Dynamic divertor by plasmoid ejection

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1. Introduction

One of the key parts of the reactor: Divertors have three essential roles for fusion reactors shown in Fig. 1: (1) to reduce heat load to the reactor wall by leading a heat flux, (2) to reduce impurity transport to core plasmas, (3) to exhaust helium ashes by neutralizing helium ions in core plasmas. High energy heat flux such as Type I Edge-Localized Mode (ELM) damages divertor plates seriously, causing frequent replacement of divertor plates. While high density and low temperature plasmas are needed at the divertor region to protect the divertor plate from the heat flux, low electron temperature at the divertor region causes impurity transport from the divertor region to the core plasma, degrading their confinement as the X-point MARFE. This serious problem for the fusion reactor is left unsolved yet, leading us to a new idea of "Dynamic Divertor". We, Univ. Tokyo team developed this dynamic divertor which is a new concept of divertor using sporadic plasmoid ejection from the main plasma to the divertor coil and insulating the divertor plate from the main plasma [1]. This paper describes the basic motion of dynamic divertor with simulation and experiment.

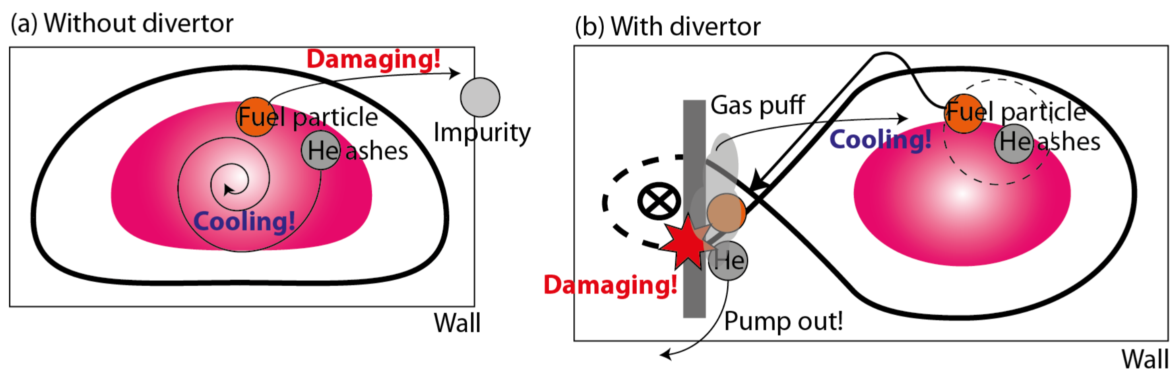

Fig. 1 Schematic views of core plasmas with and without divertor.

2. Concept of Dynamic Divertor

The dynamic divertor action has three essential steps, as shown in Fig. 2(a). First, some current drive or heating causes the main plasma to expand around the divertor region, forming a plasmoid as shown in Fig. 2(b). The plasmoid is the magnetic island ejected from the main plasma, which contains helium ashes from the core plasmas. Fuel particle and helium ashes at edge regions move along magnetic field line and pull field line and heating corner plasmas at bad curvature point that is artificially made by the divertor coil's pull force. Second, the expanding core plasma finally pinches off the small plasmoid and obviously the helium ash is also emitted with the plasmoid. Third, the plasmoid isolated from the main plasma is cooled down by argon gas puffing and finally is connected with the divertor plate. In the series of motion, the divertor plate is not connected to the main plasma, indicating that there is no heat flux directly flows into the divertor clearly.

While the classic divertor connected the divertor plate with the main plasma through an X-point of magnetic field lines as shown in Fig. 1(b), the "dynamic divertor" fully separates the magnetic field lines of the divertor plasma from those of the main plasma by an separatrix field line and they are connected indirectly by a moving plasmoid, as shown in Fig. 2(a). The magnetic field lines of the divertor plate fully isolated from the main plasma reduces significantly heat flux from the main plasma to the divertor plasma as well as impurity transport from the latter to the former. Since the plasmoid is isolated from the core plasma, we can easily cool down the plasmoid initially filled with hot plasmas from the core plasma using sufficient amount of the argon gas puff. If the plasmoid can be cooled down efficiently, intermittent plasmoid ejection from the core plasma and connection of the plasmoid with the closed field lines of the divertor coil can be an efficient dynamic divertor action scenario.

