CHIN.PHYS.LETT. Vol. 18, No. 4 (2001) 562

Energy Resolution Effects on Plasma Electron Temperature Measurements by Soft X-Ray Pulse-Height-Analysis

SHI Yue-Jiang(石跃江), WAN Bao-Nian(万宝年)
Institute of Plasma Physics, Chinese Academy of Sciences, Hefei 230031

(Received 20 September 2000)

The soft x-ray pulse-height-analysis technique is a conventional tool to measure electron temperature on tokamaks. The soft x-ray spectra distortion due to the energy resolution of the detector will affect the temperature and impurity concentration determination. To evaluate these effects, distorted spectra as functions of energy resolution are derived by numerical modelling. The results show that the low-energy resolution detector can fit for the large-sized tokamak soft x-ray spectra.

PACS: 52. 70. La, 02. 60. Cb

As a useful and conventional diagnostic to measure the electron temperature, the soft x-ray pulse-height-analysis (PHA) system[1] has been installed on many tokamaks.[2−5] The lithium-drifted silicon Si (Li) detector is generally applied in the PHA system for its high-energy resolution and absorption efficiency. However, the liquid nitrogen (LN) cooled Si (Li) detector is not only expensive but also bulky. The LN refrigerating systems make maintenance very troublesome. The oversized volume of the Si (Li) detector is a fatal inconvenience for a spatial multichannel arrangement. Nowadays, several kinds of solid room temperature detectors such as the avalanche photon diode (APD)[6] and cadmium telluride semiconductor (CdTe)[7] have been mass-produced by companies. The one and only disadvantage of these room temperature detectors is their low-energy resolution. The energy resolution of the room temperature detector is about 10–15% at 5.9 keV, while the Si (Li) detector can reach 3% at 5.9 keV. The soft x-ray PHA system will make great progress if the high quality and inexpensive, small and exquisite room temperature detector can replace the Si (Li) detector. To evaluate this possibility, distorted spectra are derived as a function of energy resolution by numerical modelling.

The intensity distribution of photons from plasma bremsstrahlung radiation may be simply represented as follows,

$$I(E) = \begin{cases} 0, & E < E_0, \\ C\exp(\dfrac{E}{T_e}), & E > E_0, \end{cases} \tag{1}$$

where T_e is the electron temperature and E the x-ray photo energy, c a constant quantity; electron, ion density, ion charge and electron temperature are assumed to be constant. The cut-off energy E_0 models the effect of the beryllium entrance windows of the detector, typically $E_0 \approx 1 - 4$ keV. We use the normalized photon number distribution function $f(E)$,

$$\int_{E_0}^{\infty} f(E)\mathrm{d}E = 1, \tag{2}$$

$$I(E) = N_0 E f(E), \tag{3}$$

where N_0 is the total number of photons in the spectrum. Thus, for bremsstrahlung,

$$f(E) = \begin{cases} \dfrac{C}{E}\exp(\dfrac{-E}{T_e}) & E \geq E_0 \\ 0 & E < E_0, \end{cases} \tag{4}$$

$$N(E) = \int_{E}^{E+\Delta E} \frac{C}{E}\exp(-\frac{E}{T_e})\mathrm{d}E, \tag{5}$$

$$\frac{\mathrm{d}P}{\mathrm{d}E} = \int_{E}^{E+\Delta E} EN(E)\mathrm{d}E, \tag{6}$$

where $N(E)$ is the number of photons in the energy range $(E, E+\Delta E)$, and $\mathrm{d}P/\mathrm{d}E$ is the power radiated into the photon energy interval $(E, E+\Delta E)$.

However, $N(E)$ will disperse to an adjacent energy channel in the spectrum because of the finite-energy resolution of the detector. To the single-energy photons, the number distribution function

$$n(E') = \frac{n_0}{\sqrt{2\pi}\sigma}\int_{E'}^{E'+\Delta E} \exp(-\frac{(E'-E)^2}{2\sigma^2})\mathrm{d}E, \tag{7}$$

where n_0 is the total number of single-energy photons, E the energy of the single-energy photons, $n(E')$ the number of photons in the energy range interval $(E', E'+\Delta E)$, and σ represents the energy resolution i.e. full width at half maximum (FWHM) W_{FWHM},

$$W_{\mathrm{FWHM}} = 2\sqrt{2\ln 2}\sigma, \tag{8}$$

©2001 Chinese Physical Society and IOP Publishing Ltd

and to a certain detector, σ is a function of photon energy E,

$$\sigma \propto E^{-1/2}. \tag{9}$$

Thus the actual spectrum is the convolution of Eqs. (5)–(8) and (9).

