*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-2.176 (2006)*

Characteristic of Disruption on HL-2A

Hangyu ZHOU, Qingwei YANG, Beibin FENG, Zhongbin SHI, Wei CHEN, Zhengying CUI, Wei LI, Yudong PAN, Yi LIU, Xianying SONG, Xiaoquan JI, Xuantong DING

Southwestern Institute of Physics, P.O.Box 432 Chengdu 610041,China

The tokamak disruption is a dramatic event in which the plasma confinement is suddenly destroyed. Detailed experimental studies of disruptions have been made in many machines. During a disruption, the plasma current and plasma thermal energy content collapse in an uncontrollable way, thereby applying mechanical forces and heat loads onto the vacuum vessel components. For that reason, the disruptions in a tokamak must be characterized and the physical processes leading to and occurring at the disruption understood.

The HL-2A tokamak (with major radius of R = 1.65m and minor radius of a = 0.4m) is operated in the following parameters: plasma current I_P = 100~400kA, toroidal field B_T = 1~2.7T, discharge duration t = 1~3s, line-average plasma density $n_e = 0.6\sim6\times10^{19}m^{-3}$, and electron temperature T_e = 600~1200eV.

After statistic of two hundreds discharges for hard disruption, the relation between current decay time and proportion are given in Fig.1. The current decay time derived from 100%-10% current magnitude in HL-2A, current magnitudes are measured relative to the initial before disruption plasma current. It is imply that the current quench time for ninety-five percent of the hard disruption is not more than 10ms and for half of the hard disruption is between 4ms and 5ms.

Fig.2 shows the results of analysis of current quench data, in which the current quench time t_{dura} divided by the plasma cross-section area and S is plotted as a function of the before disruption current density $j_{po}=I_{po}/S$. Here, I_{po} is the pre-disruption plasma current, $S=\pi a^2$ is the before disruption plasma cross-section area, and the current quench time t_{dura} represents the '90% linear decay' time (the time require for a 90% drop in the plasma current). The data given in Fig.2 imply that the normalized quench time is essentially independent of device configuration (limiter or divertor), toroidal magnetic field strength and before disruption plasma current density.

A lower bound on the normalized quench time can be obtained by a model [2] for the current quench phase in which the current quench time $t_{cq}=L_{eff}/R_p$ can be rewritten in terms of the normalized quench time as

$$\frac{t_{cq}}{S} = \frac{L_{eff}/2\pi R_0}{\eta_p} \qquad (1)$$

where L_{eff} is the effective plasma inductance, R_p is plasma resistance, R_0 is the major radius, and resistance rate $\eta_p = R_p S/2\pi R_0$. For fast current quench phase, the current decay rate is mainly determined by the plasma inductive energy internal to the vacuum vessel. Therefore, the effective plasma inductance L_{eff} can be rewritten by formula (2)

$$L_{eff} = 1.2\mu_0 R_0 l_i/2 \qquad (2)$$

where l_i=0.7 plus 20% flux between plasma boundary and first wall. Assuming power balance between joule heating from the decaying plasma current and impurity radiation loss, the average plasma resistivity can be given by formula (3)

$$\eta_p = \left(\frac{n_e}{j_p}\right)^2 f_Z L_Z(T_e) \qquad (3)$$

where n_e, f_z, L_z are respectively the average electron density, impurity fraction, the impurity radiation rate assuming coronal equilibrium. So the normalized current quench time can be determined by plasma current density j_P and the average electron temperature T_e. Fig.2 gives the normalized current quench time for electron temperature T_e=6ev. If the impurity flux is insufficient to cool the whole plasma in the current quench phase, the average temperature corresponding to the quench time is higher and it can reach to 10~20ev.

In current quench phase, the current decay results in loop voltage rising. The large loop voltage is the main reason for the runaway electron generation. So the relation between the current average decay rate $-dI_p/dt$ ($dI_p/dt=(I_{po}- I_{p1})/(t_0-t_1)$, I_{po} is the plasma current at the beginning of the disruption. I_{p1} is 10% of the plasma current at the beginning of the disruption) and maximal loop voltage vl (Fig.6) during current quench phase need to be investigated. Assuming that loop voltage in current quench phase is only caused by poloidal magnetic flux variation generated by the current decay, it can be presented in formula (4). Assuming that the magnetic field surround by voltage loop is generated by cylindrical plasma, the poloidal magnetic field can be given by formula (5).

$$V = -\frac{d\psi}{dt} \tag{4}$$

$$\psi = \int \overrightarrow{B_p} * d\vec{S} = \int_0^{R_l} \frac{\mu_0 I_p R}{(R_0 - R)} dR \tag{5}$$

$$V = -\frac{dI_p}{dt} \int_0^{R_l} \frac{\mu_0 I_p R}{(R_0 - R)} dR = -c\frac{dI_p}{dt} \tag{6}$$

where c is a constant, I_p is the plasma current, R is the major radius, R_0 is the distance between magnetic axis and equipment center, R_l is the distance between voltage loop and the equipment center. The result in formula (6) implies the loop voltage is proportion to the current decay rate. Statistics of the experiment data are consistent with simulation result, seen in Fig.3.

MHD instability seen as a precursor before a disruption trends to be caused by a locked m=2 mode. In HL-2A, about 85% of the shots accompanied by a locked mode are hard disruption. In about 50% of the hard disruption, a locked mode was recognized to be a precursor event [1]. Fig.4 shows the time interval between the occurrence of a lock mode and the occurrence of hard disruption. About 50% of the shots (Fig.4), the time interval is less than 10ms. For most of the other shots, the time interval is between 20ms and 50ms. For the disruption in which the time interval is between 20ms and 50ms, we have enough time to avoid it or mitigate it by estimating the MHD perturbation signals.

