EDGE MAGNETIC ISLANDS AND ITS APPLICATION TO THE DEVELOPMENT OF ADVANCED DIVERTOR CONFIGURATION ON THE J-TEXT TOKAMAK

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The development of advanced magnetic divertor configurations to solve the core-edge integration, the coupling of heat and particle exhaust and impurity control in high-power high-performance long-pulse plasma operation is one of the important topics in current fusion research, and is being carried out in more and more tokamak and stellarator devices. The island divertor, one of multiple attractive advanced divertor concepts, has been successfully applied on the W7-AS stellarator, and further developed on the W7-X stellarator. In the island divertor configuration, the SOL is formed by a group of magnetic islands, which form closed flux tubes around the core plasma. These edge islands are then intersected and cut open by divertor target plates. Compared with the standard poloidal divertor configuration, the island divertor configuration has a weaker correlation with the plasma current and a longer connection length, which results in a wider distribution of heat loads and also makes it easier to enter stable detachment of divertor operation [1]. Therefore, it is of great interest and significance to apply and explore the island divertor configuration in tokamak plasmas. Recently, a first attempt has been made to form an island divertor configuration in the J-TEXT tokamak [2, 3].

Formation of island divertor configuration -- On J-TEXT, the first island divertor configuration was formed by moving the $m/n = 3/1$ edge island chain outward to intersect with the divertor target. Here, m and n are the poloidal and toroidal mode numbers, respectively. In this experiment, the $m/n = 3/1$ edge magnetic islands were excited by applying RMPs with a dominant $m/n = 3/1$ component [4] in a limiter plasma with an edge safety factor, q_a, slightly over 3. By increasing the plasma current to reduce the edge safety factor, the edge magnetic islands are cut by the divertor target to finally build up the island divertor configuration. When the 3/1 edge islands are gradually opened by the divertor target, the main striking points, indicated by the floating potential measurements from the divertor Langmuir probe arrays, move to two sides of the divertor target as shown in figure 1. This reveals that topological differences considerably affect the divertor heat load patterns. Once the 3/1 edge islands are fully moved behind the divertor target, the island divertor configuration is then transformed back to a limiter configuration. The formation of the island divertor configuration strongly depends on the edge magnetic topologies, or more specifically, the interactions between the edge island and the divertor target. By optimizing the edge magnetic topology and the structure of the target plate, the divertor heat load distribution could be significantly modified, so as to increase the power deposition area and reduce the peak heat load. Such optimization processes are being carried out on J-TEXT, leveraging both 3D edge transport modelling and dedicated experiments.

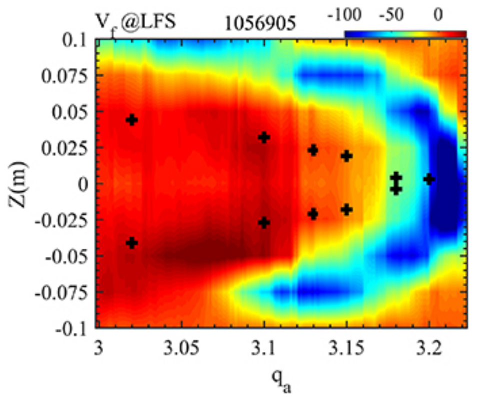

Figure 1. Dependence of LFS floating potential distribution on edge safety factor q_a. The black crosses are the strike points obtained from the field lines with the deepest penetration into the core plasma calculated by the field line tracing.

Stability of edge island -- The operation of the island divertor configuration is closely tied to the stability of the edge island. Once there is a change in the width and phase of the edge island, the island divertor configuration cannot operate stably, which can even lead to the deposition of heat load outside the divertor targets. Therefore, the stability of the edge island is of great concern in the experiment. A new type of edge island instability, the so-called self-sustained divertor oscillation, was observed in J-TEXT during divertor experiments. Since a bifurcative oscillation of ~50 Hz is observed among the edge island width, the edge H_α intensity, and the edge electron temperature, the oscillation is regarded to be a sequential repetition of the magnetic field penetration-screening transition and back-transition. The periodic collapses repeat several times until the edge islands are intersected by the divertor target. As the edge islands are gradually opened, the amplitude of the oscillation decreases, and the properties of the oscillation also change from burst-like to quasi-continuous. Thus, the divertor target structure is also significant for the stability of the edge island. In addition, the divertor oscillation shows a correlated dependence on the plasma edge density. The detailed analyses and explanations are still to be investigated.

Impurity screening effects -- The impurity accumulation at the central plasma is one of the burning issues for high-performance long-pulse plasma operation. Impurity control has become the focus of extensive attention in J-TEXT. During the application of the island divertor configuration, it was found that the $m/n = 3/1$ edge island has an impurity screening effect, especially when the O-point of the island is near the LFS divertor target. By combining a methane injection experimental study and STRAHL impurity transport analysis, it was demonstrated that the variation of the impurity transport dominates the impurity screening effect. The impurity diffusion is enhanced with a significant increase in the outward convection velocity at the edge region [5]. The interactions of the edge island and the divertor target contribute to the impurity screening effects with the dependence on the edge island width and phase. Therefore, a better impurity exhaust/screening could also be achieved by optimizing the edge magnetic topologies. In addition, the radial electric field, the plasma rotation, and turbulence are considered to play an important role in impurity screening. The detailed impurity behaviors under the island divertor configuration will be studied with the foreseen application of 3D transport codes, such as EMC3-EIRENE. Moreover, combining the electric field, plasma rotation, and turbulence into integrated scenario modeling is another important topic for further studies.

3D divertor heat loads -- For the island divertor configuration, longer field-line connection lengths at the SOL (in the magnitude of 10^2–10^3 m, much longer than the electron mean free path) could be obtained, which benefits heat load spreading on the divertor target [6]. In order to investigate the effects of the edge magnetic topology on the divertor heat load distribution, a 2D infrared thermography camera system viewing the HFS divertor target from the LFS mid-plane window with a high spectral resolution of 0.5 mm was established on J-TEXT. During the experiments in island divertor configuration, the surface temperature distributions on the divertor target could be obtained in real time. The experimental results show that the heat flux distribution on the HFS target plate depends significantly on the edge magnetic topology. Furthermore, the impact of hydrogen fueling using supersonic molecular beam injection (SMBI) on the divertor heat flux distributions is studied on J-TEXT with an island divertor configuration. It has been observed that power detachment can be achieved when the radiation front approaches the last closed flux surface after each SMBI pulse. This result may provide a method of access for divertor detachment on a fusion device with a 3D boundary magnetic structure [7].

The key points of the island divertor research on J-TEXT are to demonstrate its performances of heat and particle exhaust. Moreover, it is worthwhile to explore how to realize stable detachment operation of the island divertor, which may rely on the synergy effects of the optimized magnetic topology, plasma transport, and heat load dissipation. In particular, the core–edge integration to develop and demonstrate dissipative/detached divertor solutions for power and particle control, sufficient for extrapolation to high-performance long-pulse H-mode plasma conditions, is worth investigating.

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