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Divertor experiments in ohmic discharges of QUEST

QUESTのオーミック放電におけるダイバータ生成実験

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The plasma current start-up and ramp-up during two types of the divertor operations are experimentally studied in the limited central solenoid (CS) flux in QUEST. Depending on the inner and outer divertor coil configurations, two types of the divertor operations have been conducted and compared to have a higher plasma current. Initial coil current setting for breakdown is carefully planned for both operations. At present, the inner divertor operation provides larger plasma current because the reverse induction is smaller than others.

1. Introduction

Although the toroidal field is small in a spherical tokamak, the safety factor can be large due to the low aspect ratio. Therefore a large plasma current can be flown stably. However, as the flux of CS is small, it is difficult to induce the large plasma current. Moreover it is difficult to induce a large plasma current during the divertor operation because the divertor coil current induces the plasma current oppositely.

As the divertor coil current flows in the same direction of the plasma current, it reduces the vertical field for equilibrium. Therefore, careful operational plan is needed to increase the plasma current during the divertor operation with a limited flux of CS.

In this work we have conducted the divertor operation in QUEST with a small CS flux of 80 mVsec. In QUEST two divertor coils are installed. They are the inner and outer divertor coils. Therefore, essentially two types of divertor operation are possible. We present these two type discharges and compared their characteristics.

1. Inner and outer divertor operation

[1] Determination of the breakdown condition

To minimize the reverse induction by the divertor coil effect on the plasma current, the time constant divertor coil current is initially imposed. As CS has a cancellation coils, the vertical field at the plasma center is given by

$$B_V[0.68\mathrm{m}] = -4.6166\times10^{-6}|I_{PF35\text{-}12}|[\mathrm{A}] + 8.600\times10^{-6} I_{PF17}[\mathrm{A}] \quad (1)$$

where $I_{PF35\text{-}12}$ is the inner and outer divertor coil current connected in series, and I_{PF17} is the vertical field coil current. To apply the divertor coil current, the vertical field coil is also applied to reduce the stray field for breakdown. This relationship is shown in Fig. 1. B_v=0 means that the vertical field is cancelled by PF17 coil. In experiments breakdown took place at the open circle.

[2] Determination of the divertor configuration

Final equilibrium is determined by the Hasegawa equilibrium code. Coil currents of I_{PF17}= 0.9 kA and I_{PF26}=1.15 kA were set with $I_{PF35\text{-}12}$= -1.9 kA and I_{CS}=0 kA for β_p=0.8 to have a divertor configuration. This is shown in Fig. 2-(Left).

PF coil currents from the breakdown condition to the final operating point are linearly increased. The temporal evolution of the plasma current and divert coil currents etc are shown in Fig. 3. The initial divertor coil current is $I_{PF35\text{-}12}$=-1 kA and PF17 coil current is I_{PF17}= 0.6 kA as shown in Fig. 1. Therefore, the initial vertical field is almost 5.4 Gauss. CS flux is fully utilized for the plasma current ramp-up, and the plasma

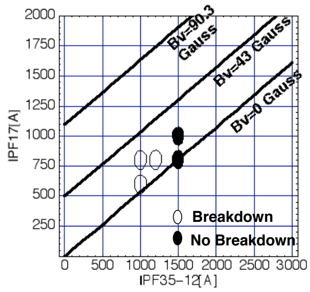

Fig. 1 Relationship between initial PF17 and series-connected divertor coil current for vertical stray field.

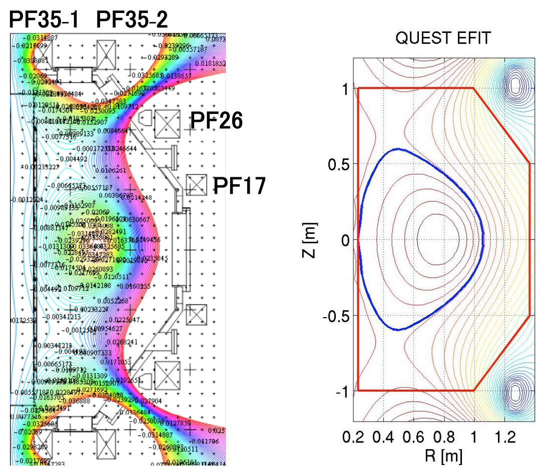

Fig. 2. (Left): Magnetic surface by Hasegawa equilibrium code. (Right): Magnetic surface at t=1.549s obtained by EFIT at I_{CS}=0 after experiments (#11631).

current reaches 40 kA. (We note that in the limiter discharge the plasma current is ramped–up to 100 kA by the same CS flux (80mVs) but by the larger vertical field. The plasma is placed at the inboard side.) It is seen that the divertor coil current induces the loop voltage to a slightly positive value, which means the reverse induction.

EFIT code shows the magnetic surface as shown in Fig. 2-(Right). Almost divertor like cross section has been obtained at I_{CS}=0 (t=1.54s). As the CS coil current cannot be reversed in the present system, the duration of the divertor configuration is very short. To have a longer divertor discharge, double swing operation of CS should be introduced.

