biased.

To explore this phenomenon more clearly, we observed firstly the time evolutions of the floating potential of different biasing. Figure 6 shows the floating potential changes due to single biasing almost instantaneously when positive biasing was applied; while it would change slower if negative biasing was imposed. That probably is due to the electrons responding to the positive biasing much faster than the ions to the negative biasing.

Fig.7 and Fig.8 show the time evolutions of the dual-biasing signals.

In Figure 7 in which I_N_O_P was imposed, when the outer electrode positive voltage V2 was applied, its current I2 changed almost immediately, while the inner electrode negative voltage V1 and current I1 changed much slower about 100μs later. The changes in floating voltage V_f and the resultant radial electrical field E_r actually obeyed the slower changes as the inner negative biasing, which demonstrated that the inner electrode played a dominant role.

While in Figure 8 with I_P_O_N, the inner positive V1 and I1 showed the same quick response. But with the outer negative, I2 was flat at the beginning, when the inner positive biasing was on, I2 fell to zero rapidly. This phenomenon again demonstrated that the inner positive electrode prevailed over the outer one. In brief, the dual electrode-biasing acts very similarly as single biasing in our dual biasing experiments

In the electrode biasing of most cases for set B, the edge E_r profiles changed significantly (Figure 9). The edge E_r trough was enlarged by negative bias, and reduced by positive biasing however a peak at a little inner radial position would occur. Both of them showed an enlarged Er gradient.

In fact, it was the inner electrode which always drew a larger current than the outer one as shown in table 1 and Figs.7 and 8. And the more current it drew, the more influence on the V_f and consequently the E_r it exerted. It was the electrode current rather than the biasing voltage that produced the enhanced E_r gradient and boosted up the $\mathbf{E_r \times B}$ flow shear effects on the plasma edge.

Conclusion

In conclusion, two separated biasing electrodes have been installed in the KT-5C tokamak to modify the radial electrical field E_r. When various combinations of biasing voltages are applied, the result is similar to the single electrode biasing. Neither single biasing nor dual-biasing electrode could hardly change the radial electrical field E_r in the interior of the plasma. The outer electrode seems almost to be shielded when the inner one is on. These results indicate that the mechanism of enhanced E_r gradient which implies the enhanced $E_r \times B$ flow shear by external biasing is intrinsically an edge effect due to the electrode induced current. A positive biasing seems to be more appreciated since it causes a larger electrode current.

After having finished the above experiments and during the period of summarizing our dual-electrode biasing work and writing the reports, we noticed interestingly by chance a theoretical work published recently by Kasuya and Itoh et al [19]. The paper proposes dual-electrode biasing, and predicts that a double-peaked E_r structure (which means stronger shear) could be created if the applied dual biasing voltages ramp up within a certain rate. In our experiments reported above we did not get the double-peak E_r, which might be due to the different experimental settings and conditions. But, it is really an intriguing issue that we would investigate in our future work.

Acknowledgements

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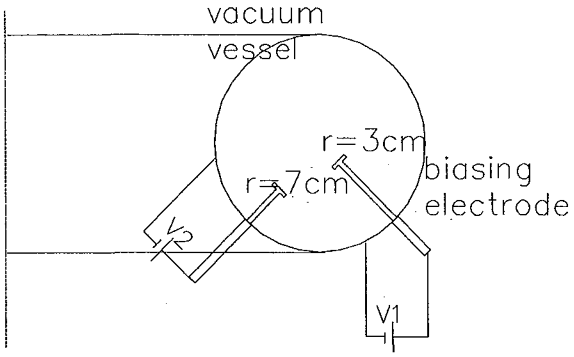

