CHARACTERISTIC BEHAVIORS OF DIVERTOR SCRAPE-OFF PLASMA IN THE TPE-2M REVERSED FIELD PINCH*

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Abstract. The divertor discharge of reversed field pinch (RFP) has been studied in TPE-2M (R/r = 0.87m/0.27m). The characteristic behaviors of divertor plasma and its effects on the core plasma are investigated by visible spectroscopy and probe measurements. The observed ion density profile at the divertor plate surface is rather smoothed out to a single hump possibly due to the particle scattering by a large amplitude fluctuation (around 15 %) of magnetic field in the open shell (divertor) region. An anomalous particle loss through the X-point region is suggested. The discharge depends on the position of X-point; when it locates near the plasma surface, the plasma may be less stable and the discharge terminates earlier presumably because the shell proximity of the core plasma surface is deteriorated. In this case, a large-amplitude, sometimes burst-like, fluctuation, is seen. The edge behaviors of core plasma in the shell region are less sensitive to the divertor field.

1. Introduction

The divertor discharge of reversed field pinch (RFP) has been studied in TPE-2M (R/r=0.87m/0.27m) [1]. The global stability and the divertor action of particles had already been observed. A slight reduction of metal impurities and enhancement of toroidal loop voltage were observed [2, 3]. In the present series of experiment, the characteristic behaviors of diverted plasma are investigated. Here, wall conditioning is newly exploited to reduce the neutral gas effect on PWI. To check the shell proximity of plasma surface in the experimental condition of shell with the axisymmetric poloidal cut, the MHD equilibrium configuration is also analyzed by a numerically fitting technique. The density profile of effused plasma on the divertor plate surface is measured by multi-Langmuir probes. Spectroscopic observation is also made for the divertor scrape-off and edge plasmas. Their behaviors are compared with a tokamak divertor discharge in a certain case. Some discussions are given on the relation of the divertor plasma profile and a high level magnetic fluctuation near the X-point.

2. Device Structure and Wall Conditioning

The cross-sectional view of the vacuum vessel, shell and coil assembly is shown in FIG. 1. The engineering aspect of setting up RFP is described in [4]. The aluminum stabilizing shell of circular cross-section (0.28m in I.D. and 20 mm thick) with an axisymmetric poloidal cut (approx. 18 degrees) is installed in the rectangular SUS vacuum vessel (10/20 mm thick, no cut in the poloidal direction) to ensure both a good shell-plasma surface proximity and a diverting space. The divertor plasma and the edge plasma of main core are measured mainly by Langmuir probes. Other diagnoses are the visible spectroscopy, soft X-ray radiation and the magnetic search coils on the shell inner surface.

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In order to reduce the effect of neutral gas on the divertor plasma and its interaction with the divertor plate surface, the inner wall surface of vacuum vessel including the divertor plate surface and the outer surface of shell are activated by titanium evaporation in the present experiment. The discharge D2 gas is injected by a fast acting puff with an intense glow discharge pre-ionization, instead of a slow puffing and an electron emitter pre-ionization. Besides, the inner surface of shell is boronized by mixed discharge of trimethyl-boron and helium gases. The boronization is very effective to suppress the impurity contamination of especially oxygen and aluminum in the setup phase, and leads to the overall enhancement of plasma conductivity [5]. Both titanium gettering and boronization reduce the outgas rate of surface and hence reduce the base pressure almost by a half. Titanium gettering is only effective for several shots, but boronization for a few tens shots. Both are successfully exploited in this series of experiment.

