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Evaluation of Current Quench Decay Time in Tokamaks and Investigation of Its Behaviours

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1. Introduction

The tokamak disruption, which is accompanied by an intense heat load on the divertor during thermal quench and large electromagnetic (EM) force on the in-vessel components during current quench, is one of the important issues for the next generation tokamak, like ITER [1]. Recently, prediction and mitigation techniques have been considerably developed. The database of current quench decay times during disruption has also been set up among the different tokamaks [2]. In the database of current quench decay time in several tokamaks, the current quench decay time normalized to the plasma cross-section area S is plotted as a function of the before disruption average current density. The characteristic current quench decay time $\tau = L_p^{eff}/R_p$ can be rewritten in terms of the normalized quench time as

$$\frac{\tau}{S} = \frac{L_p^{eff} / 2\pi R_0}{\eta_p} ,$$

where L_p^{eff} is the effective plasma inductance, η_p is the plasma resistivity and R_0 is the major radius. Some problems, however, have been found that data of the normalized current quench decay time have large scatters among different tokamaks, as well as among different operational shots. The reason for the former comes from the different criteria among various tokamaks. It is inevitable that another criterion of current quench decay time should be proposed, and/or that other scaling formalism would be applied for the database of current quench decay times.

In the experiments of large and medium size tokamaks, it is difficult to measure inner plasma parameters, such as electron temperature T_e and plasma resistivity during disruption. For instance, ECE is not appropriate for low T_e measurement of disrupting plasma (which is about a few eVs). And it is also difficult in large and medium tokamaks to measure inner magnetic fields with probes inserted deep into the hot plasma directly.

2. Evaluation of current quench decay time in JT-60U and HYBTOK-II

As mentioned above, it is necessary to prepare a new criterion of current quench decay time. There are many factors which influence tokamak discharge during disruption, such as location of plasma (shape), plasma shifting rate, interaction between vessel and plasma. To evaluate the magnitude of EM force during current quench, we have proposed a new criterion of current quench decay time, which is taken into account both dI_p/dt corresponding to magnitude of EM force induced by current quench and the impulse on the vacuum vessel. We define current quench decay time $\tau_{proposed}$ as the time-width which gives 60% of the whole plasma current (see Fig.1). This criterion represents time-width of the impulse with a dominating EM force. We have applied our proposed criterion to JT-60U as well as the small research tokamak, HYBTOK-II [4]. In Fig.2, plots of initial plasma current density j_{p0} against normalized decay time τ/S, are shown for (a) in JT-60U and (b) in HYBTOK-II, comparing two types of decay time; time-width for plasma current decreasing from 80% to 20% $\tau_{80\text{-}20}$ which has been used in ASDEX-U and C-Mod, and proposed current quench decay time $\tau_{proposed}$. It is seen that disruptive plasma current has many kinds of waveform. For instance, they contain a long tail, coming from runaway electrons caused by disruption. For applying evaluation method of current quench decay time to such a variety of plasma current waveform, our criterion has an advantage that it focuses on the period during which plasma current may decay with a dominating EM force. Therefore, our proposed criterion for current quench decay time is less

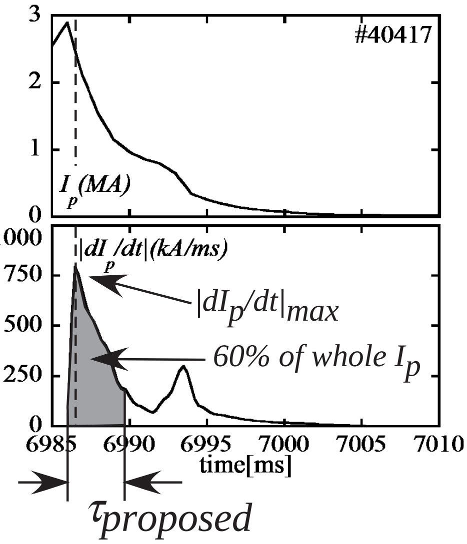

Fig.1 Typical waveform of plasma current and its time differentiation in JT-60U.

