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Characteristics of the FEB emission oscillations in HT-7

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Fast electron bremsstrahlung (FEB) emissions during lower hybrid current drive (LHCD) experiments in HT-7 tokamak have been measured by a recently developed tangential multi-channel FEB diagnostics [1]. The FEB system observe the FEB emissions in the energy range of 30~300keV. The sawtooth oscillations in the FEB signals have been observed in several target plasmas in HT-7 tokamak, such as in LHCD plasmas, LH wave current ramp-up plasmas, and LHCD with IBW heating plasmas. The FEB oscillations are well correlated with the soft x-ray sawtooth activities or the ECE sawtooth signals. Several different types FEB oscillations from HT-7 machine are presented in this paper.

Type 1. Inverted sawtooth-like oscillation

Typical inverted sawtooth oscillation in FEB emissions was observed in LH wave current ramp-up plasmas and LHCD plasmas with IBW heating in HT-7 machine. The LH wave with 260kW power was used to ramp-up the plasma current from 100kA to 200kA (from 0.2s to 0.85s) in #71773. The large oscillations were emerged in the FEB signals from the onset of current flattop at 0.85s. As shown in Fig.1, the oscillations in the FEB emissions are well correlated with the soft-x-ray sawtooth activity. They are peaked after soft x-ray crash with delay time of 1.2ms. There is no inversion surface in the FEB sawtooth-like oscillations.

The sawtooth-like oscillations in FEB emissions are also observed in LHCD plasma with IBW heating. A typical discharge waveform is presented in Fig.2. The line-averaged density $n_e=1.8\times10^{19}m^{-3}$. During the IBW heating phase, the sawtooth-like oscillations in FEB emissions were emerged. The FEB emissions are peaked after soft x-ray crash with delay time of 0.8ms.

Type 2. sawtooth-like oscillation

The sawtooth-like oscillations in FEB emissions are also observed in LHCD plasma with high density. Fig.3 shows the expanded sawtooth activity in LHCD plasma with Ip=160kA,

n_e=2.5×10^{19}m^{-3}, P_{LH}=390kW. The sawtooth period is only 7ms. The FEB emission is crashed as the soft x-ray sawtooth crash with delay time of about 0.6ms. After the crash, the FEB emissions increase linearly, behavior just like the soft x-ray sawtooth.

Type3. Burst of FEB emissions in sawtooth with m=1 mode activity

Burst of FEB emissions during LHCD is also observed in HT-7. In longer period (about 20ms) with m=1 mode instability in the soft x-ray sawtooth, the burst event is often observed in the FEB emissions, which is correlated with the m=1 mode activity and the soft x-ray sawtooth. The evolution of the FEB emissions is very interesting. Typical waveforms with this event is presented in Fig.4 and Fig.5 with two different expanded time slice. (Typical parameters: Ip=160kA, n_e=1.5×10^{19}m^{-3}, P_{LH}=430kW).

In LHCD discharge with IBW heated plasma, the burst of FEB is different with the LHCD only. There are bursts of FEB emissions corresponding to the soft x-ray sawtooth and m=1 mode. In the phase of LHCD with IBW heated. After soft x-ray sawtooth crash, the FEB emissions crashed with delay time of about 0.5~0.7ms, then it grew and damp slowly before the m=1 mode instability. When the m=1 mode damp, the FEB increase again. (Typical parameters: Ip=160kA, n_e=1.5×10^{19}m^{-3}, IBW power was 114kW, P_{LH}=400kW).

Discussion: The inverted sawtooth (type 1) in the FEB emissions may be correlated with the runaway loss. During internal disruption, runaway electrons travel from q=1 surface to the limiter, producing thick-target bremsstralung emissions [2]. While in HT-7 machine, the inverted sawtooth oscillations in the FEB emission in Fig.1 and Fig.2 are only observed when the current density is changing. They are believed to be the results of distribution of the current density, which will shift the drift orbit displacement of the runaway electrons at the edge of the plasma [3].