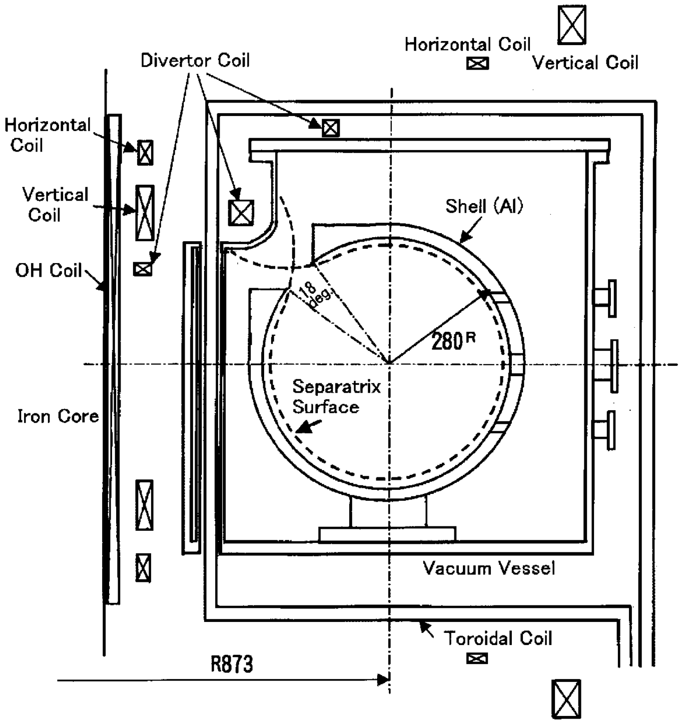


FIG. 1. Cross-sectional view of V/V, shell and coils of the divertor RFP, TPE-2M.

3. Experimental Results

3.1 General Properties of Discharge

After these processes, the experiment is carried out typically with a plasma current of 50-70 kA and the duration of around 5 ms, with the loop voltage of 100 V. The duration is limited usually by the volt-second capacity of OH circuit, however, the discharge terminates earlier in some cases, presumably due to the uncompensated horizontal and vertical error fields caused by the position of shell cut angle. To alleviate it, the external DC horizontal and vertical fields are elaborately added as well as the pulsed vertical field. The effect of pulsed field is significant especially at the toroidal cut of vacuum vessel.

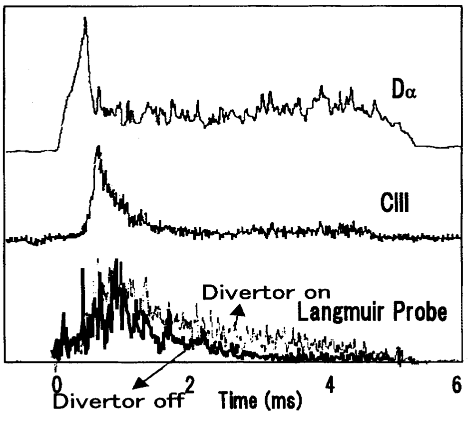


FIG. 2. Top:Dα, middle:CIII lines of the divertor scrape-off plasma seen from the oblique port, and bottom:probe current at the middle position of divertor plate.

Typical signals of Dα and CIII (464.7nm) lines seen from an oblique port and of the Langmuir probe on the divertor plate surface are shown in FIG. 2. Comparing with those of non-divertor discharge, intensities are nearly the same at the beginning of the discharge just after the setup. This may be caused by a burst of plasma particles effused out from the main plasma to the divertor region through the open shell portion, when the RFP magnetic configuration sets up. However, intensities of probe signal and line intensities at the later stage are larger in the divertor operation. In FIG. 3, profiles of ion saturation current of probe are plotted. The divertor effect is evidently seen in this divertor configuration. Although the data are largely scattered, the observed density profile is not doubly peaked, but rather smoothed to a single hump, which seems unexpected in the present divertor magnetic field configuration. It may be due to particle scattering by a large amplitude fluctuation (around 15 %) of magnetic field in the divertor region and the strongly curved shape of divertor plate.

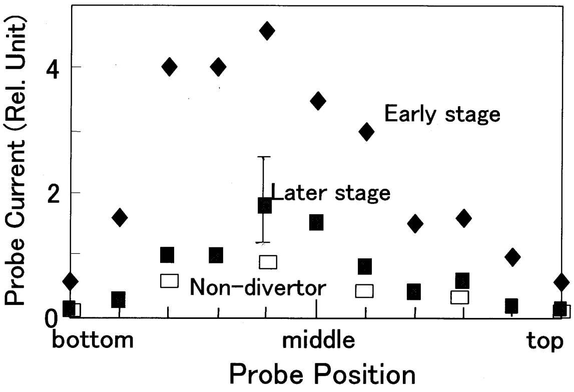
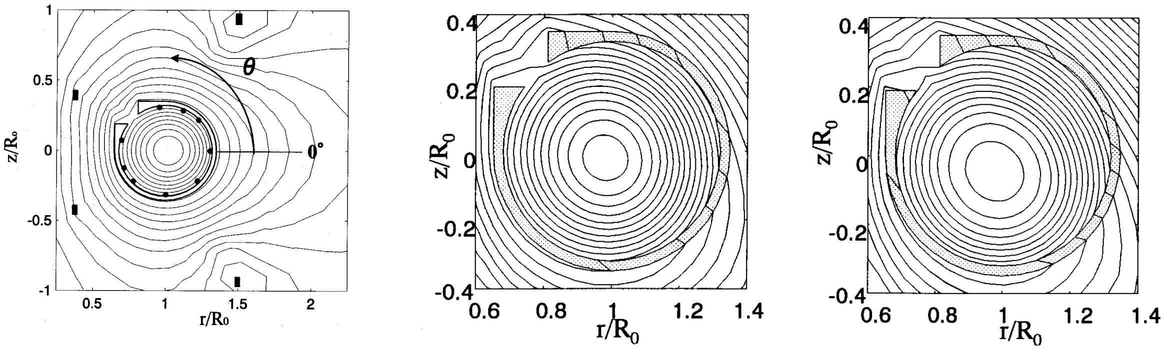


