ELSEVIER

Journal of Nuclear Materials 241-243 (1997) 338-341

journal of nuclear materials

Scrape-off layer broadening by the $E \times B$ convective cell induced by non-axisymmetric divertor biasing

Junichiro Hara [a,*], Yoshihiko Uesugi [a,b], Yukitoshi Miura [c], Hisato Kawashima [c]

[a] Department of Energy Engineering and Science, Nagoya University, Nagoya 464-01, Japan
[b] Center for Integrated Research in Science and Engineering, Nagoya University, Nagoya 464-01, Japan
[c] Japan Atomic Energy Research, Institute, Naka Fusion Research Establishment, Naka 311-01, Japan

Abstract

The effective divertor heat-load relaxation using $E \times B$ induced convective cells in the SOL is studied. The $E \times B$ convective cells in the SOL are generated by the toroidally asymmetric divertor biasing, which can control the local plasma potential in the SOL. The preliminary experiment is done in the JFT-2M tokamak with poloidal divertor. The helical SOL current flows along the magnetic field between the locally biased inboard plate and grounded outer plates, thereby modifying plasma potential in the vicinity of the current flows. The poloidal distribution of the plasma potential in the SOL measured by Langmuir probe array shows that the localized potential structure is generated by the non-axisymmetric divertor biasing with the poloidal electric field reaching up to 1.5 kV/m is generated locally. In addition to the generation of a localized poloidal electric field, the modification of the heat flux profile on the divertor plate is also observed.

Keywords: JFT-2M; SOL plasma; Divertor plasma; Biasing; Electric potential and current

1. Introduction

As a way of particle and heat flux control onto the divertor plate, the ergodic magnetic limiter and divertor biasing schemes have so far been studied [1-4]. These methods modify the magnetic and/or potential structures in the edge plasmas, including SOL plasmas. To broaden the particle and heat fluxes onto the divertor plate using $E \times B$ convective flow, an externally generated poloidal electric field can be employed. Using this unidirectional $E \times B$ flow, the active control of the helium ash exhaust from the divertor region and the impurity retention has been investigated in several tokamak devices [5,6]. The divertor biasing can generate radial and poloidal electric fields in the SOL, which can induce the $E \times B$ particle flow across the magnetic field. The radial biasing experiments are intended to generate the large radial electric field and to induce the poloidal flow which significantly modifies the poloidal particle transport. In the JFT-2M tokamak, this preliminary experiment is for the first time to induce the convective cells into the SOL plasmas and the transport modification in the SOL by non-axisymmetric divertor biasing.

The basic idea of convective cell formation by local divertor biasing will be explained in Section 2. Experimental results on the SOL and divertor plasmas modification by induced $E \times B$ convective flow caused by the local divertor biasing in JFT-2M will be presented in Section 3. The results will be discussed in Section 4, and conclusions drawn in Section 5.

2. $E \times B$ convective cells generation and its effect on the radial transport

In the open field line region, such as SOL and divertor plasmas, charged particles flow mainly along the magnetic field line and consequently the SOL width and divertor heat load profile become very narrow. The SOL width is

* Corresponding author. Tel.: +81-52 789 5429; fax: +81-52 789 3944; e-mail: j-hara@echo.nuee.nagoya-u.ac.jp.