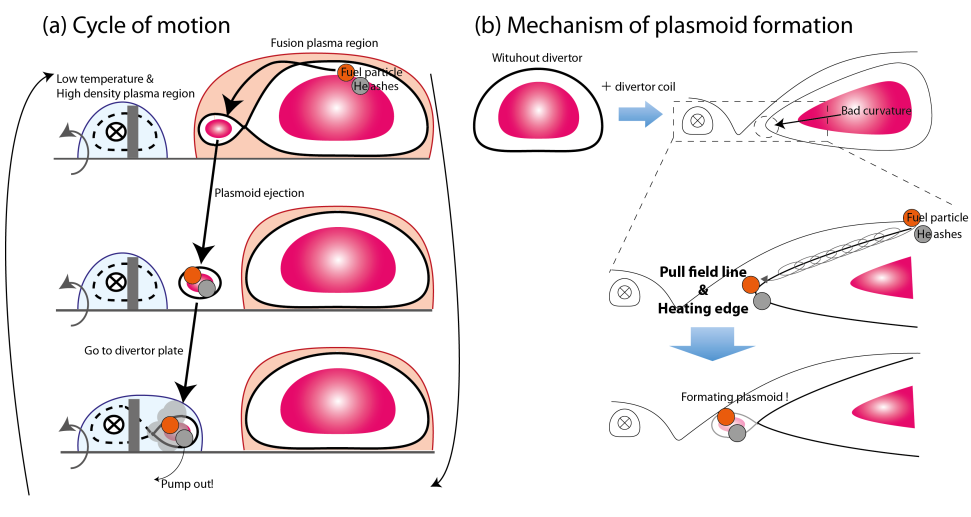

Fig. 2 (a) Cycle of dynamic divertor motion, (b) Plasmoid formation mechanism.

3. Experimental and Simulation Tests of Dynamic Divertor

3.1 Experimental Study of the Dynamic Divertor

Figure 3 shows R-Z poloidal flux contours of plasmoid ejection from the core plasma to the divertor, which is the first experimental test of the dynamic divertor action in TS-4 spherical tokamak device. The main ST plasma was formed on the left side both by inductions of the flux cores and that of the center solenoid coil. Their inductive current drive caused expansion of the main plasma at the bad curvature corner at t~600 μs. Continued heating and pull force of the divertor coil generated a plasmoid from t~600 to 614 μs and then ejected it to the divertor coil region on the right side. While the plasmoid ejection occurs once under the present condition due to the waveform limitation of the coil current, we demonstrated for the first time one cycle of the dynamic divertor in which the plasmoid is formed at the bad curvature corner and is translated to the divertor coil. The remaining problem is that the common flux between the core plasma and the divertor coil was not fully suppressed to disconnect the heat flux between the core plasma and the divertor plate from t~600 to 642 μs. We are planning to extend the distance between the core plasma and the divertor coil in order to achieve perfect dynamic divertor action.