Fig.1. Setting of the dual-electrodes

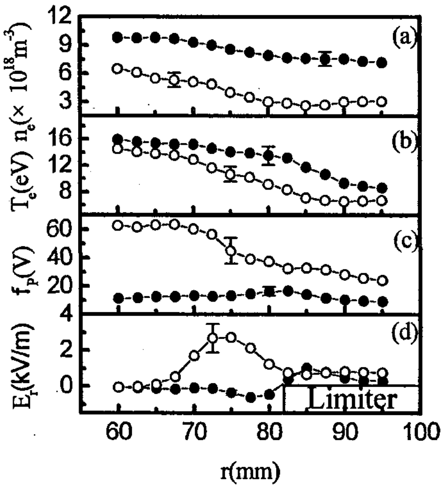

Fig.2. Radial profiles of the measured electron density, Electron temperature, plasma potential and radial electrical field

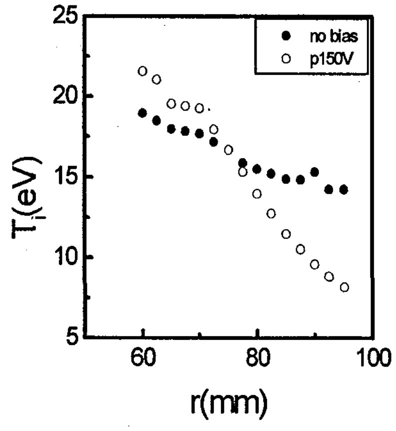

Fig.3. The radial profile of the ion temperature

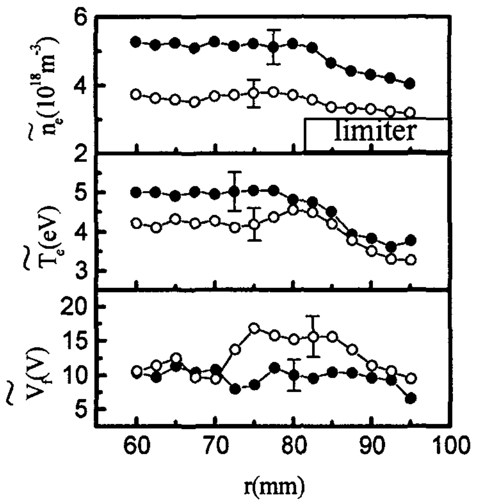

Fig.4. The radial profiles of the fluctuation levels

Set	$V_1(v)/I_1(A)$	$V_2(v)/I_2(A)$	mark
A	——	——	NB(No Biasing)
	+150/—	——	I_P(Inner Positive)
	——	+200/55	O_P(Outer Positive)
B	——	——	NB
	−200/120	——	I_N(Inner Negtive)
	−200/120	+200/90	I_N_O_P
	+200/150	−200/<10	I_P_O_N
C		——	NB
		+200/<10	I_P_O_N
		−200/45	I_N_O_P

