DIVERTOR RFP EXPERIMENT ON TPE-2M*

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Abstract

The divertor discharge of reversed field pinch (RFP) is being studied in TPE-2M. To understand the recycling process and the characteristic divertor plasma behaviors, the device was reconstructed so as to have an enough divertor space. In the new device the shell is installed in the vacuum vessel. The major and minor radii of the shell are 0.87 and 0.28 m respectively. Visible spectroscopic observation showed that both light and heavy impurity lines decreased, while Dα from the diverter plate region increased. This indicates that the divertor acts effectively in the new structural configuration. The newly found phenomenon in this vacuum vessel - shell structure is a large-amplitude axis oscillation of plasma column along with the divertor point direction, that is, the shell cut direction. It seems to be induced by the large shell cut angle or its structural form. This sort of large amplitude oscillation may enhance the flux loss in RFP. In the improved shell structure, in which the open angle of shell cut was reduced to a half (15 degrees) and the shape of shell inner surface was made quasi-circular, that oscillation is effectively suppressed. The loop voltage is relatively high in both cases, which seems due to the large - angle shell cut.

1. INTRODUCTION

The magnetic configuration of divertor discharge modifies the specific RFP configuration strongly in the edge region. Such a modification may enhance the dynamo activity if the RFP configuration should be sustained. Early experiments in TPE-2M have shown that the observed global MHD dynamo activities are similar with those of normal discharge, that is, analysis of magnetic fluctuations revealed that a nonlinear coupling of m=1 and m=0 modes occurs during flux generation process. Dynamo activity as a flux generation mechanism was maintained as in the normal discharge and no particular global instability was excited. The heat exhaust concentration to the separatrix point was observed. Total heat flux to that region is estimated at about 80% of Ohmic input power [1-3]. Spontaneous increase of soft X-ray signal from the core plasma and decrease of particle diffusion from the outward edge were also observed [4]. Due to the impurity build-up, however, the duration of discharge was limited in this configuration with a very small divertor space.

To study the recycling process, the characteristic divertor plasma behaviors and their effects on the core plasma confinement, TPE-2M device was reconstructed so as to have an enough divertor space as the second stage experiment. An inner-upper side single-null poloidal divertor configuration is formed by combination of the stabilizing shell with an axisymmetric poloidal cut and a hoop coil. The stabilizing shell is installed in the vacuum vessel to provide an enough divertor space. In this configuration the normal RFP configuration can also be formed by reversing the polarity of the divertor hoop coil current. The characteristic geometrical structure and electrical parameters of the new device are described. The plasma - wall interaction and the divertor plasma behaviors are observed by visible spectroscopy, and magnetic properties are observed by small magnetic search coil arrays.

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2. DESCRIPTION OF DEVICE

The geometrical structure of the vacuum vessel - shell and magnetic coil assemblies is shown in Fig.1(a). The close fitting aluminum shell of (2.5 cm in thickness), which is essentially necessary for the stability in RFP, is installed in the vacuum vessel to provide an enough divertor space. An axisymmetric poloidal shell cut and a divertor coil outside the vacuum vessel form the divertor configuration. The calculated divertor field profile is plotted in Fig. 1(a). The further modification of shell inner surface structure is shown in Fig. 1(b). The major and minor radii of the shell inner surface are 0.78 and 0.28 m respectively. The shell is electrically insulated from the SUS vacuum vessel. The plasma current and duration of the discharge are limited by the capacity of iron core 0.7Vs in the OH circuit. In the present experiment the maximum plasma current is 70 kA, and the duration is around 5 ms depending on the toroidal loop voltage (typically 100 V).