The sawtooth-like oscillation in type 2 is emerged in high performance plasma, the period of sawtooth is short, and the m=1 mode is absent. This sawtooth-like oscillation is similar with giant sawtooth in Tore Supra with ICRH in the hydrogen minority heating scheme [4]. The confinement of fast electrons may be affected by the sawtooth. When the sawtooth is crashed, it also causes the fast electrons to lost with delay time of about 0.6ms.

After crash, the confinement of fast electrons becomes better, so the FEB emissions intensity increases.

In type 3, due to the strong m=1 mode instability in the sawtooth, the FEB emissions are undergoing complicated process. The burst of FEB is strong near q=1 surface. The q=1 surface is localized at a normalized minor radius of about 0.34, as deduced from inversion radius measurements. In early time, the FEB emissions increase after damp of m=1 mode. At later time, the FEB is almost constant during damp of m=1 mode. While in LHCD plasma with IBW heating, the FEB burst in Fig.6 behavior inversely to LHCD plasma as shown in Fig.5. This may be due to the different current density profile or fast electron distribution.

Summary: The phenomenology here describes has a systematic character, and is observed in a large number of serial discharges based on the same scenario. There must exist some interaction between the fast electrons and the m=1 mode [5]. One triggers the other, or they are related together. Detailed experimental results are expected in coming campaign HT-7 machine.

References:

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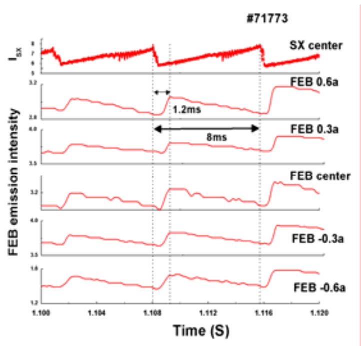

Fig.1 FEB oscillation in current ramp-up discharge (#71773).

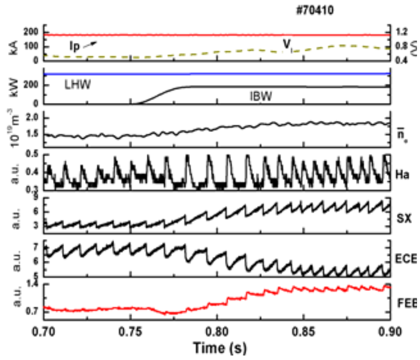

Fig.2 Waveforms of LHCD pulse during IBW heating (#70410).

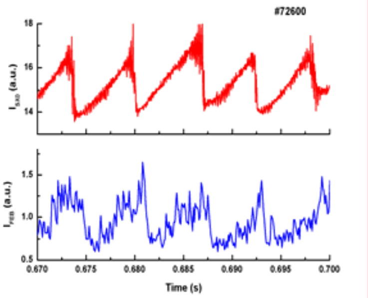

Fig.3 FEB oscillation in high density LHCD discharge (#72600).

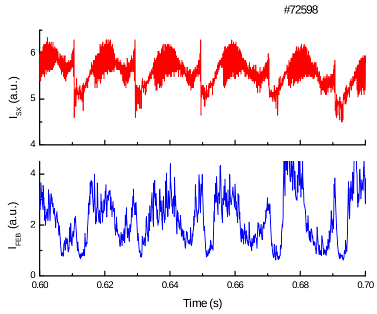

Fig.4 FEB oscillation in LHCD discharge (#72598).

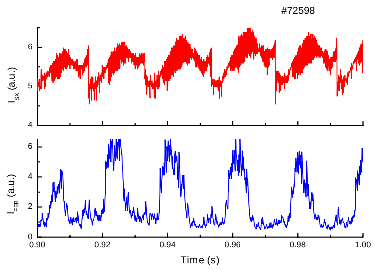

Fig.5 FEB oscillation in LHCD discharge (#72598).

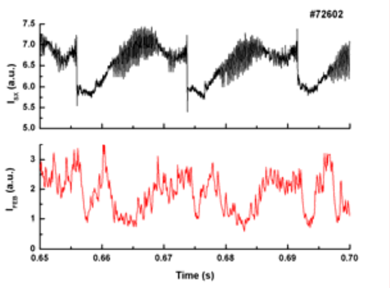

Fig.6 FEB oscillation in LHCD+IBW discharge (#72602).