ANALYSIS OF THE SPECTRAL EMISSIONS FROM MAIN AND DIVERTOR PLASMAS DURING GIANT SAWTEETH CRASHES IN JT-60U

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Spectroscopic analysis of the main and divertor plasmas produced in JT-60U Tokamak under ICRF heating was carried out by means of various VUV and visible spectrometers. Sawteeth oscillations were stabilized for ICRF powers larger than 2-4 MW resulting in giant sawteeth which terminated in violent crashes. The effects of these giant crashes were tracked down to divertor and edge regions spectroscopically.

INTRODUCTION

Sawtooth relaxation oscillation also known as internal disruption is a well known phenomenon that occurs in high temperature fusion devices which causes fast loss of confinement in the core plasma. In JT-60U tokamak (as in other large tokamaks) very long period "monster" sawteeth are excited during the application of high power ICRF. When ICRF power exceeds 5 MW, the plasma is stabilized against sawtooth instability for over 3s after which a strong crash occurs either at the end of the ICRF pulse or after its turn-off [1]. A spectroscopic analysis of the main and divertor plasmas of JT-60U under ICRF heating of different powers was carried out by means of various VUV and visible spectrometers [2] including a high spatial resolution 38 channel filter system looking at the divertor plate region [3]. Most important results from this analysis included the observation of the impurity accumulation during sawteeth stabilization and the pronounced effects of the giant crash on the divertor plasma emissions.

SPECTROSCOPIC ARRANGEMENTS

The set-up for the spectroscopic observations of the plasma in this experimental phase in JT-60U are indicated in Fig. 1 where the geometries of other diagnostics essential for our data base as FIR interferometry, bolometer array and Langmuir probes at the divertor and ECE are also included.The spectroscopic measurements of the main plasma are carried out using a 3m grazing incidence and a normal incidence VUV spectrometers from the top of the tokamak, a visible spectrometer from the bottom and a 523.2 nm filter array (for Z_{eff}) from the equatorial plane. Furthermore a normal incidence VUV and visible spectrometers look up the main plasma at an angle with respect to the vertical line of the device. For the divertor plasma, observation with a normal and grazing incidence VUV spectrometers and a visible one are used. The visible emission profiles in 4 different wavelengths from the divertor are obtained with a 38 channel filter system observing the divertor plate region through the main plasma. A Langmuir probe array (15 channels) buried in the divertor plate region is used to provide T_e and n_e at that region.

RESULTS AND DISCUSSION

Typical waveforms of I_p, ICRF power, n_e and T_e and time variations of the VUV emission of L_α, CII, CIII from divertor plasma as well as visible emissions of H_α from the edge of the main plasma in JT-60U are shown in Fig. 2.

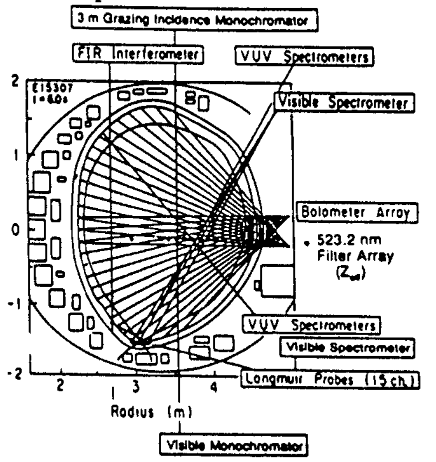


Fig. 1. Geometry for spectroscopic measurements of main and divertor plasmas in JT-60U.

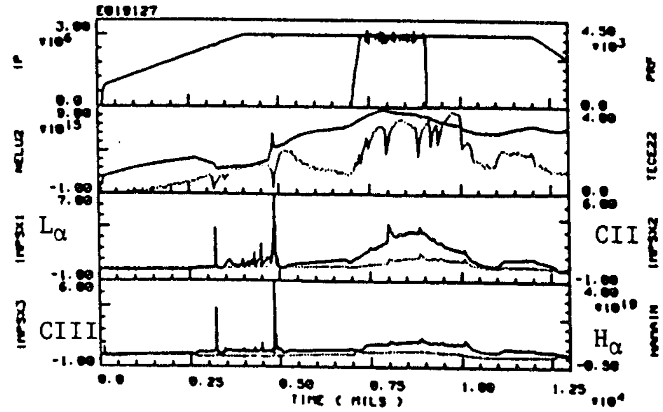


Fig. 2. Waveforms of main parameters and some emission signals from divertor and main plasma.

When ICRF heating with a power level above 4 MW is applied, the central plasma temperature grows quickly from 1 to 3 keV which increases the current concentration near the axis of the toroidal plasma. The value of q near the axis becomes less than 1 triggering sawteeth which are detected easily in the T_e and soft X-ray signals. Sawtoothing plasma was observed through visible and VUV emissions from divertor and main plasma. The emission signals from divertor plasma are shown in Fig. 3(a) which correspond to the same discharge with parameters shown in Fig. 2. Notice the peaks in the VUV signals accompanying the sawteeth crashes indicated in the T_e and n_e signals.