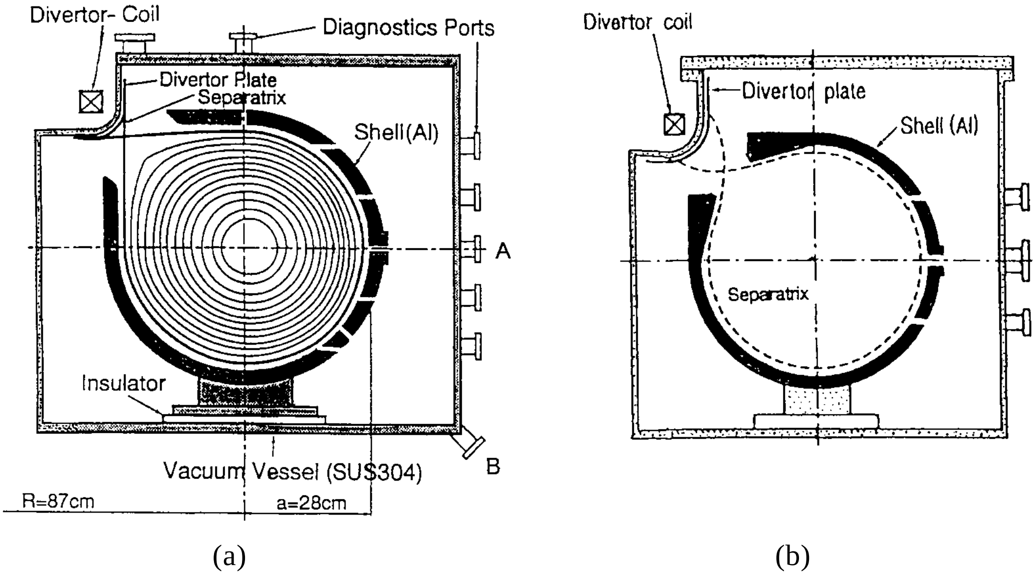


Fig. 1 Cross-sectional view of vacuum vessel – shell structure of TPE-2M.

3. EXPERIMENTAL RESULTS

3.1. Global behaviors of discharge

In Fig.2 are shown typical waveforms of the plasma current, the toroidal loop voltage, the toroidal flux and the toroidal field on the shell inner surface at the configuration of Fig. 1(a).

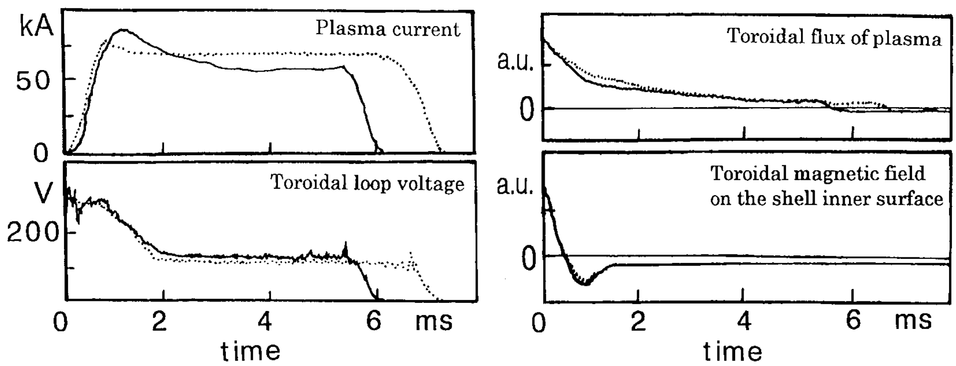


Fig. 2 Typical waveforms of the plasma current, the toroidal loop voltage, the toroidal flux and the toroidal field on the shell inner surface at the configuration of Fig. 1(a). Full lines; with divertor, dotted lines; non-divertor.

In this series of experiment, the maximum plasma current is limited at 70 kA to protect the electrical insulation of the toroidal shell gap. The toroidal flux in Fig. 2 is measured by magnetic loops wound around the shell and compensated by calculation. The RFP discharge duration is around 5 ms, which is limited at present by the flux capacity of iron core transformer, 0.7 Vs. The toroidal flux reverses its sign at current termination. The waveforms at the normal discharge are also shown by dotted lines in Fig.2. The toroidal loop voltage is typically 100 V. The loop voltage is slightly higher and the duration is shorter in the divertor operation [5]. The higher loop voltage in the divertor configuration may be explained by the additional flux loss due to the modification of edge field profile by the divertor. The loop voltage, 100 V, seems generally higher in this minor radius of 0.28 m, compared with 30 V in the old device in which the minor radius is 0.2 m. One of possible reasons is a large shell cut angle of 30 degrees, which permits a faster flux loss compared with a full covering shell. It also seems to induce an axis oscillation of plasma column along the direction of divertor point, which is described afterwards. These two facts lead to a higher loop voltage.

3.2. Observation of plasma - wall interaction

The interaction of plasma with the shell surface was observed by visible spectroscopy. In Fig.3 are compared the intensities of CIII and AlI lines viewed horizontally (from A-port in Fig. 1(a)), and Dα line in the direction viewing the divertor plate (from B-port in Fig.1 (a)) with those of normal discharge. In the divertor discharge, both impurity lines decreased to 1/2 or less, while Dα from B-port, which indicates the degree of interaction of diverted plasma with the divertor plate (cooling and neutralization of diverted plasma), increased by about 2 times. The edge observation instead of port-A observation shows the tendency more clearly. The reduction of heavy impurity is generally more evident than the light impurity as in the former device [4]. These results mean that the surface of plasma is more limited by the magnetic field than the material limiter (SUS and Mo) and the interaction of plasma with the shell wall is reduced and the plasma effuses to the divertor plate, that is, the divertor acts effectively in this configuration. The shell proximity of plasma (shell minor radius / plasma minor radius) is slightly deteriorated in the divertor configuration (approximately from 1.05 to 1.08 by equilibrium calculation), which can lead to a less stable state. However, any distinguishable changes in the fluctuation level of magnetic signals at wall surface were not observed with the divertor configuration. So that we can consider the main plasma is confined stably with divertor as well.

