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2D Hall-MHD investigation of spherical tokamak formation and merging by using the induction of a pair of internal PF coils

Tara Ahmadi[1], Yasushi Ono[2]

[1] School of engineering, University of Tokyo [2] School of frontier sciences, University of Tokyo

e-mail (speaker): tara.ahmadi.smart@gmail.com

Experimental studies [1,2] of the merging start-up in the spherical tokamak revealed the formation of the paramagnetic toroidal field during the plasma formation [3]. In spite of the experimental results regarding the ST formation, there is no numerical work studying the toroidal field during the plasma formation and merging in details. Therefore, the goal of this work is to (a) show the evolution of the toroidal flux during plasma formation and the merging process, (b) mechanism of magnetic pressure equilibrium inside the plasma.In this work, we investigate the plasma toroids formation due to the in-vessel PF coils by using the Hall-MHD (HMHD) system of equations.

Our MHD simulation has the pre-merging temperature value $T_0 = T_i$= 10eV, density n_0= 5 times $10^{18}m^{-3}$, the normalized resistivity 5×10^{-6}, and the normalized viscosity 5×10^{-4} inside a toroidal domain with the radius of 1m and Z=±1.1m. Note that the normalized hyper resistivity is assumed $\Lambda=1\times10^{-8}$ while the calculated Hall coupling factor is 1.4×10^{-1}. The B_0 is the constant toroidal magnetic field 0.5/R, while the poloidal field is produced by the in-vessel PF coils. The PF coils current ramps down in time inductively increasing the plasma current. Therefore, at I_{PF} =0(pinch-off moment), the formed plasma toroids separate from the coils area moving toward the mid-plane where they merge together. Note that a pair of equilibrium field (EF) coils is located outside the domain to maintain the radial force balance.

The dotted line in figure 1a shows the initial value of the toroidal magnetic pressure with a slight increase due to the injection of the internal toroidal field. After the pinch off, the toroidal pressure profile shows the pressure peaks near the coils (±0.5m), magnetic axis of the ST plasmas ± 0.3m, and current sheet.

The dotted line in figure 1b illustrates the poloidal magnetic pressure at t= 49.29µs. At this time, only two peaks are observed at z=± 0.4m which refers to the rise of the plasma formation near the two PF coils. During the plasma formation, the poloidal magnetic pressure decreases around the coils leading to the formation of plasma at this region. At t=84.09µs, the observed peaks in poloidal magnetic pressure at z=± 0.35m correspond to the ST plasmas. While, the other peaks at z=± 0.5m note the increase in the reversed PF coils current.

Figure 1c shows the pressure gradient parameter over the z-direction at t = 49.29µs and t=84.09µs. It is clear that inside the separatrix the gradient of total pressure is relatively low before the plasma formation, while the strong dynamic of the merging process is clear at t=84.09µs.

It was found that the injection of the toroidal flux generated due to the decline in the poloidal flux inside the formed plasma toroid is responsible for the pressure balance at the plasma formation stage. During the plasma formation, the internal toroidal field injection starts from the initial moments when the decline in the poloidal pressure breaks the pressure balance.

After the formation of the two ST plasmas, the toroidal field pressure along with the repulsive force between the reversed PF coils current and plasma current pushes the formed plasma toroid toward the mid-plane where they merge together. Note that at this stage the internal toroidal magnetic field is the main driving force expands the plasma toward the mid-plane.

Reference

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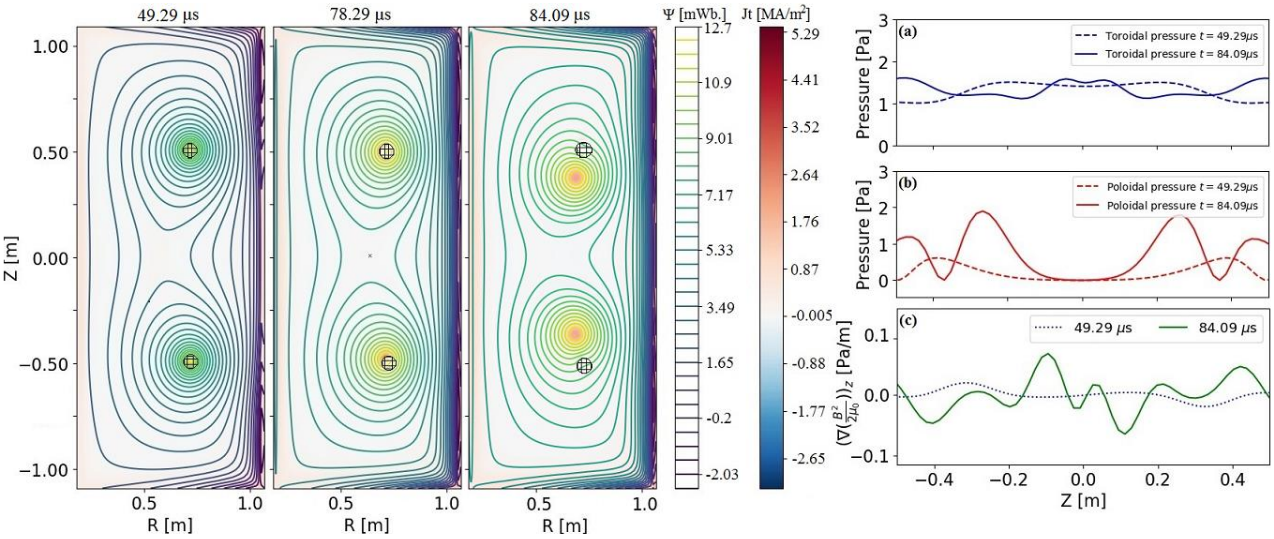

Figure 1: The toroidal current density and poloidal flux during the plasma formation 49.29µs, pinch-off 78.29µs and start of merging 84.09µs. Toroidal (a) and poloidal (b) magnetic pressure along with the pressure gradient (c)