In our numerical modelling, the channel width of the PHA system is a tenth of T_e, and the cut-off E_0 equals T_e at the same time. T_e^d is calculated in the range from $2T_e$ to $4T_e$ in our model. The FWHM is the energy resolution at 5.9 keV. $W_{FWHM} = 0$ means that there is no energy dispersion. Figure 1 shows the spectra for $T_e = 1$ keV. The whole shape of the spectrum is hardly distorted except at the low-energy range. We can select a higher minimum energy limit to avoid the serious distortion in the low-energy range. The relative error of derived temperature is no more than 10% when the energy resolution changes from 3% to 40% at 5.9 keV.

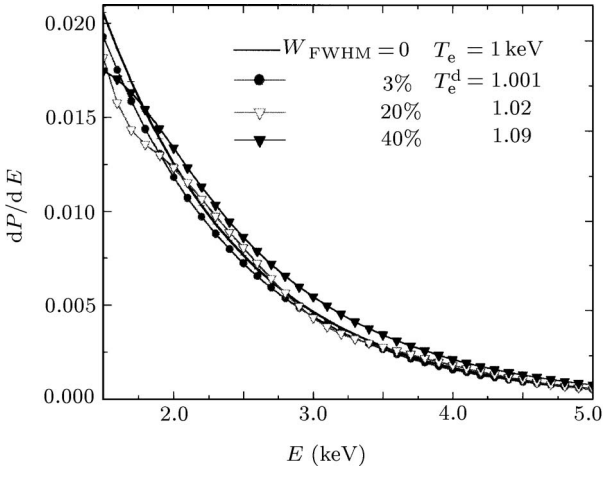

Fig. 1. Soft x-ray spectra for $T_e = 1$ keV.

The central electron temperature can easily exceed 5 keV in large-sized and medium-sized tokamaks. One of the designed parameters of HT-7U tokamak is that the electron temperature should reach 5 keV. Figure 2 gives the spectra for $T_e = 5$ keV. We can see that both the distortions of spectra and the relative error of derived temperature due to the energy resolution decrease as the electron temperature increases. This is very favourable for large tokamaks because of their high electron temperature.

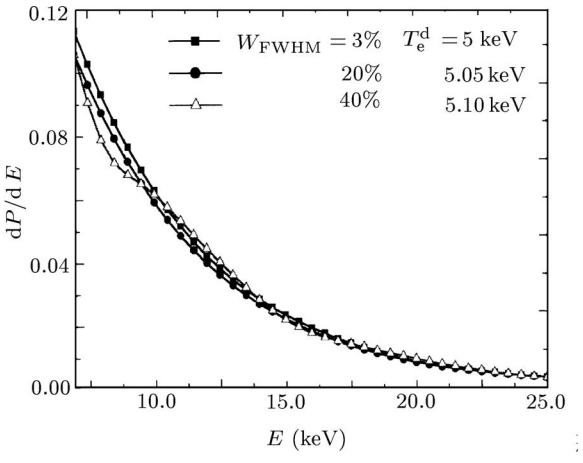

Fig. 2. Soft x-ray spectra for $T_e = 5$ keV.

The results of numerical modelling show that the spectral distortion caused by the energy resolution is acceptable. The room temperature detector by which energy resolution is inferior to the Si(Li) detector can be applied in tokamak (especially large-sized tokamak) soft X-ray PHA diagnostic. The small size of the room temperature detector is of great advantage to high spatially-resolved multi-detector arrays which is important and useful for the study of tokamak plasma.

References

[1] Hutchinson I H 1987 *Principles of Plasma Diagnostics* (Cambridge: Cambridge University Press) p 175

[2] Liang Y F, Yin S J, Fang Z S and Liang R Q 1997 *Fusion Eng. Des.* **34** 201

[3] Goeler S V, Stodiek W, Eubank H, Grebenshchikov S and Hinnov E 1975 *Nucl. Fusion* **15** 301

[4] Silver E H, Bitter M, Brau K, Eames D, Greenberger A, Hill K W, Meade D M, Roney W, Sauthoff N R and von Goeler S 1982 *Rev. Sci. Instrum.* **53** 1198

[5] Pasini D, Gill R D, Holm J and van der Goot E 1988 *Rev. Sci. Instrum.* **59** 693

[6] Squillante M R, Farrell R, Lund J C, Sinclair F, Entine G and Keller K R 1986 *IEEE Trans. Nucl. Sci.* **33** 336

[7] Dabrowski A J, Iwanczyk J and Szymczyk W M 1978 *Nucl. Instrum. Methods* **150** 25