FIG. 3 Profile of ion saturation current of probe on the divertor plate surface.

3.2 MHD Equilibrium Analysis

The equilibrium position and shape of plasma in a combined system of external field and finite conductivity shell with a poloidal cut are analyzed by a numerical code, EAFP [6]. This is important to check the shell proximity of plasma surface during the discharge under the circumference of the unusual shell cut position and the diverted magnetic field. The fitting function of $I(\Psi)$ in the Grad-Shafranov equation is $I(\Psi)=1+\Sigma x_j(1-\Psi)^j$, ($j=1$ to 5). The input experimental data are poloidal field intensities at 9 positions on the shell inner surface and the total plasma current. A good agreement is obtained between the experimental data and numerically fitted data. In FIG. 4, restored magnetic surfaces are shown in the middle stage of discharge when no divertor field is applied. It is seen the plasma moves downward slowly. This is considered to be caused by the poloidal shell cut position, 45degrees upside in the inboard side. This position of shell cut generates the unfavorable vertical and horizontal magnetic fields. The vertical field is compensated by steady and pulsed field coils in the present data, but the horizontal field is not done.



(a) (b) (c)

FIG. 4 (a) Reference magnetic flux surfaces including the finite conductivity shell and positions of coils. (b) and (c) are details of reconstructed magnetic flux surfaces in the middle stage of the discharge (3 ms between them). All are the case of non-divertor discharge.

3.3 Divertor Plasma Profile

The sharp peak of probe current can be seen usually at the reversal time of B_t, when the RFP configuration sets up. As the divertor current increases, the peak becomes steeper. However, in the shell region where the plasma particle hits the shell wall surface, such a sharp peak is not observed.

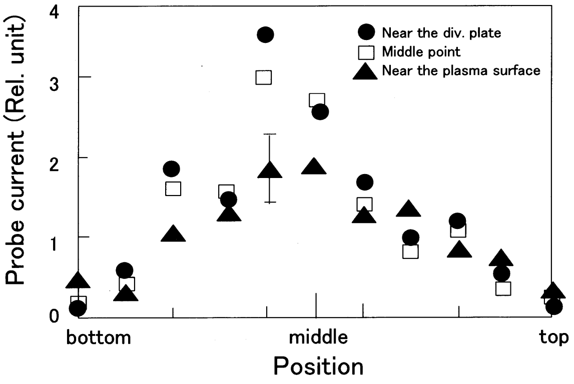


FIG. 4. Dependence of the density profile on the position of X-point, full circle:near the divertor plate, square:middle point, full triangle:near the plasma surface.

In FIG. 4, the spatial profiles of saturated probe current at the divertor plate surface in the later stage are compared for three positions of X-point by varying I_{div}/I_p values. (full circle; 4 cm from the divertor plate surface, square; the middle point, and full triangle; 5 cm from the original circular surface of plasma). When the X-point exists near the divertor plate surface, the profile is sharply peaked, as two separatrix lines are close to each other. When the X-point is located near the plasma surface, the shell proximity of the whole plasma surface is deteriorated (a complete shaping is not possible only by the shell and a few shaping coils outside the shell), then the plasma may be less stable and the discharge usually terminates earlier. In this case, a large amplitude fluctuation (sometimes burst-like), which is much larger than on the shell surface, is seen in the signal. This will lead to the broadening of scrape-off layer and then the peaks of profile may be smoothed more.

