Using D-alpha spectrum to study fast ion on HL-2A

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Abstract—In magnetic-confined fusion devices, fast ion is the main power source in the self-sustained burning phases, therefore it is very important for us to understand the behavior of fast ion. On tokamak device, fast ions were always generated by neutral beam heating, microwave heating and fusion. When fast ions collide with neutral beam, some fast ions neutralize and radiate electromagnetic wave, some of which is in visible spectrum, however the intensity of this light is always the continuum radiation level and is about two orders of magnitude lower than the thermal charge-exchange spectrum (CXS), beam emission spectrum (BES). To investigate fast ion behavior, this paper using 2 methods to evaluate fast ion spectrum on HL-2A, one is using the simulation of spectra (SOS) program to simulate the spectra, the other is to extract the fast ion spectrum by fitting the experimental data of BES spectrum. Both methods reach a same conclusion the fast ion spectrum on HL-2A is very weak.

I. INTRODUTCTION

The tokamak device is the most promising type of confined fusion devices, which can be a leading candidate to transform fusion energy into electricity power, therefore it will be prototype of next generation device-ITER. When heating power is on, plasma temperature of tokamak increases, fast ion is usually generated at the time [1, 2]. The fast ion has a much higher temperature than thermal ions, it carries a lot of energy and momentum which are the main source of heat. In 2009[3], HL-2A realized that toroidal magnetic field reached 2.7 T, plasma current reached 450 kA, electron and ion temperature gets 5 keV and 1.5 keV, plasma density is 1-8×10^{19} m^{-3}. Because of the importance of fast ion, there comes the work to study it on HL-2A. The paper is organized in the following orders, Sec. II METHOD, will briefly introduce the SOS program and the fitting method for BES spectrum. Sec. III RESULTS, gives the results including simulation of HL-2A spectrum by SOS program and analysis the MSE experimental data by fitting. Sec. IV SUMMARY.

II. METHOD

In tokamak device, there are known two ways to diagnostic the fast ion, one approach is the neutral particle analysis(NPA) which is to collect the escaping neutrals from plasma[4], this technology has been widely used on many tokamak devices. Another way is depended on the neutral beam injection. In analytical method, some models use slowing-down method to simulate fast ions generated by neutral beam injection(NBI) [5-7]. When neutral beam collide with plasma particles, it will emit some photons, such as H-alpha light which can be detected by a camera easily [2, 8].

SOS program

SOS program simulate the active beam induced spectrum by three models: fast ion CXS, thermal ions CXS, motional stark effect(MSE) and the bulk ion CXS. The reference[9] had briefly introduced the program. In this paper, the program only evaluates spectrum in a line of sight(LOS) on the middle plane that LOS is along the direction of NBI.

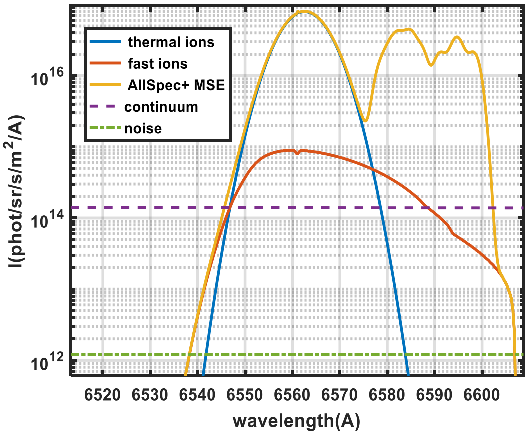

Fig. 1. Fast ion spectrum simulation is calculated at r/a = 0.3 against wavelength

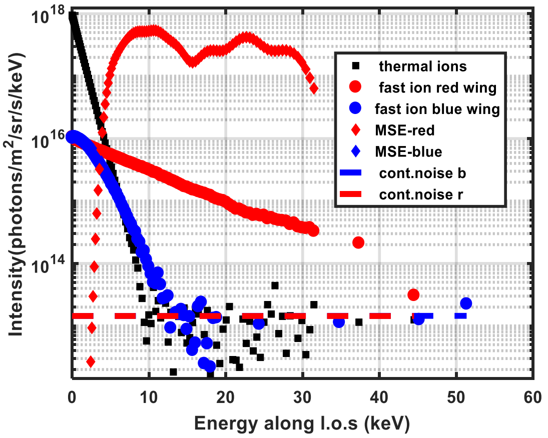

Fig. 2. Fast ion spectrum simulation is calculated at *r/a* = 0.3 against energy.

Fitting method

BES acquired on HL-2A, includes CXS from the ion, impurity (especially the two lights 6578.05 Å and 6582.8 Å from CII) and the spectrum of MSE spectra. The beam neutrals have very high velocity together with magnetic field, $\boldsymbol{E} = \boldsymbol{v} \times \boldsymbol{B}$, and cause a very strong electronic field formed, then a motional Stark effect comes out. For typical neutral beam speed is of several 10^6 m/s and the magnetic field is the order of several Tesla (3 T is the limit for HL-2A), so the electric field are about the magnitude of 10 MeV/m, the splitting caused by MSE is 10 times larger than Zeeman splitting. If the electric field is much stronger, then a quadratic stark effect become significant[10]. For HL-2A, we only considered MSE will be reasonable.

