

MHD Simulation of Merging Fueling Method Used for ST Plasma

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Three-dimensional resistive MHD simulation was carried out in order to develop a method to fuel the plasma core by merging two Spherical Torus (ST) plasmas. A relatively small ST plasma was translated into the axial direction by external magnetic field control and made to collide with the larger ST. In this calculation, ballooning instability occurred in both plasmas during translation, while the magnetic surface was observed to collapse from the Poincare plot of the magnetic lines. It was observed that the magnetic lines in the core regions of the two STs were connected to each other and that the merging was completed.

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As ITER construction progresses, the establishment of fueling technology to fusion burning plasmas is still a key unresolved issue. Neutral particles injected as fuel are ionized in the periphery and have difficulty reaching the core under the high temperature conditions of 10 keV or more, such as those of burning plasma. For this reason, it is urgent to develop a method of supplying particles to the burning plasma core. Under these circumstances, the concept of the merging fueling method is proposed [1].

Progress in plasma merging experiments via the magnetic reconnection process was taken as the background to this proposal [1]. Historically, merging experiments of spheromak have been carried out at TS-3/4 [2, 3], SSX [4], and others. Additionally, Tri-Alpha Energy Inc. has succeeded in generating field-reversed configuration (FRC), with good confinement performance, by merging two FRC plasmas [5, 6]. In recent years, merging experiments of spherical torus (ST) plasmas have also been carried out at UTST, and reports have been submitted on the generation of high energy electrons during the merging process [7].

The merging fueling method [1] aims to supply particles to large plasma via the merging of two ST plasmas with different sizes. The purpose of this preliminary research was to analyze the process of axially translating and colliding the small secondary plasma pushed by the magnetic pressure difference to the large plasma by using the three-dimensional (3-D) MHD simulation, and to determine research tasks in the merging fueling method. There are several reports on the reproduction of the plasma merging phenomenon by MHD simulation [8–10]. However, the 3-D simulation of two large and small ST collision phenomena has not been carried out so far.

In this paper, we clarify the change of the macroscopic

plasma structure, especially in the translation/collision process in the category of the ordinary MHD model. Additionally, by considering the development of the fueling method, it was necessary to simulate and predict whether the particles in the smaller secondary plasma could reach the larger main plasma core. For this reason, a particle trajectory calculation was performed based on the MHD simulation. Thus, it was clarified whether ions in the secondary plasma could go into the closed magnetic surface of the main plasma through the translation/collision process.

In order to simulate the collision process of the two ST plasmas, we used the 3-D MHD simulation code MIPS (MHD infrastructure for plasma simulation) [11], which is applicable to toroidal plasmas. Here, the cylindrical coordinate system ($r\theta z$ -system) was employed, where the direction of the translation was along the z -axis. A time-variable external magnetic field generated by the poloidal field coil current was added to the magnetic field in the resistive MHD equations.

The initial equilibrium state of the ST plasmas was the solution to the Grad-Shafranov equation. The plasma parameters, such as temperature, density, confinement magnetic field, and so on, corresponded to the D-³He fueled advanced fusion reactor core plasma [12]. The machine major and minor radii for the confinement of the main plasma were 6.7 and 4.2 m, while the length of the confinement region for the main plasma was 30 m. Here, by assuming that ions and electrons were in a thermal equilibrium state, we set the temperature $T_i = T_e = 118$ keV on the magnetic axis. We assumed that the initial density was uniform at $1.97 \times 10^{20} \text{ m}^{-3}$. The toroidal magnetic field at the magnetic axis of the main plasma was 4.33 T, which corresponded to the local toroidal beta value of 0.20. In the present calculation, the characteristic Alfvén time τ_A was

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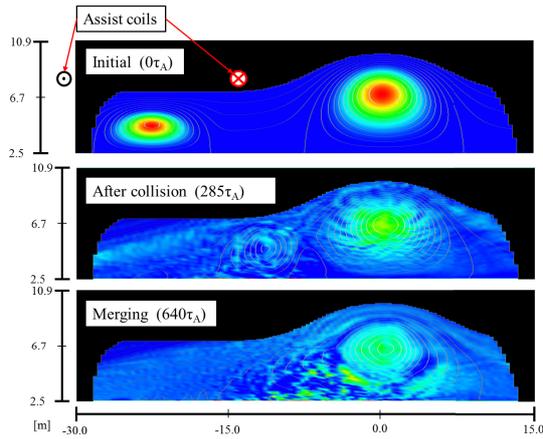


Fig. 1 Color contour plot of plasma pressure and contour line of magnetic field integral values $\psi(r, 0, z)$ on r - z plane ($\theta = 0$) at $t/\tau_A = 0, 285,$ and $640,$ respectively. Pressure value was normalized by toroidal magnetic pressure.