PII S0022-3115(96)00525-9

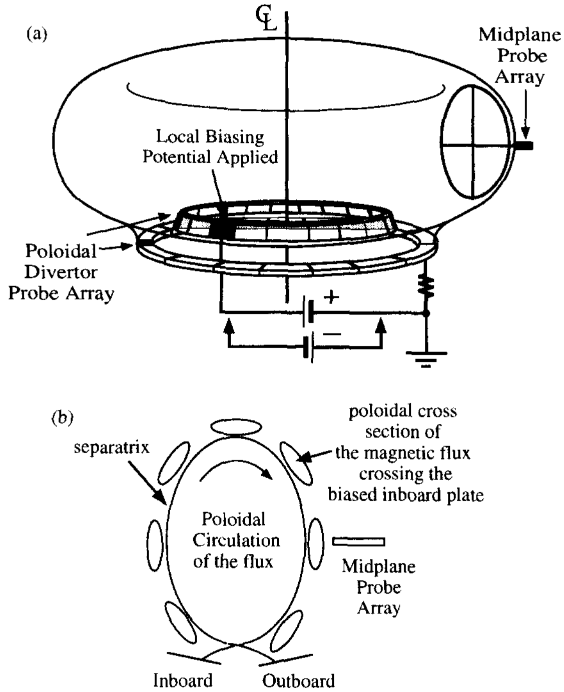

Fig. 1. Schematic diagram of the experimental apparatus in the JFT-2M (a) and the poloidal circulation of the biased magnetic flux on the poloidal section of the tokamak (b).

simply given by the particle balance in the parallel and perpendicular direction as [7]:

$$\lambda_{SOL} = \left(\frac{2 D_\perp C_S}{L} \right)^{1/2} \tag{1}$$

where $D_\perp$, L and C_S are the radial diffusion coefficient, the connection length between the stagnation point and one of the divertor plates and the ion sound speed, respectively. When the unidirectional radial particle flow in the SOL is induced, the modified SOL width is given by

$$\lambda_{SOL} = \frac{v_\perp}{C_S} L + \left\{ \left(\frac{v_\perp}{C_S} L \right)^2 + \frac{2 D_\perp L}{C_S} \right\}^{1/2} \tag{2}$$

where $v_\perp$ is induced perpendicular (radial) particle flow. Eq. (2) shows that the unidirectional radial flow strongly modifies the SOL width if $v_\perp \geq (2 C_S D_\perp / L)^{1/2}$. In the conventional divertor biasing, the induced radial flow is not large enough to broaden the SOL and divertor plasma width since the generated poloidal electric field is usually weak [5].

There is a more effective convective flow generation method, the so called convective cells (CCs) method [8]. Since the CCs transverse the magnetic field in the poloidal cross section, $E \times B$ convective flow circulates in the CCs. Owing to the SOL plasmas circulation, a plasma particle has a large radial step size between collision with an ion and/or neutral particles when the CCs are larger than the ion Larmor radius. Rough estimates show that the perpendicular electric field about 2 kV/m inside the convective cell will modify the SOL transport. As a result, the SOL width expands and the radial particle diffusion is expected to increase more than the Bohm diffusion.

The convective cells in the SOL are induced by the non-axisymmetric electric potential structure [9–14]. We induce the asymmetry of the plasma potential structure in the SOL by the local divertor biasing method. In Fig. 1 a configuration of the local divertor biasing and a schematic view of the induced $E \times B$ convective cells are shown. The positive and negative biasing voltage is applied to one of the electrically isolated inboard plates, and all the outboard divertor plates are grounded. In this configuration the divertor current flows helically along the magnetic field, and the induced potential profile must be affected directly by the helical structure of the tokamak magnetic field. The poloidal structure of the induced plasma potential in the SOL is obtained using a midplane Langmuir probe array by changing the biased plate in the toroidal direction shot by shot.

3. Experimental results

In JFT-2M, both inboard and outboard poloidal divertor plates consist of 14 graphite plates, which are electrically isolated and can be biased individually. In the experiment, the biasing voltage is applied to neighboring two plates among the 14 inboard divertor plates while other plates are floating. All the outboard plates are grounded. When the local divertor biasing (LDB) is applied, the helical SOL current flows from the biased inboard plate to the outboard one through the SOL plasma. Fig. 2 shows a toroidal distribution of the SOL current flowing into the outboard-plates. The magnetic field lines that cross the biased inboard plates are numerically traced. As a result, the toroidal distribution of the divertor current shown in Fig. 2

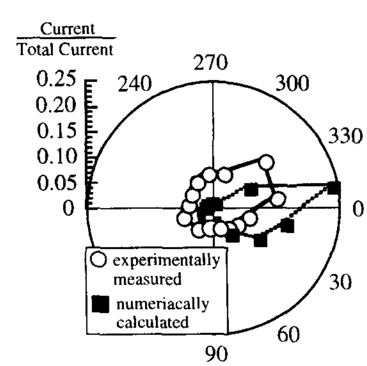

Fig. 2. Comparison of the helical SOL current toroidal distribution on outboard plates.

roughly agrees with that obtained by the field line tracing and 1D SOL current calculation [15].