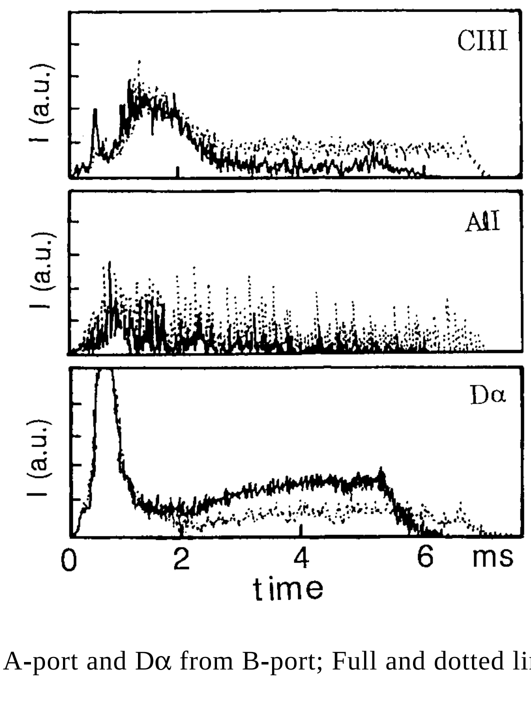
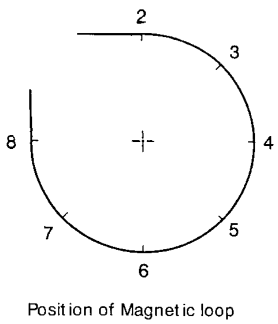


Fig. 3 Impurity lines from A-port and Dα from B-port; Full and dotted lines show the same with Fig. 2.

3.3. Characteristic plasma axis oscillation

The newly found phenomenon in this vacuum vessel - shell structure is the axis oscillation of plasma column along with the divertor point direction, that is, the shell cut direction (m/n=1/0 mode). The period and amplitude of the oscillation are around 0.75 ms and 0.15 respectively. It seems to be induced by the large shell cut angle or its structural form. The similar phenomenon was also observed in a very low q tokamak operation ($0<q<1$). In Fig. 4 are shown Br signals at the four inner surface positions with the case of very low q tokamak operation, where the discharge continues longer. This kind of large oscillation may enhance the flux loss in RFP, which is a cause of additional anomalous loop voltage in the divertor RFP discharge. In fact, the loop voltage is a little higher and the discharge duration is shorter in the divertor discharge at the same plasma current, compared with the normal discharge. To improve it, the shell cut angle was narrowed; the open angle was reduced to a half (15 degrees) and the shape of shell inner surface was made quasi-circular as shown in Fig. 1(b). The experiment in the improved shell structure showed no such oscillation of plasma column. However other global discharge properties remained unchanged. No loop voltage reduction nor impurity reduction was observed. The relatively high loop voltage observed in these discharges is estimated to be caused by the still large - angle shell cut.



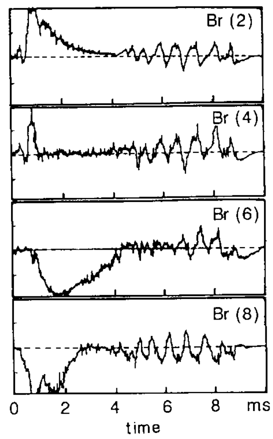


Fig. 4 Br oscillations showing an axis oscillation of plasma column along the direction of shell cut.

4. SUMMARY AND CONCLUSION

In summary, the divertor discharge of RFP in the outer vacuum vessel - inner shell structure with an enough divertor space has successfully been operated, and the plasma - wall interaction is effectively controlled. To improve the global plasma operation, boronization of the wall is being tried, and Ti gettering is planned. The initial experiment with boronization resulted in improvement in vacuum conditioning, and the plasma conductivity is slightly enhanced. The main efforts are being paid for higher plasma current and longer discharge time operation to ensure a higher performance.

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