Table 1. Different combinations of dual-biasing voltages

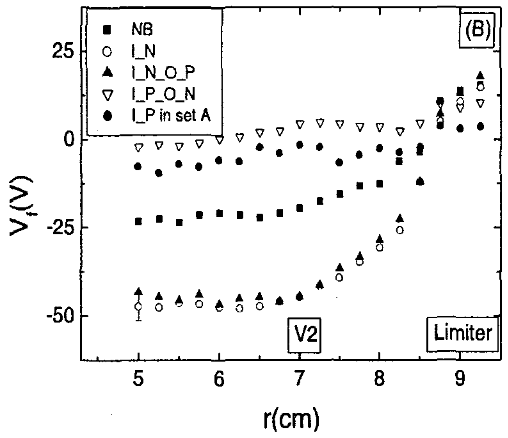

Fig.5. Profiles of V_f in Set B

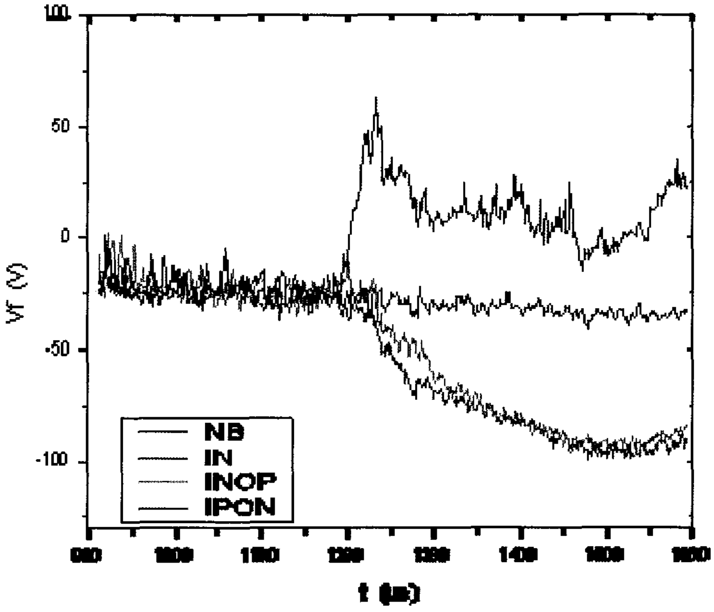

Fig.6. The time evolution of V_f

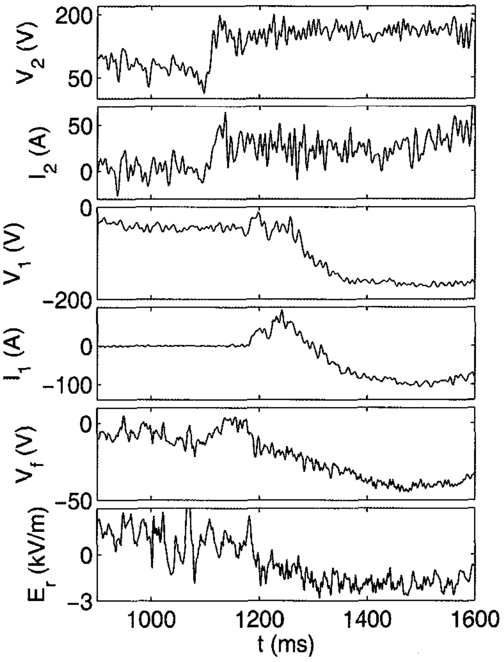

Fig.7. The time evolution of INOP in Set b

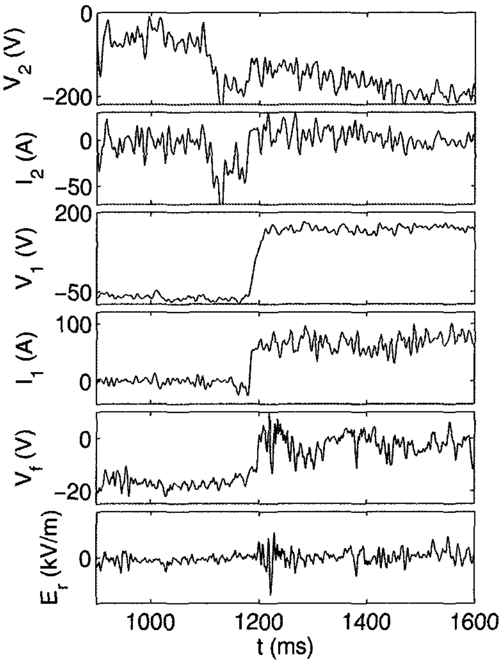

Fig.8. The time evolution of IPON in Set B

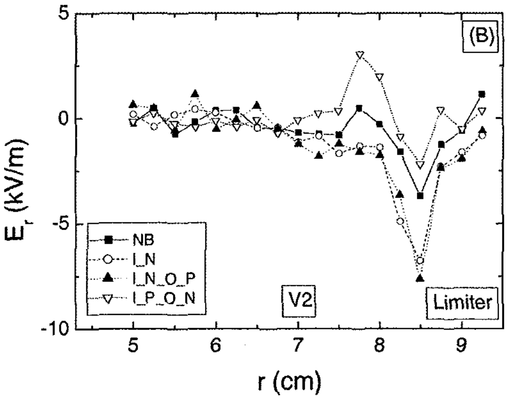

Fig.9. Profiles of Er at various biasing conditions in Set B