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Optimization of plasma start-up using external coils in transient-CHI experiments on HIST

HISTトランジェントCHI実験における外部磁場コイルを用いたスタートアップの最適化

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Transient Coaxial helicity injection (CHI) has been successfully demonstrated in the Helicity Injected Spherical Torus (HIST) device for solenoid-free plasma start-up in a ST. The internal magnetic field measurements have verified the formation of the closed flux surfaces (flux closure) during the start-up phase without the use of the central solenoid coil. The formation of an X-point near the gun muzzle is followed by magnetic reconnection due to the $\boldsymbol{J}\times\boldsymbol{B}$ plasma flow from the gun. The closed poloidal flux $\Psi_{\rm p.closed}$ increases proportionally with the toroidal current $I_{\rm t}$ as increasing the injection voltage $V_{\rm inj}$ across the inner and outer gun electrodes. However, the lower injector bias poloidal flux□$\Psi_{\rm bias}$ continues to increase the injection current $I_{\rm inj}$ at the edge after the formation of closed flux causing the magnetic structures to be disruptive. To avoid the arcing phenomena at the absorber region of the flux conserver, we have applied the rear bias flux, resulting in the improvement of the plasma current start-up.

1. Introduction

An advantage of the Spherical Torus (ST) is the low aspect ratio and so elimination of a central solenoid coil is required for attractive high-beta fusion reactors based on the ST concept. Thus alternate methods for the plasma start-up that do not rely on the central solenoid are necessary for the viability of the ST concept. The non-inductive current drive by the CHI had been demonstrated for spheromaks and ST plasmas. While this method offers the potential for steady-state current drive, it was found that this approach could not produce the enough amount of the closed flux because it relies on non-axisymmetric magnetic activity to drive current on closed flux region. Unlike the steady-state CHI (edge current drive), in transient CHI (T-CHI) only axisymmetric reconnection during plasmoid ejection process from the injector is believed to be adequate for generating a high quality closed flux. The transient CHI without requiring for dynamo is a promising candidate for the non-inductive plasma start-up. So far, the T-CHI method has been successfully applied to NSTX for the start-up followed by inductive ramp-up. This coupled discharge has now achieved plasma currents larger than 1 MA [1]. Understanding the physics of the flux closure during T-CHI still remains as a key issue, which is the primary purpose of the HIST experiments.

2. Installation of new bias coils on HIST

The HIST device can form and sustain the ST plasmas (high-q: q>1 and low-q including spheromaks: q<1) and is characterized by utilizing the variation of the external toroidal field (TF) coil current $I_{\rm tf}$=0~125 kAturns. The detail explanation of the HIST is represented in the reference [2]. To measure time evolutions of poloidal flux $\Psi_{\rm p}$ contours, we inserted 2D magnetic pick-up coil arrays on the poloidal cross section. This 2D flux plots data provide us the maximum value of the poloidal flux. In this experiment, we have newly installed two bias coils (an inner bias coil and a rear bias coil) in the inner electrode and on the central conductor, respectively, as shown by Figure 1. When the plasmoid ejected from the gun muzzle reaches to the rear gap hole of the FC, the gun current flows between the FC and the central

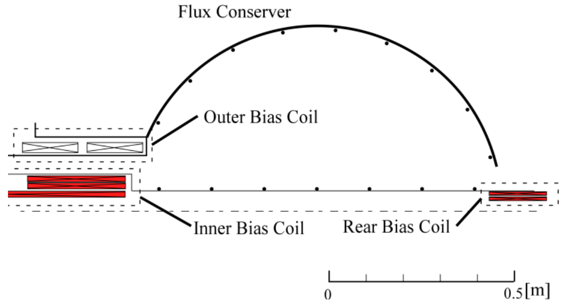

Fig.1 New bias coils installed on HIST

conductor due to the arcing discharge on the gap. The T-CHI experiments on NSTX also observed such an arcing phenomenon at the absorber region, after then which was improved to obtain the much better results. The rear bias coil is located at the helicity absorber region of the rear gap of the FC to prevent the gun current for flowing along the FC surface and the occurrence of arcing at the gap space. We expect that the vacuum magnetic field lines produced by the rear bias flux coil leave the plasma away from the rear gap and keep plasma detachments from the FC.

