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Effect of interaction between current outside plasma and the MHD equilibrium on the current decay time during the current quench phase in tokamak disruption discharges

トカマクディスラプション時のプラズマ外電流とMHD平衡の相互作用の研究

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In order to study the effect of the plasma current profile on the growth rate of the VDE and the current decay time during the tokamak disruptions, the plasma behavior is analyzed in a JT-60U disruptive discharge by DINA code, which is one of the most popular MHD analysis codes during the disruption phase. We find that the plasma current profile would affect the VDE growth rate and the plasma current decay time in the disruption phase.

Major disruption in tokamak plasmas is one of the most important issues to be resolved in the development of nuclear fusion power plant. Especially, the suppression of the VDE (Vertical Displacement Event) is very important because it would make the fatal damage to the device through the induction of the halo current. Recently, some effective operational method to avoid the disruption are under development based on the experiment and the numerical calculation. However, the avoidance methods of the disruption and the suppression method of the VDE has not been established.

According to the previous researches of the disruption in JT-60 tokamak[1,2], disruptive discharges with the VDE and the fast current quench, which is characterized as the current decay time normalized by the plasma poloidal cross-section is less than 3ms/m^2, were often observed. The plasma current decays to keep the averaged current density constant in time, which suggests that the reduction rate of the plasma cross-section area due to the VDE determines the current decay time. In another numerical analysis of the disruptive discharges[3], the authors found that the growth rate of VDE strongly depends on the vertical magnetic axis location just before current quench start, the growth rate of VDE was predicted small enough when the axis location is set at a special point ("neutral point). The application of the proposed operational method based on the above results enabled the JT-60 plasma to make the strongly reduced vertical displacement and the slow current quench in a disruptive discharge[4]. However, in the above previous researches, the effect of the plasma current profile on the VDE growth rate and the current decay time has not been taken into account. The vertical positional instability, which would be related with growth rate of VDE, strongly depends on the plasma current profile because the driving force of the instability is the electro-magnetic force between the plasma current and the magnetic filed in the torus-major radial direction.

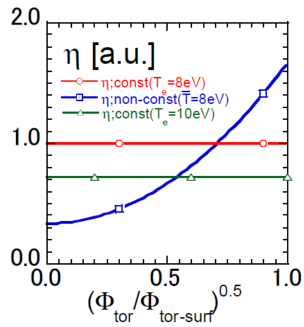

Fig1. The resistivity profiles.

In this paper, we numerically study the plasma current profile dependence on the VDE growth rate and the current decay time during the disruption phase in JT-60U by the DINA [5] code, which take the time-dependent interaction between the external coil current, the eddy current and the plasma current into account, and it was used in Ref.[2]. The analyzed discharge is #31780 discharge of JT-60U, same with that in Ref.[2].The calculations start just after the current quench starts. The initial MHD equilibrium configuration is evaluated from the FBI code [6] and the magnetics data. Here the resistivity is set constant in time, but it has the radial profile as shown in Fig.1 through the electron temperature(T_e) and/or Z_{eff} radial profiles because our concern is the

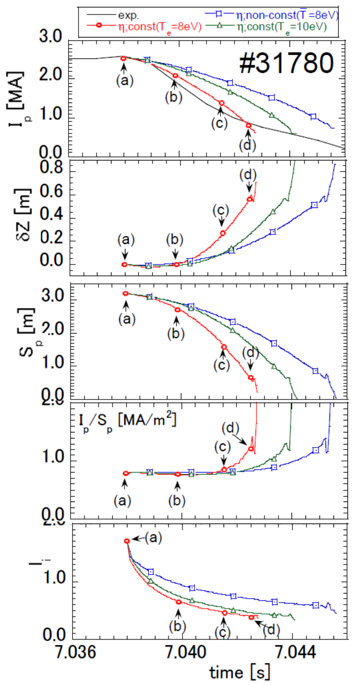

Fig.2 Time evolution of plasma parameters.

plasma current profile effects on the VDE and the current decay. It should noted that in DINA code, the plasma current profile is determined by the diffusion equation of the poloidal magnetic field, its boundary condition is determined by time-evolution of the coil currents and the eddy current profile. And it should be noted that in Ref.[2], the resistivity changes in time, and is constant in space because their concerns are the development of the methods to determine the T_e and the Z_{eff} consistently with the joule heating and the charge state equations.

Figure 2 shows the calculation results. The 1st upper, the 2nd, the 3rd, the 4th and the bottom figure corresponds to the time evolution of the plasma current, the displacement of the vertical location of the plasma current center, the plasma poloidal cross-section area, the averaged plasma current density and the internal inductance, respectively. The thin black , the red, green, and the blue curves corresponds to the experimental data, the cases that the resistivity is constant in space with T_e=8eV and Z_{eff}=3, the resistivity is constant in space with T_e=10eV and Z_{eff}=3, and the resistivity has the radial profile with averaged T_e~8eV and Z_{eff}=3. In the spatially constant resistivity cases, the lower the resistivity is, the longer the current decay time is, and the slower the VDE and the reduction of the plasma cross-section area. In the case that the resistivity has the peaked radial profile, the current decay time is longer, the VDE and the reduction of the plasma cross-section area is slow comparing with the specially constant and same averaged resistivity case. In all cases, the averaged plasma current density keep constant till the plasma currents reach the half at the initial plasma current, which means the current decay time determine by the growth rate of VDE in all cases. Figure 3 shows the plasma boundary shapes at the times shown by (a), (b), (c) and (d) in Fig.2. The thin black curve in Fig.3 shows a limiter in JT-60U. Figure 3 shows that the displacement of the plasma current center to the top left and the consequent plasma touch to the limiter leads to the plasma poloidal cross-section area reduction. The time evolution of the l_i shows that of the plasma current profile. In the all cases, the internal inductance decreases, which means the current profile is getting broad in time. The reduction rate of the l_i little depend on the value of the resistivity, but the reduction rate in the case that resistivity has a peaked profile is lager than that in the specially uniform resistivity.

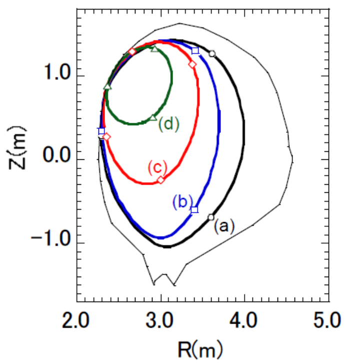

Fig.3 Time evolution of plasma shape.

We find that the plasma current profile would affect the VDE growth rate and the plasma current decay time in the disruption phase by the value and the profile of the resistivity. The study of the initial plasma current profile effects on the VDE growth rate and the current decay time is the near future subject. And the study of the relationship between the growth rate of the vertical positional instability and the VDE is another future subject.

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