5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Plasmoid Formation and Ejection in TS-6 Merging Tokamaks Experiment

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Multiple blob/plasmoid structures were measured in current sheet of merging spherical tokamak(ST) plasmas in TS-6, using high-resolution and high-accuracy print-circuit-board (PCB) type magnetic probe array.
The features of the current sheet of ST merging experiment can be summarized as follows:
(1)current sheet is not uniform but there are formation of a single plasmoid and multiple blobs
(2)some of those blobs have close flux inside but others especially the edge of a continuous blobs don't have closed flux.
(3)If there are closed flux inside blobs the size of closed flux tend to be 1/2-1/5 of the blob size.

We have been investigating on reconnection heating characteristics of merging ST plasmas for direct access to burning plasma without using any additional heating like NBI[1]. The reconnection heating depends on the current sheet structure which is left unsolved for a long time due to lack of high-resolution and high-accuracy magnetic field measurement. As shown in Fig. 1(a), we developed the PCB type magnetic probe array with 5mm-resolution[2], whose accuracy is about 0.1%. It made clear formation of a single plasmoid and multiple blobs in the current sheet of merging STs.
The magnetic field lines deformed by the tilt motion looks promoting the current sheet splitting. The Hall current density deform/rotate the current sheets depending on polarity of applied toroidal field B_t.
Since electrons move along magnetic field lines much faster than ions, the current sheet always has radial Hall current j_{Hall} flowing toward the X-point. It also produces negative and positive potential wells for ion acceleration The $j_{Hall}\times B_t$ force rotates the current sheet, deforming the magnetic field lines promoting multiple blob formation.

The other cause of multiple blobs formation is fluctuations in magnetic field z-component Bz due to small scale local structures such as plasmoids. Jt is calculated by magnetic field using following equation.

$$J_t = -\frac{1}{\mu_0}\nabla \times B = \frac{1}{\mu_0}\left(\frac{dB_r}{dz} - \frac{dB_z}{dr}\right)$$

In other words, the spatial derivative of the magnetic field structure determines the current density distribution.

Fig. 1(b) shows radial profile of *Bz* at z=0 (solid line) and the radial derivative of *Bz* (dotted line). of sample current density profile which has blob structure (Fig. 1 (a)). *Bz* crosses zero at three radial positions. The central null point corresponds to the island O-point accompanied by the X-point on each side. Since there are *Bz* fluctuations, radial derivative of *Bz* peaks around them.

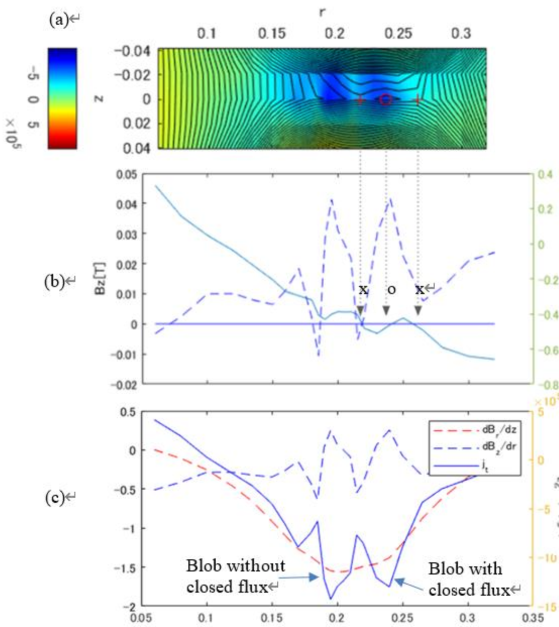

Fig. 1 (a) R-Z contours of poloidal flux and toroidal current density jt (color) (red symbols: o and + indicate O-point and X-point positions, respectively), (b) radial profile of *Bz* at *z*=0 (solid line) and the radial derivative of *Bz (d Bz /dr)* (dotted line), (c) radial derivative of *Bz* (d *Bz* /d*r*) ,axial derivative of Br *(dBr/dz)* (blue and red dotted line) and *Jt*

Fig. 1(c) shows Jt calucurated by by subtracting *dBz/dr* and *dBr/dz*. As shown in Fig. 1(c), radial profile of *dBr/dz* is not fluctuating. Then *Jt* has two peaks (=two blob) derived by *dBz/dr*. Fluctuation around r=0.25[m] is caused by plasmoid, and the other fluctuation around r=0.2[m] is not because of plasmoid. It may depend on downstream magnetic field configuration including magnetic field line deformation or other reason.

References

[1] Y. Ono et al., Nuclear Fusion **59**, (2019), 076025.
[2] M. Akimitsu et al, PFR **13**, (2018), 1202108.