The behaviors are compared with a low q tokamak discharge. The tokamak discharge usually continues longer than the RFP discharge, and is less sensitive to the parasitic field caused by the poloidal and toroidal cuts of the vacuum vessel or shell. In some cases, the sudden hump appears in the saturated probe current when the divertor field is applied (FIG. 5). The increased signal is not proportional to the divertor field, but rather a sharp peak appears abruptly. This is considered to be a sort of triggered loss of particle from the near-resonant q plasma surface. The spatial profile of the increment is weakly doubly humped (FIG. 6), different from the RFP divertor discharge.

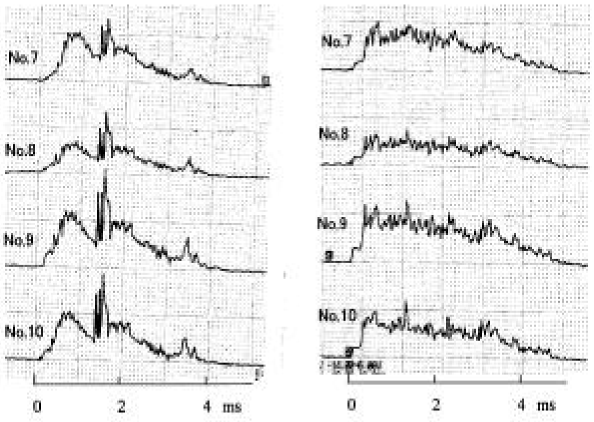


FIG. 5. Probe current at tokamak operations. Left: divertor, right: non-divertor. The number shows the position (1:bottom, 5:middle, 10:top).

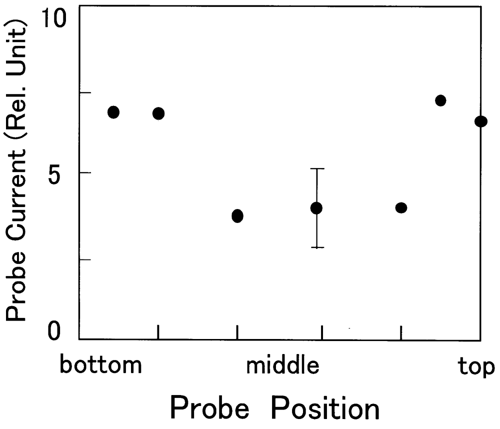


FIG. 6 Profile of increment of probe current at divertor plate surface.

The parameters of divertor plasma are estimated. The temperature estimated by the saturated V– I characteristics of probe is as high as 50 eV, while the temperature at the edge of main plasma (near the shell surface) is lower than that (around 30 eV). The density of divertor plasma is only a few times smaller than the edge density of main plasma. These facts also suggest the loss through the X-point region is rather large. The reasons may be the short connection length because of $B_t \ll B_p$ and the large amplitude fluctuation of local magnetic field (on the order of 15 % for both B_t and B_p) in the open shell (divertor) region. This level of magnetic fluctuation is much larger than that at the shell surface (a few %).

3.3 Other Edge Plasma Characteristics

The light impurities (C, O), D_α and the metal impurity (Al) of the edge plasma of main core are investigated. O and Al impurities are reduced to below the background level presumably owing to the effect of boronization. The differences in CIII and D_α line behaviors, the magnetic fluctuation at the shell surface, the density fluctuation level and the temperature (typically 30 eV) are very small with and without divertor. The observations that the light impurities and the fluctuation levels of density and magnetic field do not change with the divertor field except the case of strong divertor field are not unreasonable since the plasma surface proximity to the shell surface does not change remarkably (the shell proximity is around 8 % with the divertor). The slight transient increase of SX radiation and decrease of density fluctuation that were observed in the former version of vessel/shell [7] are not observed in the present version of vessel/shell structure.

4. Discussions and Conclusion

In summary, the divertor discharge of RFP in the inner shell/outer vacuum vessel has been investigated in TPE-2M, and some characteristic behaviors of divertor scrape-off plasma are newly found. In the RFP configuration, a burst of particles generally come out of the main core through the open shell portion at the reversal time of B_t field. An anomalous particle effusion by a strong magnetic fluctuation through the shell cut/X-point is suggested in the divertor discharge. On the other hand, the properties of density diffusion and magnetic fluctuation in the shell region are rather insensitive to the edge field modification by the divertor field. No clearly unfavorable effect of the divertor field on the core plasma characteristics has been observed far.

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