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Investigations of disruption on the HL-2A tokamak

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Major disruption is a serious problem for tokamak operation. The major disruption can be caused by several reasons, for example, the low-q discharge, the MHD instability and mode locking, the vertical displacement events (VDEs) and the high density operations. When the major disruption occurs, it can not only generate great heat loads on the first wall and divertor plates, but also leads to the large electromagnetic force because of the halo current. Therefore, how to avoid the disruption is an important issue on tokamak operation. To control and mitigate it, the mechanism and the characters of disruption have to be well known. A lot of experimental and theoretical studies of the major disruptions have been presented.

The HL-2A tokamak [1] (R=1.65m and a=0.4m) has a close, symmetric and double-null divertor. It can be operated in the parameters of plasma current I_P=480kA, toroidal field B_T=2.8T and discharge duration T_D=5.0s with double null or single null divertor configuration. The lower single null (LSN) divertor configuration has been achieved [2] by utilizing the plasma current and position feedback control.

To understand the disruptions, the Hugill diagram is commonly utilized to describe the discharge regimes. In the high density operations on HL-2A, some shots which are W/O disruption are given in Fig.1. The trajectories in blue and in cyan are stopped at the red star symbols which present the disruptions. The red stars are very close to the Greenwald limit, which implies that they are density limit disruptions. The red and orange traces present the evolutions of disruption free

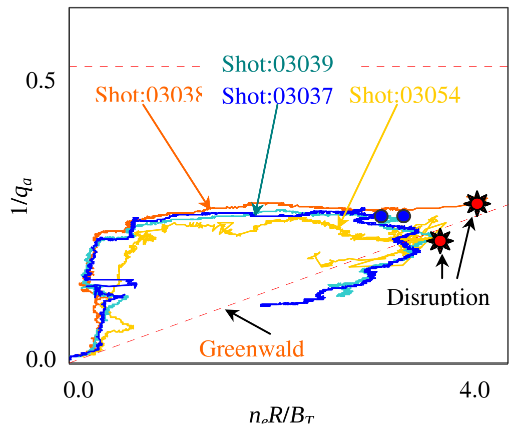

Fig.1. Discharge trajectories, w/o disruption discharges on Hugill diagram. The red star symbols denote the place of disruption occurrence, and the blue solid circles indicate disruption free discharges.

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discharges. The blue solid circles imply that the highest plasma densities are reached in the plasma current plateaus (i.e. in the maximum plasma current of each shot). Then the plasma current decreases and the plasma density increases continually. In this case, the Greenwald limit can be easily exceeded.

The evolutions (disruption discharge, shot 03038) of plasma radiation, impurity radiation, plasma density, electron temperatures, and soft X ray emission are presented in Fig.2. When the last sawtooth collapses at t=462ms, the normal plasma operation ends. From this time, the electron density $\bar{n}_e$ increases rapidly. Simultaneously, the soft X ray emission crashes, and the plasma thermal channel begin to shrink. In fact, the electron temperature at the edge region decreases early than it is at the plasma core. The similar feature is also found in the image of soft X ray emission. In addition, the plasma radiations what are detected from edge chord (r=-38cm) and central chords (r=3cm and r=-20cm) increases and decrease only a little respectively. The negative r in T_e signals means that the measurement point is in the high field side. But the negative value of r in the plasma radiation signals mean that it is below the mid-plane. Considering the enhancements of impurity radiation, we notice that the CIII radiations increase a little. The MARFE formation does not be observed. It is suggested that the impurity radiation is not the most important reason for disruption in this shot. At t=470ms (denoted by the second dashed line in Fig.2), the electron central temperatures and the soft X ray emission begin to collapse. 2ms later (t=472ms), the electron temperature almost decreases to the half of

