Study of Current Oscillations and Hard X-ray Emissions in Pre-cursor Phase of Major Disruptions in Damavand Tokamak

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Abstract. In a previous report, it had been noticed that during the rapid phase of the plasma in Damavand tokamak, disruption groups of fast neutrals were injected into the plasma core from the edge of the plasma column at a frequency of 8kHz. Also during the pre-disruption stage, the regular oscillations of the transverse fluxes of low energy neutrals at the same frequency of 8 kHz were observed at the periphery of the plasma column. In this report, we notice that the plasma current just after the beginning of the major disruption is accompanied by a series of similar in-phase oscillations at the same period of hard x-ray emissions. Hard x-ray activities before disruption consist of series of spikes. We have detected that the set of spikes are uniformly distributed in time domain, forming an orderly periodic series of oscillations at a frequency of 6.0kHz. Since, these oscillations follow the oscillation phase of hard x-rays even after finishing hard x-ray activities, it is concluded that runaway electrons, which are responsible for the production of hard x-rays bursts and small current oscillations, are incorporating significantly in the disruption mechanism as well.

1. Introduction

In a previous report, the results of a study of processes accompanying the major disruption in the Damavand tokamak were presented [1]. The basic parameters of Damavand are listed in Table 1.

Maximum Plasma Current	Elongation	Major Radius	Minor Radius	Aspect Ratio	Toroidal Field	Discharge Time
38kA	<1.5	36cm	7cm	5.1	1.2T	<25ms

TABLE 1. Basic parameters of Damavand tokamak.

Measurements of the radial profiles and energy distributions of neutral fluxes during the rapid phase of a disruption show that groups of fast neutrals with energies E_n = 0.3–1.0 keV are injected into the plasma core from the edge of the plasma column at a frequency of 8kHz. During the pre-disruption stage, the regular oscillations of the transverse fluxes of neutrals with energies E_n < 1.5 keV at a frequency of 8 kHz were observed at the periphery of the plasma column. The line emission of impurity ions, which can be associated with the population of excited states through charge-exchange correlates with the increase in oscillations observed in the transverse neutral flux.

Here, we notice that the plasma current just after the beginning of the major disruption is accompanied by a series of similar oscillations at the same period of hard x-ray emissions. Since these oscillations are both in-phase and in-frequency with hard x-rays, it is possible to conclude that runaway electrons play an important role in triggering the major disruption in Damavand.

2. Results and Discussions

In Figs. 1-3, the profiles of measured plasma current, loop voltage, and hard x-ray emissions are recorded for three typical shots. The peak plasma current in all figures is about 5kA. The disruption has been induced by suddenly increasing the loop voltage to some extent. The plasma current starts to grow up to approximately 1kA, and disrupts about 1ms after then.

