INVESTIGATION OF PLASMA PARAMETERS IN SAWTOOTH OSCILLATION BY ABSOLUTE INTENSITY OF SOFT X-RAY EMISSION IN JT-60SA INTEGRATED COMMISSIONING PHASE

[1]R. SANO, H. HOMMA, M. TAKECHI, T. NAKANO

[1] National Institute for Quantum Science and Technology (QST), Ibaraki, Japan

Email: sano.ryuichi@qst.go.jp

An electron temperature profile with 0.9 keV at the plasma centre was evaluated from the power spectrum of bremsstrahlung measured by a soft x-ray diagnostic system in JT-60SA integrated commissioning phase. It was observed at sawtooth crashes that the electron temperature decreased while the electron density and/or effective charge increased, respectively. Changes of the profile of products of the electron density and the effective charge indicated a possible inflow of electrons and/or impurities across the inversion radius.

In JT-60SA, a soft x-ray diagnostic system with two photodiode arrays, each of which were equipped with Be filters with different thickness to measure soft X-ray intensity at different energies, was installed [1]. Because the soft x-ray diagnostics system views the lower half of plasma with upper null configurations, the soft x-ray emission power density profile in core plasma can be obtained with reconstruction methods, such as Abel inversion [2]. From the reconstructed emission power density profile with two different energy ranges, the power spectrum of bremsstrahlung at each location can be obtained by "two filters method" [3]. From the power spectrum, the electron temperature and product of electron density, n_e, and square root effective charge, Z_{eff} could be evaluated on the assumption that bremsstrahlung dominated soft x-ray emissions.

Figure 1 (a) and (b) show profiles of reconstructed soft x-ray emission power in low-energy (1 - 8keV) and high-energy (2 - 8 keV) ranges, electron temperature, and $n_e\sqrt{Z_{eff}}$ before and after a sawtooth crash in a He discharge (#E101008, I_p = 0.5 MA) by ohmic heating. Both emission profiles are peaked at the plasma centre. The ratio of the emission profiles results in electron temperature profile with around 0.9 keV at the plasma centre as shown in Fig 1 (c). Further analysis with the electron temperature and both the soft x-ray emission profiles shows the profile of $n_e\sqrt{Z_{eff}}$ is peaked at the plasma centre as shown in Fig. 1 (d).

The validity of the profiles in figure 1 is investigated with a comparison between bremsstrahlung emission intensity taken by a visible spectrometer, which views in a tangential direction, with that taken by the soft x-ray diagnostic system, which views on a poloidal cross section using a synthetic signal scheme as shown in Figure 2. The measured visible bremsstrahlung emission and the synthetic signal are

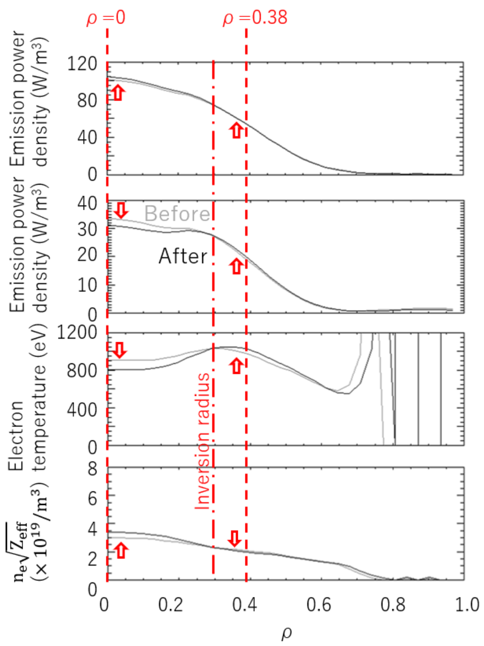

Figure 1 Reconstructed profile of measured soft x-ray emission with (a)low-energy range (1 - 8keV) and (b)high-energy range before sawtooth crash. (c) Evaluated electron temperature profile and (d) product of evaluated electron density and square root of effective charge by two filter method. (#E101008, I_p = 0.5 MA). Gray and black lines indicate before and after sawtooth crash, respectively.

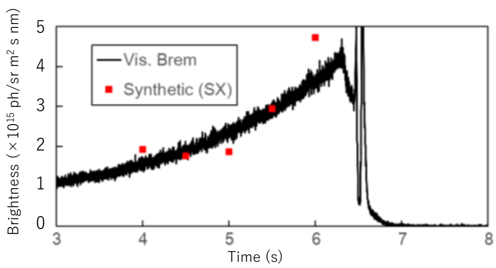

Figure 2 A time trace of (black) measured visible bremsstrahlung emission and (red) synthetic visible bremsstrahlung emission evaluated by the soft x-ray diagnostic system (#E101008).

consistent within statistical error, showing the absolute emission power density profiles evaluated by the soft x-ray diagnostic system, shown in Figure 1, are valid in terms of uncertainty quantification.