III. RESULTS

Simulation of HL-2A spectrum by SOS program

On HL-2A, neutral beam energy is 50 keV and the power is 0.6 MW, E : E/2 : E/3 is about 0.68: 0.18: 0.13 as. Plasma parameters are $T_i = 1$ keV and $T_e = 1$ keV， $n_e = 2.5\times10^{19}$ m^{-3}, B_{tot} = 1.4 T. The spectrum acquisition system parameters are assumed as follows: Quantum efficiency

η =0.9, F-number is 2.8, integration time t = 20ms, Dispersion is 0.0115 nm/pixel, the slit is set to 0.2 mm.

Figure 1 shows simulating spectrum, this figure gives a theoretical approximation of the spectrum from the point (r/a = 0.5), the spectrum is shown in logarithmic coordinates of y-axis, the x-axis is in wavelength. The yellow line is the sum of the all spectrum, at the right side of the sum spectrum, the three peaks are mostly contributed by three MSE lines. Obviously, it is much higher than the red line which is fast ion spectrum we are interested in. The dash purple line is continuum spectrum which is mostly the bremsstrahlung spectra. At the bottom and above the x-axis is the noise level. Figure 1 shows the signal to noise ratio can simply be estimated by the intensity of the continuum and the noise, which it is about 10^2. Figure 2 also makes clear that the intensity of fast ion is much smaller than the thermal ions or the MSE signal, whereas fast ion spectra in the blue wing of the D-alpha spectrum may be detected as solid blue circle shows if the beam energy is much larger.

Fitting results of the experiment data

Figure 3 is BES data (shot 19680) taken by high resolution spectrometer on HL-2A, while it only shows about 5 nm region at the red wing of thermal spectrum. The black line is raw data. The red solid line is fitting spectrum, which includes CII lines, fast ion lines, thermal lines, and MSE lines, while MSE lines include full, half and third energy lines, which each will be split into 3 (I_π, I_δ, and I_π) lines that we just used a very simple model to simulate MSE spectrum. Two yellow lines are CII spectra which always comes from the edge of plasma where the cold particles gathered, therefore the position and the interval of the two lines are fixed relatively, and they were usually used for wavelength calibrating. The dash red line is the fast ion spectrum we are interested in.

In figure 4, the irregularity line is the remnant when we subtract CII, thermal and MSE lines from experimental data, the smooth line is the fitting fast ion spectrum. It just shows the same trend with SOS results, but the remnant spectrum is too weak to be convinced. There is much discrepance near the D-alpha spectrum, which is caused by the sharp decline of intensity of D-alpha, also a thermal and a hot line cannot fit the D-alpha spectra that well, therefore the remnant is in a sharp changing at the D-alpha spectrum region.

Unfortunately, under the certain geometry circumstance, we used to focus on the MSE spectrum with a narrow band spectrograph, whereas the blue wing is optimal for detecting.

IV. SUMMARY

In this paper, one simulation and one fitting method have been taken to evaluate fast ion spectrum, them both give a similar conclusion that the fast ion spectrum intensity is very low on

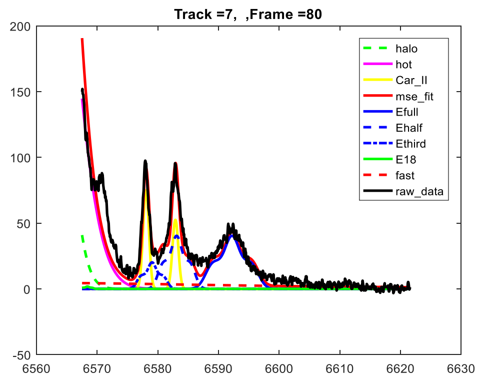

Fig. 3. Fitting the experiment beam emission spectrum, the detail of the fitting is shown in the text.

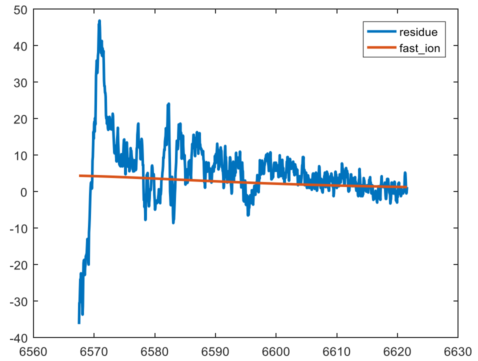

Fig. 4. The fast ion signal extract from beam emission spectrum.

HL-2A. To make sense of the results, there is still much work to be done in both methods, the detail of the SOS program in simulation of HL-2A has to be checked, and some more sophisticated models should be taken into consideration in the fitting method. Due to the limitation on HL-2A, fast ion density is much smaller than other Tokamak devices, therefore, the analysing work is much challenging but valuable, also the diagnosis of fast ion is much promising on HL-2M in the future.

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