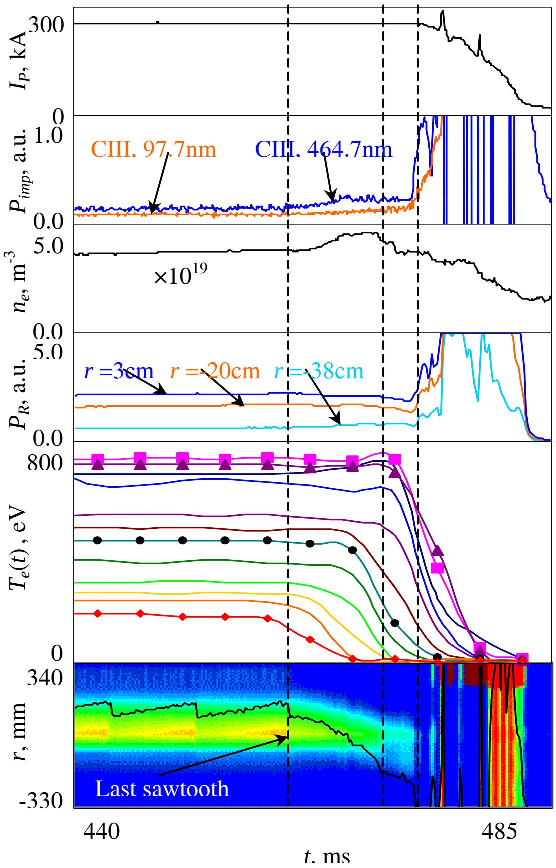

Fig.2. Evolutions during density limit disruption. From the top down, are the plasma current, impurity intensities, electron density, plasma radiations, profiles of electron temperature, and the soft X ray emissions, respectively. In the electron temperature block-frame, the marks ◊ and Δ denote that the electron temperatures $T_e(r)$ are at the different minor radius. The black trace in the bottom block-frame is the intensity of soft X ray emission. Its profile is presented by an image.

the original value, and the intensity of soft X ray emission drops to zero. At this time, the plasma current begins to quench, and the extreme burst of plasma radiation occurs, as presented in Fig.3. The strong radiation starts from plasma central region when the electron temperature drops down (t=472ms). And a kink-like formation of radiation is observed. The kink-like radiation is believed that it is with an m=1 formation and occupies the most of central plasma, as shown in Fig.3. We can not associate this m=1 radiation with the MHD instabilities because no MHD perturbations are detected in this period. After the kink-like radiation, the plasma radiation suddenly increases to a higher level within very short time.

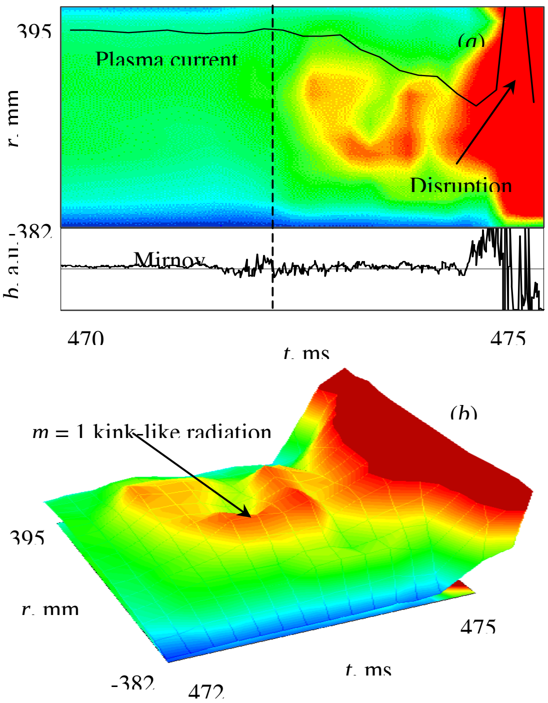

Fig.3. Evolutions of plasma radiation at disruption. a) are the waveforms of plasma current (the black trace), image of plasma radiation, and MHD perturbation $\tilde{b}$. b) is the 3-D representation of plasma radiation.

To contrast with shot:03038, the different characters of density limit disruption are presented in Fig.4. In this shot (shot:03054), duration of plasma current damping down spends about 120ms accompanying by a series of soft disruptions. When the value of $\bar{n}_e/n_{GW}$ (plasma density/Greenwald density) keeps at about ~1.0, a series of soft disruptions occur in t=475ms~560ms (from the first to the third dotted line). The soft disruptions can be determined by the observations of spikes on the waveforms of loop voltage, hard X ray and impurity emission signals.