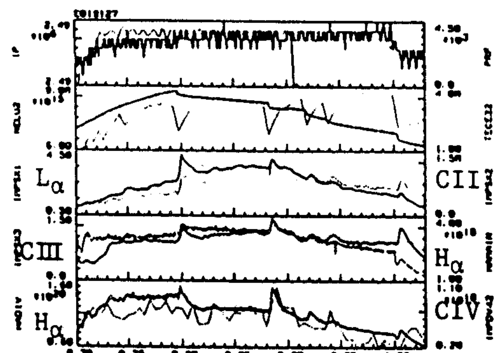


Fig. 3(a). Impurity line emissions from divertor during sawteeth.

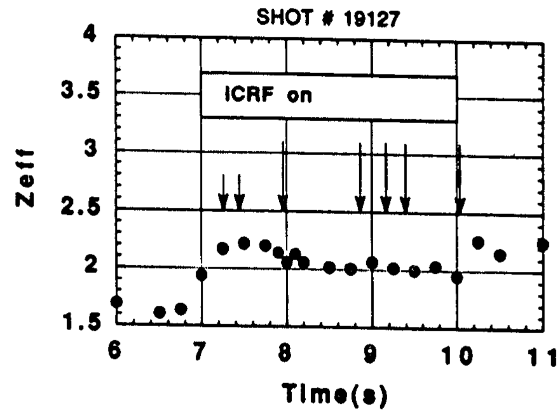


Fig. 3(b). Behaviour of Z_{eff} in the plasma center in a sawteething ICRF discharge.

These clear responses of emission peaks were not seen in the visible emission signals from divertor regions in frequently sawteething discharges. It must be noticed that the sawteeth periods in this case are already very long, reaching 0.7 s because at 4 MW ICRF injection there is already a sawtooth stabilization process in action. In Fig. 3(b) we show the behaviour of Z_{eff} near the center of the plasma in the same discharge. When ICRF is turned-on there is a fast increase of Z_{eff} (from 1.6 to 2.2) in this deuterium discharge. This rise in Z_{eff} is then stopped due to the presence of small sawteeth (indicated by small arrows) and then Z_{eff} stays practically constant (around 2.0) due to the repetition of sawteeth with reasonably long periods (monsters) that end up in very intense crashes. One possible interpretation of Fig. 3(b) is that the sawteeth, including monsters, hinder the impurity accumulations in the core plasma, ejecting them during the crashes. In contrast, the long stabilization of monsters by the application of higher power ICRF (Fig. 4(a)) increases the confinement of the plasma in the core which results in the accumulation of impurities at that region consequently reflecting in higher Z_{eff} of central plasma, as is evidenced by the result of Fig. 4(b).

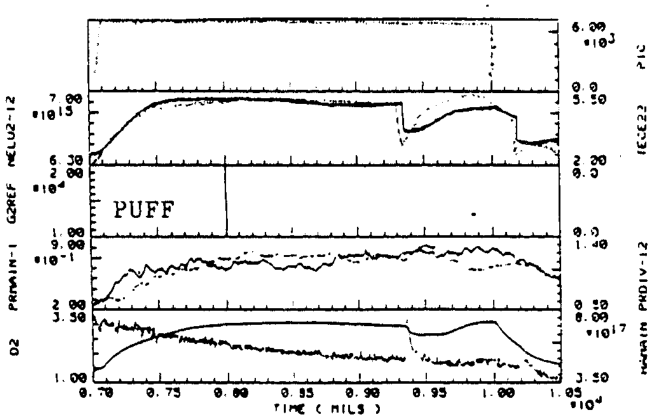


Fig. 4(a). Discharge data (#19274) for the case of very long monster stabilization by ICRF injection.

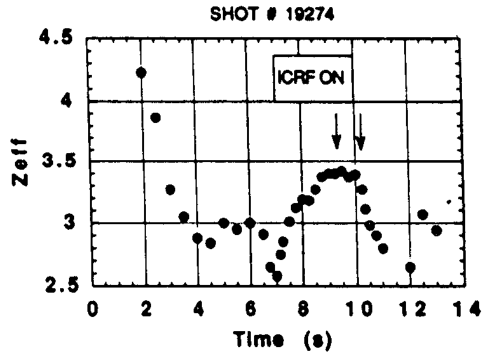


Fig. 4(b). Behaviour of Z_{eff} at the central plasma during the discharge #19274.