Further, evolutions of reconstructed soft x-ray emissions at the plasma centre (ρ = 0) during sawtooth oscillations are shown in Figure 3 (a) and (b). The low-energy and high-energy soft x-ray emissions show an increase of 2.5% and a decrease of 5% at sawtooth crash, respectively. This change corresponds to a decrease of the electron temperature by 60 eV as shown in Figure 3 (c). From the theoretical equation of bremsstrahlung, the change of the low-energy and the high-energy soft x-ray emissions should be same direction with the only in terms of the change of the electron temperature. To produce the opposite emission change in Figure 3 (a) and (b), an increase of electron density, n_e, or effective charge, Z_{eff}, at sawtooth crash is required. Figure 3 (d) indicates that $n_e\sqrt{Z_{eff}}$ increases by about $2 \times 10^{18}/m^3$ at sawtooth crash. Figure 3 (e) - (h) shows the evolutions at ρ = 0.38 outside the inversion radius of the electron temperature oscillation. In figure 3 (f), the phase of oscillation for high-energy soft x-ray emission is inverted from the plasma centre (ρ = 0). On the other hand, low-energy soft x-ray emission shows the same phase oscillation as the plasma centre. This result indicates that phase inversion in soft x-ray emission is observed only in high-energy emission. Furthermore, $n_e\sqrt{Z_{eff}}$ at ρ = 0.38 decreases by $0.5 \times 10^{18}\ m^{-3}$ at sawtooth crash. This result indicates that the increase of $n_e\sqrt{Z_{eff}}$ in sawtooth crash at the plasma centre can be caused by electron or ion influx from outside the inversion radius. In a rough estimation from figure 1 (d) with an assumption of $Z_{eff} = 2$, the increase of the total number of electrons at inside the inversion radius can be evaluated to be $3.2 - 3.6 \times 10^{18}$ in each sawtooth crash. It is also observed that the increased electrons are transported across the inversion radius between the sawtooth crash.

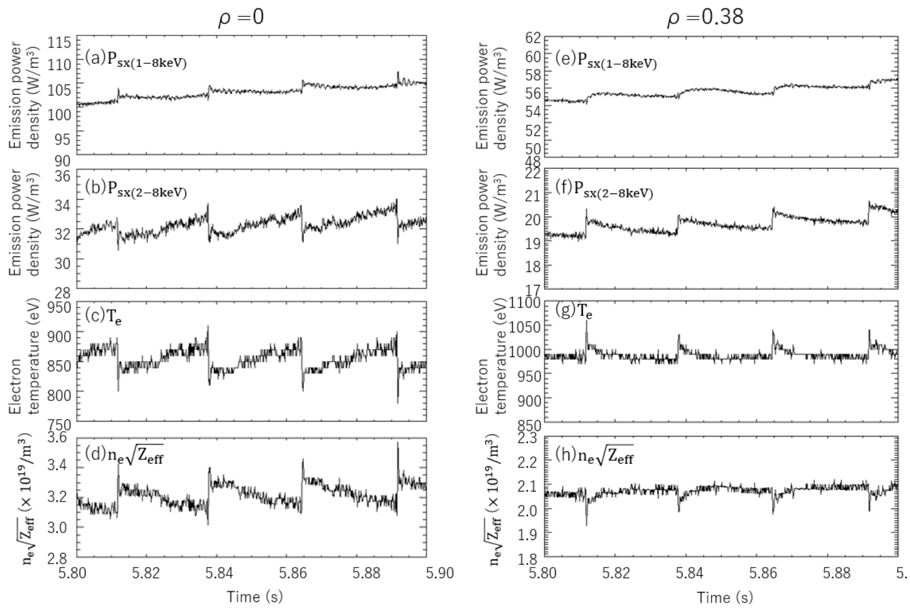

Figure 3 Evolutions during sawtooth oscillation for (a)(e) low-energy soft x-ray (1 keV – 8keV with 7 μm Be filter), (b)(f) high-energy soft x-ray (2 keV – 8keV with 50 μm Be filter), (c)(g) electron temperature and (d)(h) $n_e\sqrt{Z_{eff}}$. (a)(b)(c)(d) are evolutions for ρ = 0, (e)(f)(g)(h) are for ρ = 0.38.

Using the power spectrum of bremsstrahlung, evolutions of plasma parameter profiles were evaluated in sawtooth oscillation. The evaluation indicates that the observed opposite phase oscillations between high-energy and low-energy bremsstrahlung emissions are due to opposite changes in the electron temperature and density or effective charge.

ACKNOWLEDGEMENTS

JT-60SA was jointly constructed and is jointly funded and exploited under the Broader Approach Agreement between Japan and EURATOM.

REFERENCES

[1] R. Sano, et al., Rev. Sci. Instrum. 95, 073532 (2024);
[2] Y. Yamashita, JAERI-Memo 87-206 (1987).
[3] T. P. Donaldson, Plasma Phys. 20, 1279 (1978).