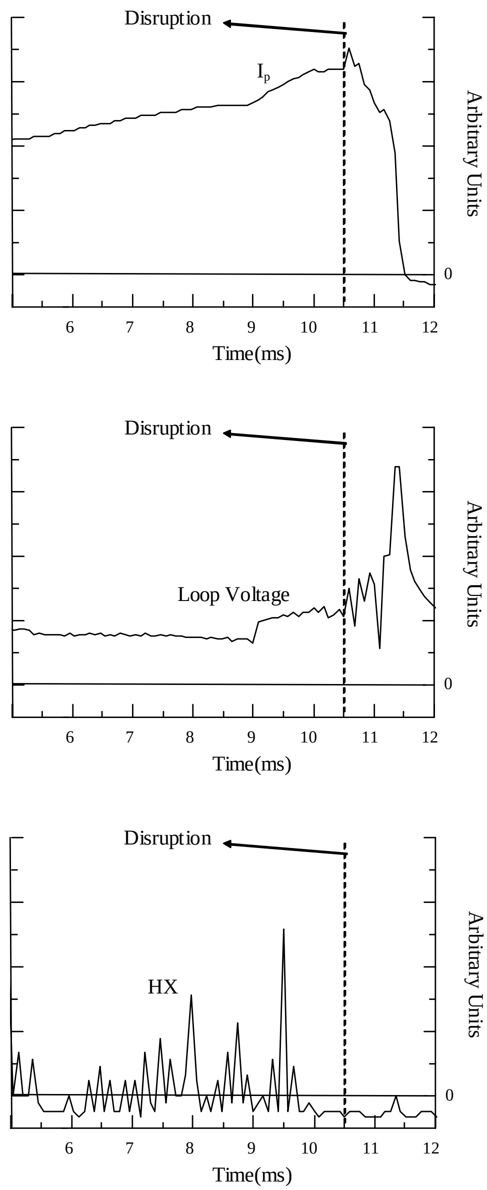

FIG. 1. Plasma current, loop voltage and hard x-ray in shot 1.

Before this period, emission of hard x-rays due to runaway electrons is oscillating exactly at the same frequency and at the same phase. As it is evident from the figures, the hard x-ray activity before disruption consists of a series of spikes. Each spike is connected to a relaxation in the electron velocity distribution function [2]. The set of spikes are almost uniformly distributed in time domain, forming an orderly periodic series of oscillations. We have measured the frequency of these oscillations to be roughly 6.0kHz.

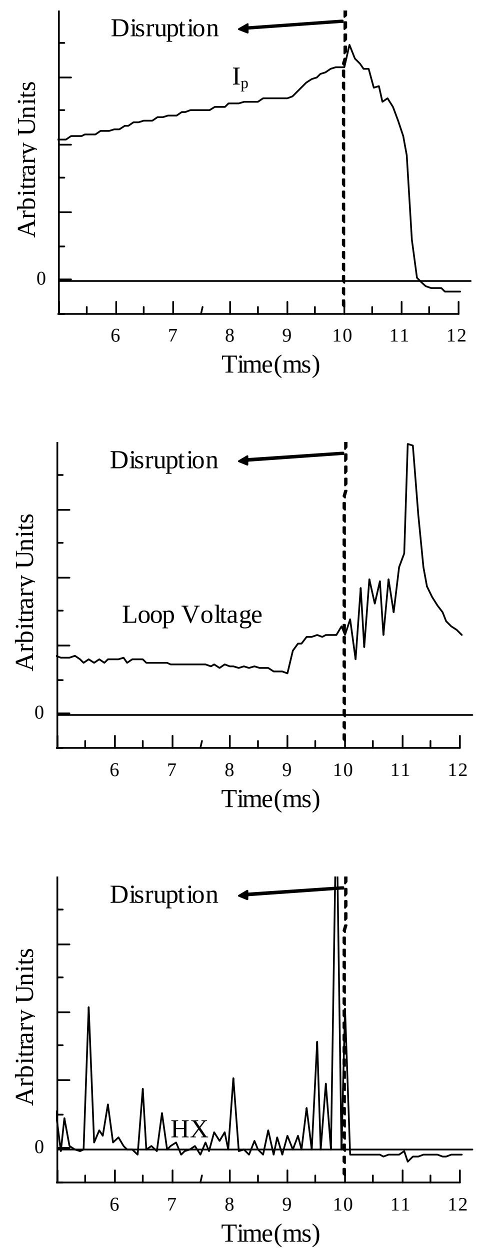

FIG. 2. Plasma current, loop voltage and hard x-ray in shot 2.

The disruption starts with an initial fast current rise followed by current decay. This is due to the rapid reduction of internal inductance. Since the stored magnetic energy cannot be lost so fast, the plasma current rises initially. Correspondingly, the loop voltage increases simultaneously. The decay of plasma current occurs in two regimes: the first regime corresponds to slow decay, in which the plasma current is oscillating and reducing down to ~70% its maximum value, and the second regime corresponds to fast decay, in which the plasma current totally vanishes abruptly in about 0.2ms. In the first regime, the loop voltage also oscillates with large amplitude. As is evident in all figures, there is no appreciable hard x-ray activity after disruption. This is in justification of what is widely believed to happen after disruption due to major loss of runaway electrons.