3. Experimental results

Figure 2 shows time evolution of poloidal flux contours during the current start-up phase. The plasmoid is ejected from the gun muzzle, after then the magnetic reconnection occurs to create the X-point. We can see in the figure that closed flux region is surrounded by the open field lines intersecting with electrodes. Note that the plasmoid ejected from the gun has not reached to the bottom of the FC until t=0.13 ms. During this start-up phase, the toroidal current density profile is peaked around the magnetic axis (R=0.3 m). After this time, we have observed that in the case of lower bias flux, the plot of poloidal flux contours are destroyed and ordered closed flux surfaces disappear.

Figure 3 shows time evolution of poloidal flux Ψ_p and toroidal current I_t, when we applied the rear

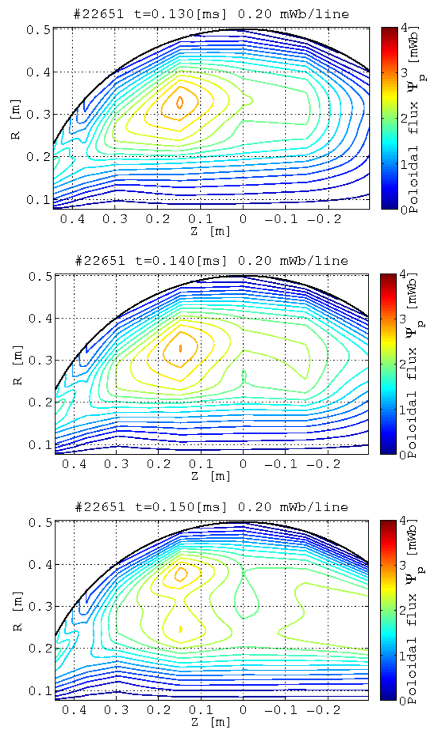

Fig.2 Poloidal flux contours plot

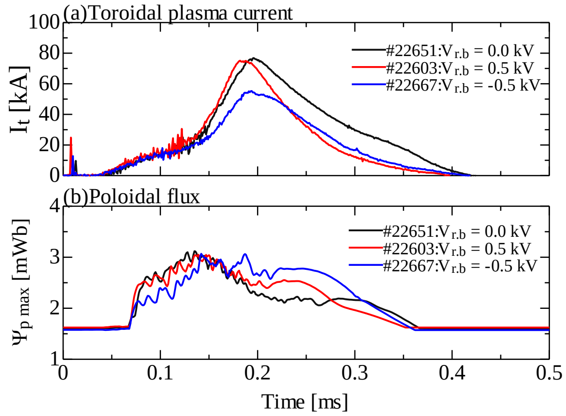

Fig. 3 Comparison of time evolution of poloidal flux Ψ_p and toroidal current I_t between with and w/o the rear bias magnetic fields $\Psi_{r.bias}$. The polarity of $\Psi_{r.bias}$ was changed for the comparison.

bias magnetic field. The negative polarity corresponds the direction of bias field lines which is the same as that of the ST. The positive polarity causes the ST field lines to open due to reconnection. We can see that the waveform of I_t shows that fluctuations occur until t= 0.14 ms. This further increase in I_t after this time indicates that the arcing discharge occurs at the gap region of the FC. In the negative polarity case of $\Psi_{r.bias}$, the increase in I_t is reduced and the rising time of the Ψ_p becomes slower, although the peak value of Ψ_p is not changed. Furthermore, the Ψ_p maintains the high value for the period of 0.1 ms. In the positive polarity case of $\Psi_{r.bias}$, the poloidal flux contours are deformed just after t= 0.15 ms and lots of small magnetic islands appear. This is consistent with the faster decay of I_t compared to the other cases.

4. Summary

In summary, an X point is formed in the gun muzzle region, followed by formation of closed flux surfaces after the bubble burst event. To avoid the unexpectedly occurrence of the arcing phenomena, we applied the bias flux around the rear gap hole of the FC. The experimental results suggests that the arcing gun current over 30 kA is effectively reduced, which results in the maintenance of the poloidal flux.

Acknowledgments

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