The poloidal electric field (E_p) is measured by a mid-plane probe array. Fig. 3 shows a measured poloidal variation of the E_p. The poloidal variation is obtained by changing the location of the biased plates toroidally. Before the biasing voltage is applied, the poloidal variation of E_p is small. But during divertor biasing applied the E_p has a periodical structure in the poloidal direction, which means that the plasma potential is strongly changed where the magnetic field line connects with the biased plates. In short, controlled plasma potential on the local magnetic flux is achieved by the LDB. In this experiment the maximum E_p up to 1.0 kV/m is observed in the case of + 120 V biasing and the corresponding $E \times B$ drift velocity is about 1.2 km/s.

The transport modification due to the $E \times B$ convective cells' formation is strongly related to both the magnitude of the induced electric field and its two-dimensional scales in the poloidal cross-section. Although we have not obtained two-dimensional structures of the induced E_p so far, we think that a relatively large scale convective cell might be induced by the present LDB experiment because of the SOL current broadening due to the magnetic shear effect and cross field diffusion. Besides the asymmetric E_p generation in the SOL, we have observed a significant change of the heat flux onto the divertor plates. As mentioned before, the LDB mainly modifies the plasma potential in the SOL where the magnetic field lines connect with the biased inboard plates. This asymmetry of the potential structure might be extended to the divertor plasmas. Fig. 4 shows the poloidal profiles of the electron temperature, the ion saturation current and the calculated heat flux onto the divertor plates that are connected with the biased inboard plates by the magnetic field. A significant modification of the electron heat flux can be seen when the biasing voltage is applied. On the other hand, we have not observed such a large change of the electron heat flux onto other divertor plates which have no field line connection to the biased inboard plate.

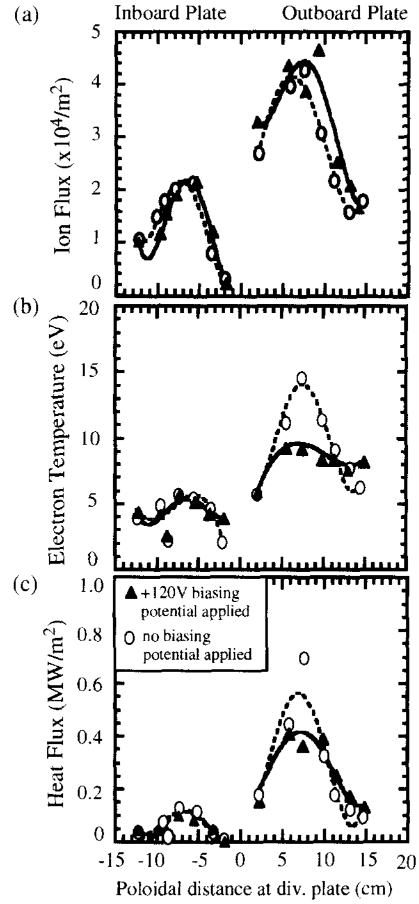

Fig. 4. Poloidal profile divertor plasma parameter versus ion flux (a), electron temperature (b) and heat flux onto divertor plate (c).

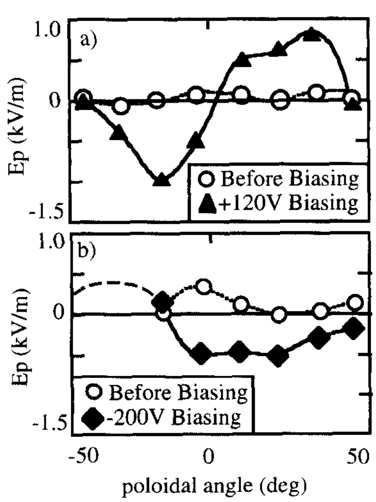

Fig. 3. Poloidal profile of the poloidal electric field in + 120 V (a) and − 200 V (b) biasing modes measured by the midplane Langmuir probe array.