$2.25 \mu\text{s}$ and the magnetic Reynolds number (or Lundquist number) was 2.5×10^5 . The secondary plasma was smaller and should have lower temperature than the main plasma. In the present calculation, however, the peak temperature of the secondary plasma was the same as the main plasma temperature. The subject of future research was determined as adjusting the calculation condition of the MHD simulation to the scenario of the merging fueling method for the $\text{D-}^3\text{He}$ nuclear fusion burning plasma. Additionally, flexibility will be needed in the equilibrium calculation.

The secondary plasma was located between two poloidal field coils in order to assist the translation motion. The coil currents were flowing in the opposite direction in order to accelerate the secondary plasma toward the main plasma by the magnetic pressure difference. On the other hand, the main plasma stayed at the initial position because the fixed vacuum region (the black-filled part in Fig. 1) was set around it and fulfilled the role of a virtual shell.

As a result of the simulation, the collision/merging process of the plasma shown in Figs. 1 and 2 was confirmed. Here, Fig. 1 shows the pressure profile on the $\theta = 0$ plane and the contour line of the poloidal field integral value was also drawn for the reader's reference. The Poincare plot of the magnetic line is shown in Fig. 2, where the starting point of tracking was set in the main plasma and the positions passing through the poloidal plane with $\theta = 0$ were plotted.

The figures at $t/\tau_A = 0$ in Figs. 1 and 2 corresponded to the initial state of the simulation. The magnetic surface structure at the same time in Fig. 2 coincided with the contour line of the magnetic flux in Fig. 1. The moment of $t/\tau_A = 285$ is immediately after the head-on collision between the two ST plasmas. Concurrently, as shown in Fig. 2, the magnetic lines that started tracing from inside of the main plasma, connected to the part of the secondary plasma; therefore, it could be confirmed that the magnetic

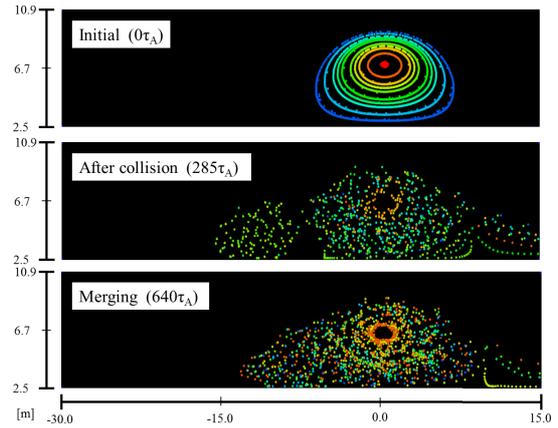


Fig. 2 Poincare plot of the magnetic lines at $t/\tau_A = 0, 285,$ and $640,$ respectively.

lines of the two plasmas were mixed. Additionally, at this stage, it could be seen that instability occurred in the two plasmas observed from the pressure distribution in Fig. 1, and the stochastic surface in Fig. 2. In the main plasma, this instability occurred at $t/\tau_A = 100$. Additionally, from the occurrence of this instability to $t/\tau_A = 285$, it was understood that the flattening of the pressure was progressing. $t/\tau_A = 640$ in Figs. 1 and 2 shows the state just after the plasma was merged. The merging, in which the secondary plasma was absorbed in the main plasma, was completed. The duration of the merging process (620 - 640 Alfvén time) was short in comparison to the time of translation/collision processes. It can be seen that the magnetic surface structure recovered in the core region due to the dissipation of the magnetic field's high wavenumber component, which was caused by instability and the merging process. It can be hypothesized that the reconnection of the magnetic lines of the two plasmas occurred, and that the secondary plasma was suddenly drawn into the main plasma by the tension of the magnetic field.

Despite the collapse of the magnetic surface in the merging phase, a sharp increase in the number of ion particles contained in the main plasma was observed from the particle-tracking calculation. This increase was found to be approximately 10% of the ions initially held by the secondary plasma. A detailed investigation on particle fueling will be carried out in a subsequent study. Based on the findings of this preliminary study, since ballooning instability was observed during the merging phase, further research should focus on the wide parameter range without instability, and investigate the magnetic surface structure and the exchange of particles between the two plasmas during the merging process of the two ST plasmas.

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