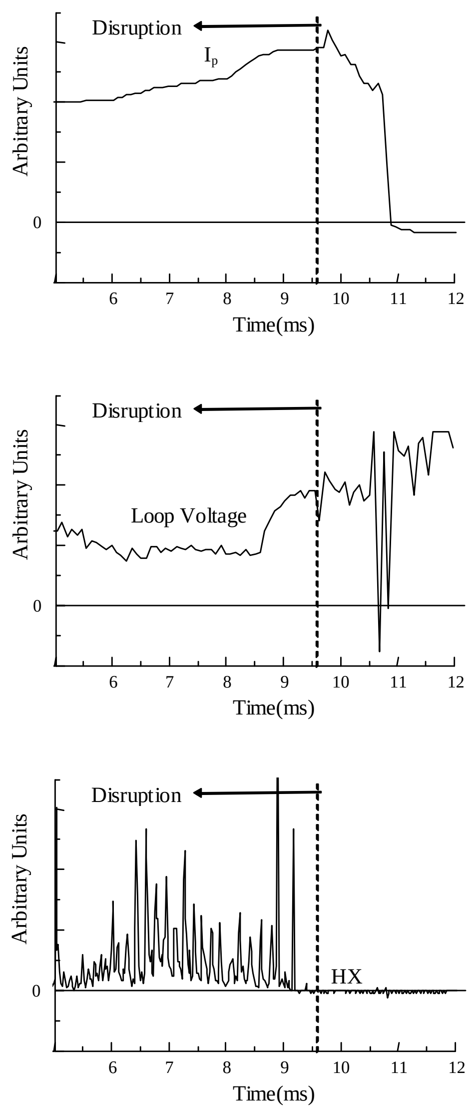

FIG. 3. Plasma current, loop voltage and hard x-ray in shot 3.

The frequency of oscillations in the first regime is measured to be about 6.0kHz, being equal to the value for hard x-ray oscillations. Meanwhile, these oscillations follow the oscillation phase of hard x-rays even though there are no detected hard x-rays. Therefore it can be concluded that the micro-instabilities driven by runaway electrons, which are believed to be responsible for the production of hard x-rays bursts and small current oscillations, are incorporating significantly in the disruption mechanism as well.

Fig. 3 presents another shot with considerably higher hard x-ray activity prior to disruption, but one can notice that the frequency of hard x-ray oscillations is still the same. It is extremely interesting that the loop voltage oscillations after disruption have the highest amplitude comparing to the previous figures. This shows that these oscillations are not driven simply by runaways, and a more complicated mechanism is behind this behavior, linking them possibly to bulk m=2 tearing instabilities.

Of course, runaway electrons are unlikely to be the main cause for major disruptions in Damavand. Because first of all, *m*=2 on-axis tearing modes are supposed to be responsible for that, being already verified experimentally on our tokamak, and secondly, all disruptions in these experiments are somehow induced externally through sudden increase of loop voltage. However, these experiments reveal that at least there is a connection between runaway electrons and disruptions in tokamaks. If there is a reverse mechanism, it would be probable that unpredictable disruptions could be avoided through control of runaways.

Supports for this conclusion are: oscillations of hard x-rays and loop voltage have the same frequency, regardless of the total amount of hard x-ray activity, or equally, runaways; these oscillations follow the same phase; and there is also an apparent correlation between the amplitudes of hard x-ray bursts before disruption and loop voltage peaks after disruption.

3. Conclusions

We have presented a simple analysis of hard-x ray activity and loop voltage in major disruptions in Damavand. We have noticed that hard x-rays oscillate at a frequency being almost constant, regardless of the total amount of runaway electrons. While hard x-rays are absent after the pre-cursor phase of major disruption, however, the loop voltage follows the same oscillation phase and frequency, and even amplitude to some extent. Therefore, we finally can conclude that micro-instabilities driven by runaways are somehow, directly or indirectly, tied to *m*=2 tearing instabilities, and hence major disruptions might be predictable by monitoring the pattern of runaway energies and distributions. In summary, there is still much more physics in major disruptions to be understood than expected before.

References

[1] AMROLLAHI, R., al., Plasma Phys. Rep. **23** (1997) 561.
[2] DOLAN, T., Fusion Research, Pergamon Press (1982).