4. Discussion

The tokamak magnetic field configuration has a shear structure with minor radius. Although the biasing voltage is applied locally to a specific inboard plate, the magnetic shear in the SOL broadens the magnetic flux tube and degrades the locality and helical symmetry of the electric field generation. The magnetic field line tracing shows that despite the area of the plate biased is just one seventh of the total area of inboard plates in the toroidal direction, the magnetic flux tube connecting with the biased inboard plate spreads roughly over half of the outboard plates. This spread must reduce the magnitude of the induced electric field and create a complicated $E \times B$ convective cell structure.

The present local divertor biasing can generate the non-axisymmetric electric potential and induce the local $E \times B$ convective cells, which are expected to modify the local particle and heat transport. These non-axisymmetries and locality of the particle and heat flux onto the divertor plates can aggravate the problem of the heat removal from the divertor plates. To improve the uniformity of the heat load profile on the divertor plates, the rotating biasing in the toroidal direction can be applied. In this method, locality of the heat load might be averaged out in time. When we use the rf power source and rf antenna instead of the dc power supplies to induce the $E \times B$ convective cells, the direct energy input to the SOL plasma from a biasing power supply may be reduced [9,11].

5. Conclusions

The generation of the $E \times B$ convective cells by non-axisymmetric divertor biasing and its effect on the particle and heat transport in the SOL are discussed. To generate the CCs in the SOL, a poloidally asymmetric structure of the plasma potential needs to be generated. For the purpose of the asymmetric potential generation in the SOL, we have studied the local divertor biasing (LDB) method. In the LDB method, the local divertor current flows helically through the SOL plasma and the plasma potential profile on the local magnetic flux where divertor current flows are modified. In the preliminary experiment on JFT-2M, it is observed that the plasma potential on the local magnetic flux connected to the biased inboard plates by the magnetic field is controlled and affected strongly by the LDB. Significant modification by the LDB application is also observed in the electron heat flux onto the divertor plate.

Acknowledgements

The authors would like to thank Dr. S. Takamura and Dr. N Ohno (Nagoya University) for many useful discussions. We are deeply indebted to the JFT-2M group for their help in our experiment.

References

[1] T. Shoji et al., JAERI-memo 06-181 (1993) 10–16.
[2] S. Takamura, Phys. Fluids B 2 (1990) 1947–1948.
[3] R.R. Weynants and G. von Oosts, Plasma Phys. Controlled Fusion 35 (1993) 177–189.
[4] H. Tamai et al., IAEA-CN60/A-1-II-3 53–92.
[5] M.J. Schaffer et al., Nucl. Fusion 35 (1995) 1000–1007.
[6] C.C. Klepper et al., Nucl. Fusion 33 (1993) 533–545.
[7] P.C. Stangeby, Phys. Plasma–Wall Interaction Controlled Fusion B 131 41–97.
[8] R.H. Cohen and D.D. Ryutov, Division of Plasma Physics APS Meeting Department (1995).
[9] R. Van Nieuwenhove et al., Fusion Eng. Des. 12 (1990) 231–235.
[10] B. LaBombard and B. Lipschultz, Nucl. Fusion 27 (1987) 81–98.
[11] G. Li et al., Nucl. Fusion 34 (1994) 659–664.
[12] D.A. D'Ippolito and J.R. Myra, Phys. Fluids B 5 (1993) 3603–3617.
[13] A.V. Nedospasov et al., Nucl. Fusion 25 (1985) 21–27.
[14] H. Otsuka and the JT-2M group, Nucl. Fusion 33 (1993) 523–531.
[15] A.V. Chankin, J. Nucl. Mater (1996), submitted.