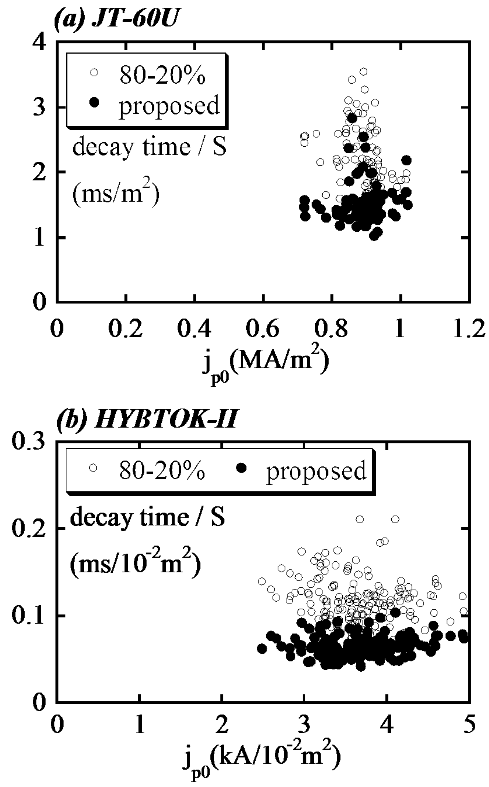

Fig.2 Normalized current quench decay time compared between $\tau_{80\text{-}20}$ and $\tau_{proposed}$ versus plasma current density before disruption.

influenced by the variety of waveform. It is seen in Fig.2 that the plots based on current criterion have a larger scatter than those based on new criterion in both tokamaks. The variance of plots on the current criterion and the new one in JT-60U is 2.69 [ms/m^2] and 0.98 [ms/m^2], respectively. Also, in HYBROK-II, it is 1.33 [10^{-2}ms/m^2] on the current criterion and 0.17 [10^{-2}ms/m^2] on the new one.

3. Direct Measurement of Inner Plasma Parameters during Disruption in HYBTOK-II

The HYBTOK-II tokamak has an advantage that the electron temperature T_e and/or magnetic fields in the core plasma are able to be measured directly with probes. To take this advantage, we have investigated the inner plasma parameters during disruption. In HYBTOK-II, the plasma current decreases through the phases of slow and then fast decay during current quench. In the experiments, a very rapid decrease (10-30 μs << current diffusion time) of the poloidal magnetic field B_θ at an inner radial position has been observed just before the onset of current quench (see Fig.3). It indicates that the inner plasma current was expelled out promptly just before current quench. Furthermore, in local profile measurement of the T_e with triple probe, we have observed its parabolic profile flattening along the radius with time during disruption (see Fig.4).

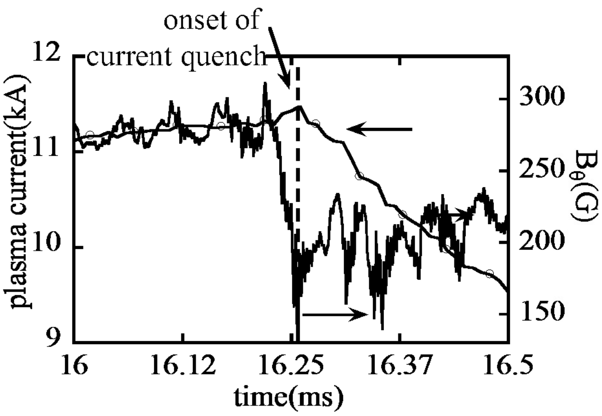

Fig.3 Temporal evolution of inner poloidal magnetic field at inner radial position (ρ=0.55).

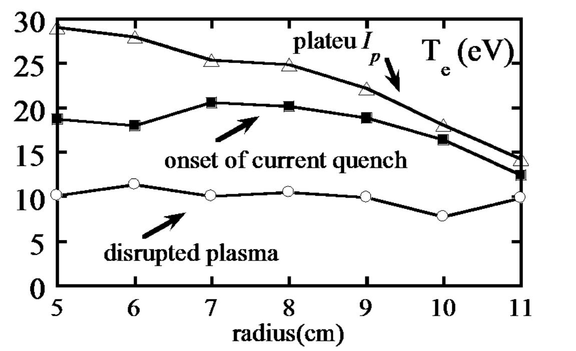

Fig.4 Electron temperature profile.

4. Summary

In addition to the current criterion of plasma current quench decay time in JT-60U, we have proposed a new criterion and applied it to disruptive shots in JT-60U as well as in HYBTOK-II to compare with $\tau_{80\text{-}20}$. In the experiment in HYBTOK-II, we have observed the temporal evolution of T_e and B_θ with probes inserted deep into the plasma during disruption. A very rapid decrease of B_θ has been observed at inner radial positions just before the onset of current quench.

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