In this case (5 MW ICRF, He discharge) the Z_{eff} at center increased from 2.5 to 3.5 in 2.3 s, during the ICRF pulse, after which a violent crash degraded the plasma in global terms. The effect of this giant sawtooth crash was tracked down to divertor and edge regions spectroscopically. The influence of the heat pulse (known to be carried mainly by diffusive electrons in such large tokamaks [4]) on the divertor plasma was marginal in discharges with frequent sawteeth without complete stabilization as in the case of discharge of Fig. 3(a). On the other hand, its effect on the impurity emission profiles was very perceptible when long sawtooth stabilization periods were achieved with ICRF powers $\geq 5MW$, as is shown in Fig. 5(a), (b), (c). Notice the sudden increase of the emission at t=9.4 s when the crash occurred. In other similar discharges, we observed typically a 20-30% jump in the emission at the peaks over the sawtooth stabilized phase. For the JT-60U discharge with even longer periods of sawtooth stabilization (3 s) obtained with higher ICRF powers ($\sim$ 6 MW), the divertor visible emission profile enhancement due to the heat pulse is even stronger, reaching enhancement factor greater than 300% as is shown in the result of emission profile of CIV of Fig. 6.

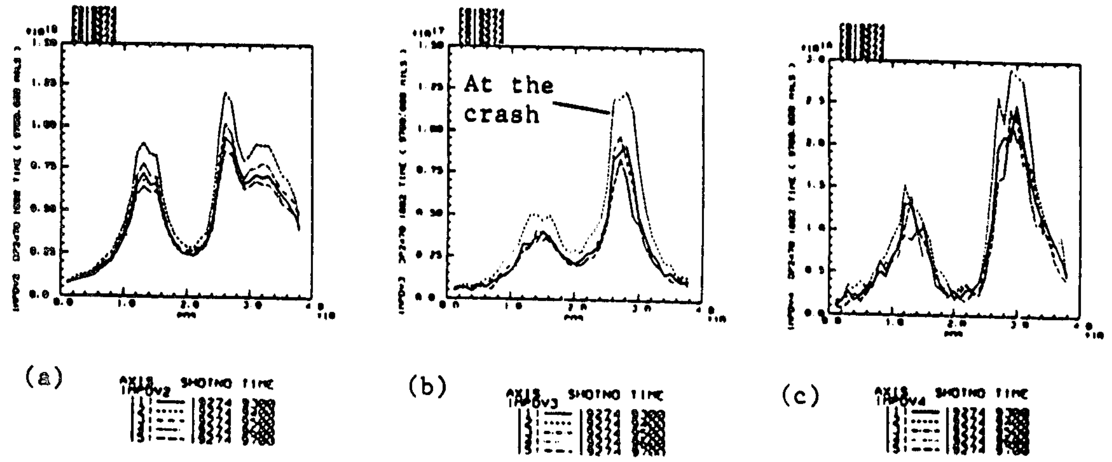
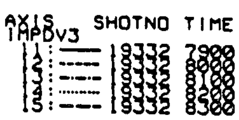
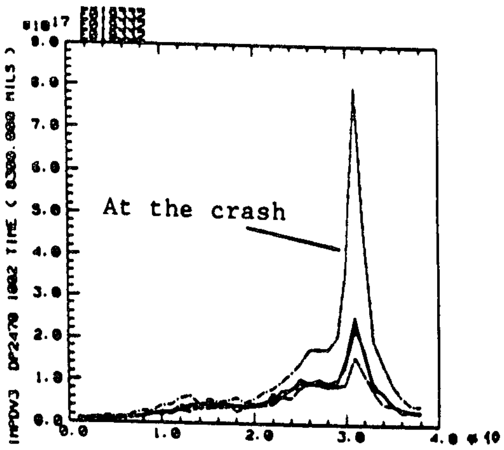


Fig. 5. Behaviour of the emission profiles of HeI(6678Å), CIV(5801Å) and CII(6580Å) soon after the crash (at $t \cong 9.4$s) of a monster sawtooth with 2.3 s stabilization by ICRF injection into a He discharge.

Fig. 6. Example of very strong enhancement in the CIV emission at the divertor after a monster crash produced in 6 MW ICRF injection.





Considering an extremely small variation of the plasma density (< 4%) due to the sawtooth crash compared to the large variation of T_e($\geq$ 40%), we can suggest that the enhancement of the emission from the divertor after the crash is mainly due to the increase of the temperature at that region caused by the heat pulse carried by the diffusive electrons. This may explain a sudden enhancement of the neutron signals after the giant crashes in high power ICRF heated discharges. It is possible that an increase of sputtering due to this large temperature variation provides a channel for large influx of elements from the divertor to the main plasma. This is in accordance with a recently obtained result in JT-60U in which it has been demonstrated that a large amount of boron embeded in the divertor plates are injected into the main plasma during the crash, resulting in an enhancement of B(p,n)C reactions at the core region[5].

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