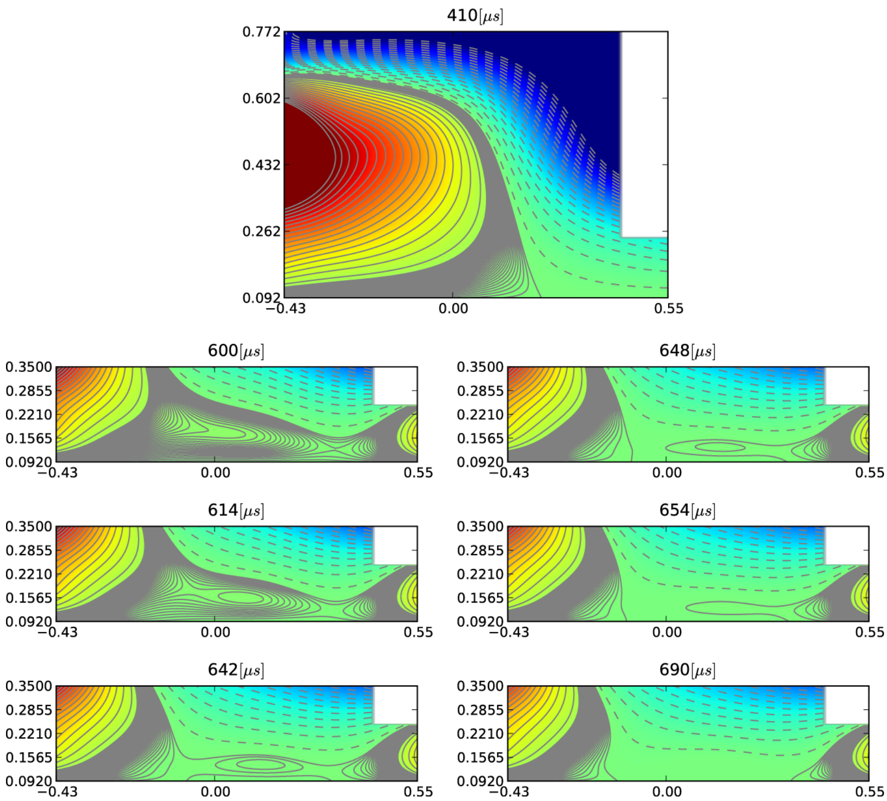

Fig. 3 Poloidal flux contours of ejecting plasmoid for the dynamic divertor in the TS-4 spherical tokamak device.

3.2 Simulation Study of the Dynamic Divertor

Figure 3 shows R-Z poloidal flux contours of one cycle of the dynamic divertor action calculated by a 2-D MHD simulation code [1]. This simulation solved 2-D MHD equations in the cylindrical conductive boundary with toroidal electric field by the CS coil. From t=0.63T_A to 1.51T_A, the main plasma was heated by the ohmic heating coil, forming a plasmoid around the left end of the ST plasma with the bad curvature. The plasmoid was accelerated by the magnetic pressure of the PF1 coil and was detached from the main plasma at t~1.56T_A. Finally, the plasmoid was attracted by the PF2 coil current and was connected to the divertor plate located on the simulation boundary. Though the MHD simulation cannot include the gas puff's effect or kinetic effects, our simulation result indicates the divertor action do not connect the field lines of the divertor plate to those of the main plasma, suggesting the dynamic divertor reduces significantly the heat flux to the divertor plate.

Unlike the experimental results, our MHD simulation does not have any limitation of coil current control. It demonstrated successfully the proposed repetitive plasmoid ejection, as shown in Fig. 4(b). It ejects plasmoid multiple times with ejection period of 5T_A under the present operation condition. Our next target is to demonstrate the continuous plasmoid ejection without changing the coil current for the more realistic fusion reactor operation.

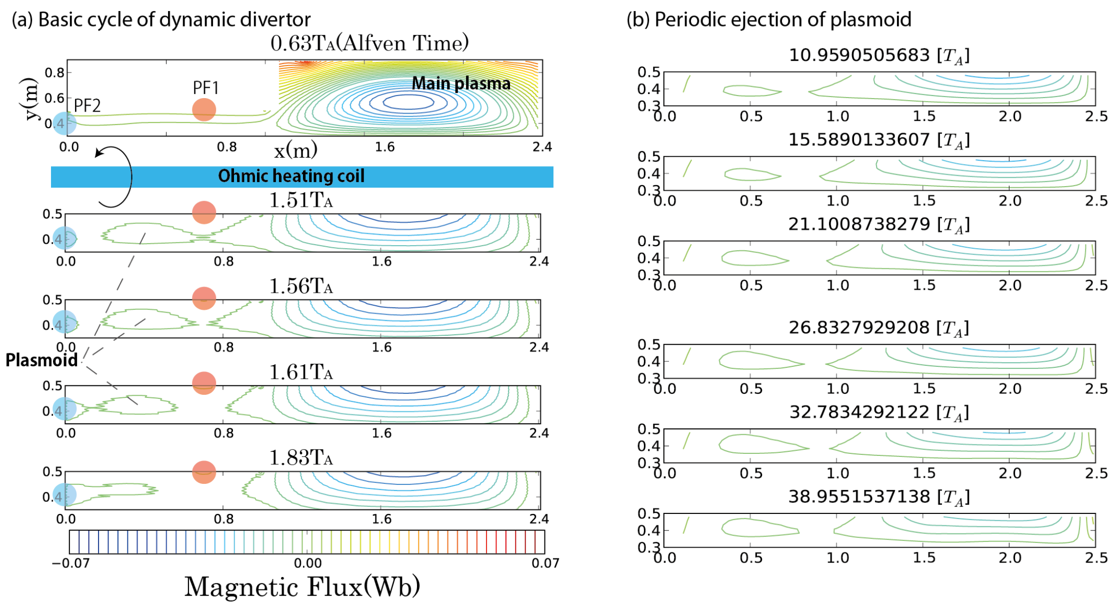

Fig. 4 Poloidal flux contours of ejecting plasmoids for the dynamic divertor in the 2-D MHD simulation.

References

[1] S. Inoue, Y. Ono, S. Ito, IEEJ Trans. FM, 131, 11, 963 (2011)