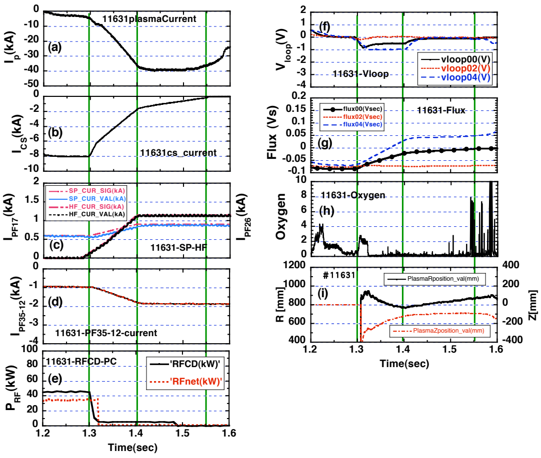

Fig.3. Temporal evolution of the inner and outer series-connected divertor discharge in QUEST. (a) Plasma current, (b) CS current (c) PF17 and PF26 coil current (d) PF35-12 coil current connected in series (e) RF power (f) loop voltages (g) magnetic flux loop signals (h) Oxygen impurity and (i) plasma position. (#11631).

2. Inner divertor operation

[1] Determination of the breakdown condition

When the inner divertor PF31 coil alone is used, the vertical field at the plasma center is given by

$$B_V[0.68m] = -0.5433\times10^{-6}|I_{PF31}|[A]+8.600\times10^{-6}I_{PF17}[A] \quad (2)$$

where $I_{PF35\text{-}1}$ is the inner divertor coil current. Larger inner divertor coil current I_{PF31} can be applied because it produces a small opposite vertical field to the equilibrium.

[2] Determination of the divertor configuration

Using the Hasegawa equilibrium code, PF coil currents of I_{PF17}= 0.95 kA and I_{PF26}=0.8 kA were set with the inner divertor current of $I_{PF35\text{-}1}$= -5 kA and I_{CS}=0 kA for β_p=0.8 to have a divertor configuration. This is shown in Fig. 4-(left).

The temporal evolution of the plasma current and divertor coil current etc are shown in Fig. 5. As the time constant divertor coil current of 5 kA is imposed, no reverse induction effect exists. As initial vertical field is 24 Gauss, it is larger than the previous case. The plasma current is induced up to 60 kA by full CS flux. It is

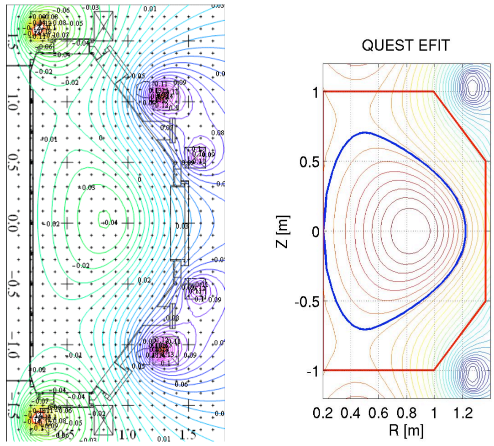

Fig. 4. (Left): Magnetic surface by Hasegawa equilibrium code. (Right): Magnetic surface at t=1.44s obtained by EFIT at I_{CS}=0 (#12712).

observed in these experiments that inner divertor operation is producing more plasma current for the same CS flux.

EFIT code shows the divertor like magnetic flux surface as shown in Fig. 4-(Right) at I_{CS}=0 (t=1.44s).

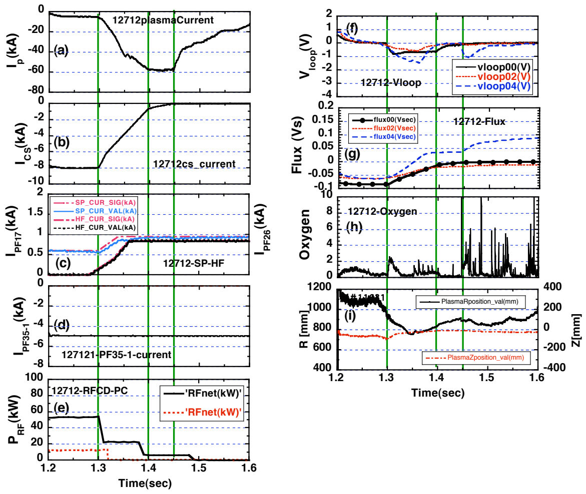

Fig.5. Temporal evolution of the inner divertor discharge in QUEST. (a) to (i) are the same as in Fig. 3. (#12712).

This result may show that an inner divertor with a snowflake divertor may be a better choice for a ST to have a larger plasma current. As series-connected inner and outer divertor corresponds to the Super X divertor (SXD), more studies are needed from the viewpoint of ramping-up the large plasma current with SXD.

References

[1] MITARAI Osamu, NAKAMURA Kazuo, et al., (2010) Plasma and Fusion Research: Volume 6, 1402003 (2011)

[2]MITARAI Osamu, NAKAMURA Kazuo, et al. J. Plasma Fusion Res. SERIES, Vol. 9 (2010) p100-105.