Although the soft disruptions gradually lead to the losses of plasma store energy and the decrease of central electron temperature during t=500~560ms (from the second to the third dotted line), but the contraction of electron temperature profile is not observed, as shown in Fig.5. In this period, the impurity emission and hard X ray radiation don't enhance obviously. It indicates that no huge store energy is released by plasma radiations, and no much runaway electrons is produced. Because the plasma density keeps constant, it is reasonable to believe that the balance between Ohmic power input and the losses of plasma energy and particles is maintained. However, the maintenance of plasma density after $t\approx$500ms implies that the anomalous particle outflux disappears.

The major disruption occurs at t=560ms. The central electron temperature drops down, its profile become narrow and the plasma thermal channel shrinks from 560ms. Central temperature decreases a lot and has an obvious outward shift. This is the typical feature of contraction of plasma thermal channel. And then it leads to the plasma current rapid quench at t=570ms.

The density limit disruption often occurs when the discharges approach the Greenwald limit in HL-2A Ohmic plasma. The disruptions usually undergo two stages. Firstly: soft X ray emission decreases, and profile of electron temperature begin to shrink then to collapse. The plasma radiation doesn't have an obvious enhance and the plasma current doesn't quench. This stage lasts about 8~12ms. The second: the huge of storage energy loses, and the plasma current quenches. The plasma radiation extreme burst, and the plasma current drops to zero. The major disruption always occurs after the electron temperature shrinkage and collapse. The contraction of plasma thermal channel maybe plays a key role in major disruptions.

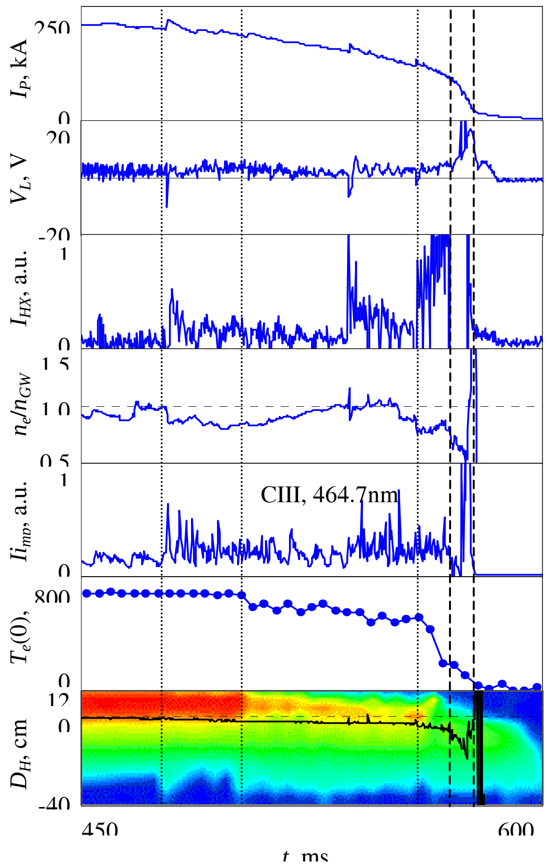

Fig.4. The evolutions during disruption. From the top down, are the plasma current, loop voltage, intensity of hard X ray radiation, ratio between plasma density and Greenwald density limit n_e/n_{GW}, impurity emission, central electron temperature, horizontal plasma displacement D_H (with black trace) and the profile of electron temperature which is presented by an image, respectively.

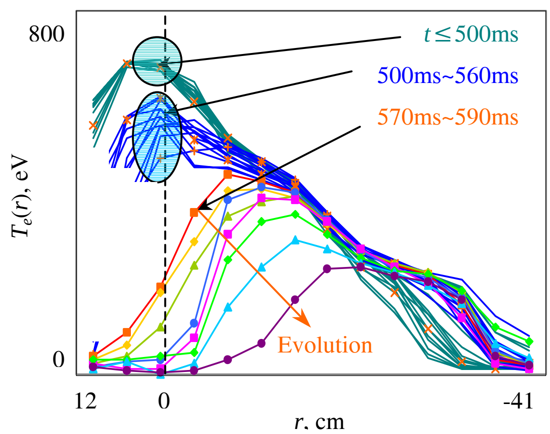

Fig.5. Temporal evolution of the electron temperature profile $Te(r)$ during disruption.

[1] Liu Y, Yan J C, Zhou C P, et al, Nucl. Fusion 44 (2004) 372.

[2] Yang Q W, Ding X T, Yan L W, et al, Chin. Phys. Lett. 21 (2004) 2475.