In two years experiment, about 20% of the disruptions are secondary disruption. It is important to investigate the secondary disruption for avoiding and mitigating major disruption. To investigate the secondary disruption, the time interval between occurrence of the minor disruption and occurrence of the hard disruption is counted, see in Fig.5. It is indicate that for 85% of the secondary disruption the time interval is between 20ms and 90ms.It is possible to be avoided and softened for major disruption in these secondary disruptions by identifying the minor disruption signals.

References:

[1] Yang Q W, Zhou H Y, Feng B B et al 2006 Chin. Physics 23 891.
[2] ITER Physics Basis 1999 Nucl.Fusion 39 2137

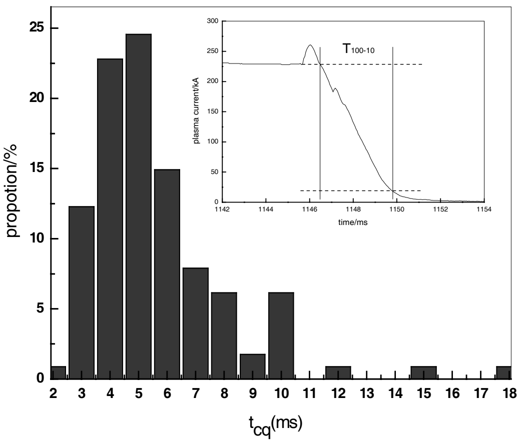

Fig.1 Histogram of current quench time obtained from 100-10% current thresholds in HL-2A

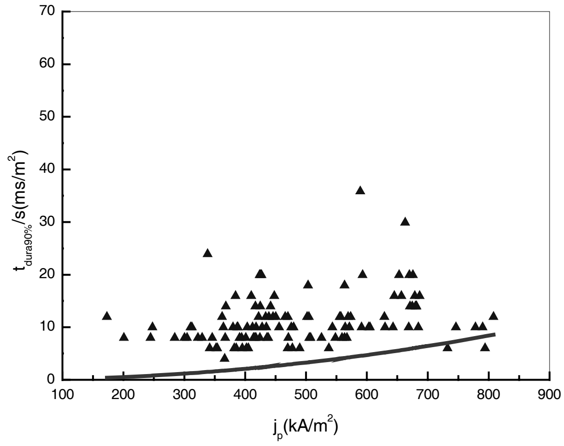

Fig.2 Time average current quench times divided by plasma cross-section area versus plasma current density before disruption

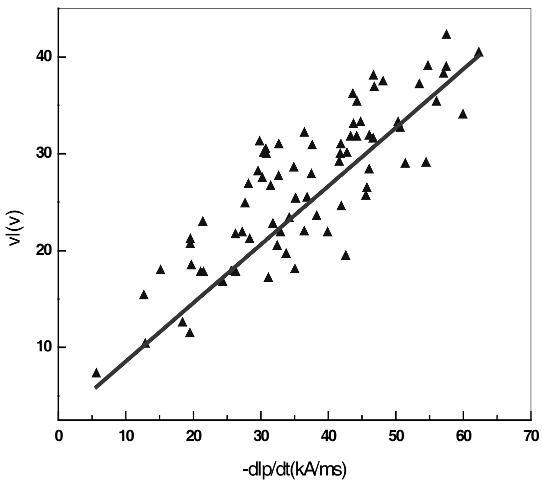

Fig.3 The current average decay rates versus the maximal loop voltage during disruption. The triangle symbol stands for the experimental data and the line stands for the simulative results

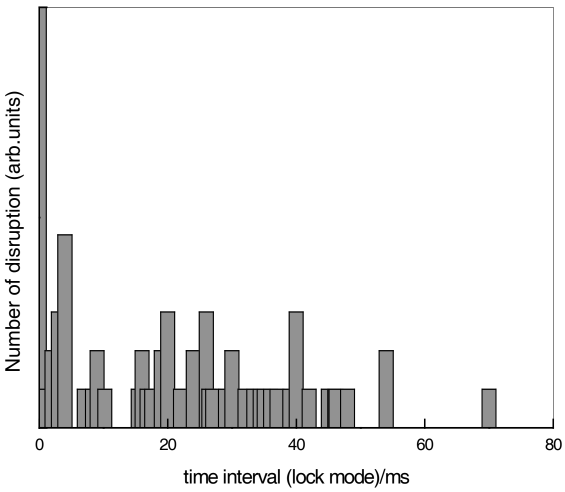

Fig.4 The relation between time interval and number of disruption

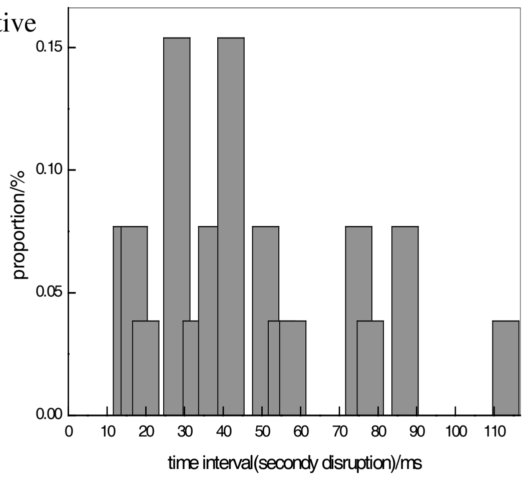

Fig.5 The relation between time interval and disruption proportion