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Measurement of ion temperature profile based on CXRS in HL-2A tokamak

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1. Abstract

Spatially resolved measurements of ion temperature are critical for understanding plasma dynamics, and in most present-day magnetic fusion devices, charge exchange recombination spectroscopy (CXRS) has become the basis for one of the standard diagnostic equipped with neutral beam injection (NBI)[1, 2] . A heating NBI (50kV extraction voltage, 24A beam current) has been installed on the HL-2A Tokamak. In accordance with the actual geometry of HL-2A, a CXRS diagnostic system, in particular the optical collection system, is designed. In the 2008 experimental campaign, the CVI 5292-Å (n=8–7) charge-exchange recombination (CXR) line is chosen for ion temperature and profile measurements during NBI. Initial measurements show that the CX signals have enough SNR to obtain ion temperature and it's profiles. A code that intends to be fast and reasonably accurate have been developed to perform a fitting analysis of the measured spectrum.

2. Set-up of CXRS and it's optical system in HL-2A

As shown in Fig.1, a wide-view CXRS diagnostic which will span $0 \le \rho \le 1$ is needed in HL-2A to measure the ion temperature and profile in the equatorial mid-plane. Direct detection of the NBI-plasma interaction is not possible with the port geometry, so a specially designed collective optical system is needed. Fig.2 is the schematic diagram of the collective optical system. A part of collective system was installed inside the vacuum chamber, which can effectively converge light flux and change the light direction for measurement, composed of a metal mirror and a lens. All lenses out of vacuum are coated to

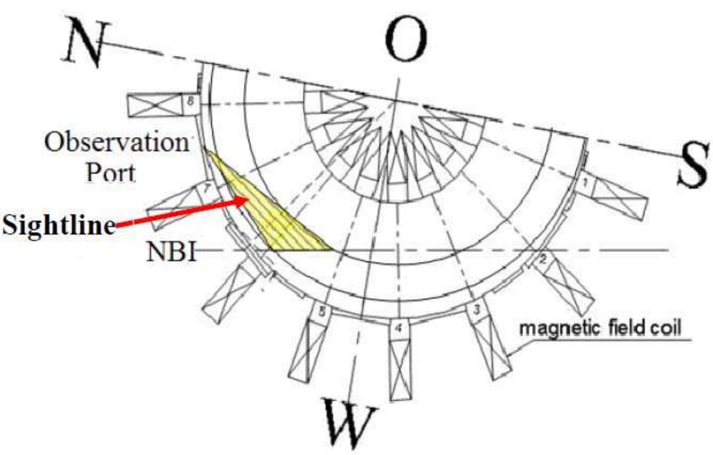

Fig. 1 Arrangement of NBI and CXRS

increase the optical transmission, and lenses are designed to reduce spherical aberration and coma. In order to avoid the attenuation of optical transmission due to plasma or glow discharge in vessel, a shuttle is used, the windows is closed by the mechanical shutter and can be opened when needed.

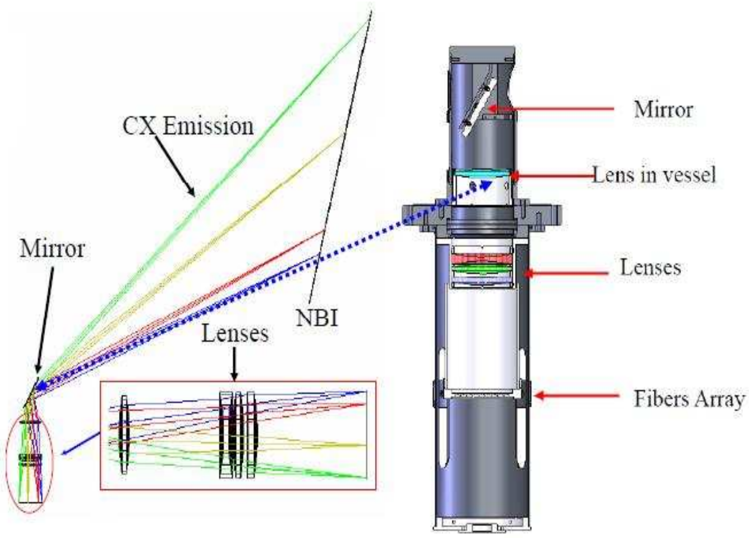

Fig. 2 Optical collection system on HL-2A

The ray tracing of Fig. 2 shows how these image the beam onto an image dissector. The light emitted from the region of beam-plasma interaction is accepted by the periscope window, reflected by the metallic mirror and focused through 4 lenses onto the fiber optic array. Then the light is conducted to the spectrometer by optical fibers. The fibers are placed vertically at the entrance slit of astigmatically corrected Czery-Turner spectrometer with a focal length 0.5m and an aperture of f/8.0. On spectrometer the Optical Fiber Adaptors is installed, which matches the f/# of the optical fibers to the f/# of the spectrometer thereby optimizing throughput and minimizing stray light. The diffraction grating is 2400g/mm. Spatial resolution of the optical system [3] , determined by the viewing chord-flux surfaces intersection at the beam position, is about 3cm in the plasma core and about 1cm at the edge.

3. Data analysis and results

The CVI 5292-Å (n=8–7) CXR line is chosen for ion temperature and it’s profile measurements during NBI in HL-2A. This because: 1) The fixed and movable limiters and two domes of the divertors are covered with the graphite tiles，so carbon is the major impurity and this will produce enough emission; 2) And visible spectrum allow to multi-chord measurements using visible spectrometers coupled to the plasma with lenses and relatively inexpensive fiber optics [4] .

In addition to the strong local CX emission at the beam intersection, there is an unwanted background which came from electron impact excited emission at the plasma edge. To remove this unwanted contribution, we subtract a background frame taken at a time before the neutral beam is turned on from the signal frame taken at the time of interest during the neutral beam pulse [5] . Also, a dark frame of data taken after the plasma discharge, is used as a reference and is subtracted from both the signal and background frames. Fig.3 shows the typically CVI emission detected by the CXRS system. The signal is given by the difference of the signals detected with and without beam injection (integration time: 50ms). In this case, beam CX intensity is 60% of the detected signal. The ratio between this active signal and the background from plasma emission is about 2.

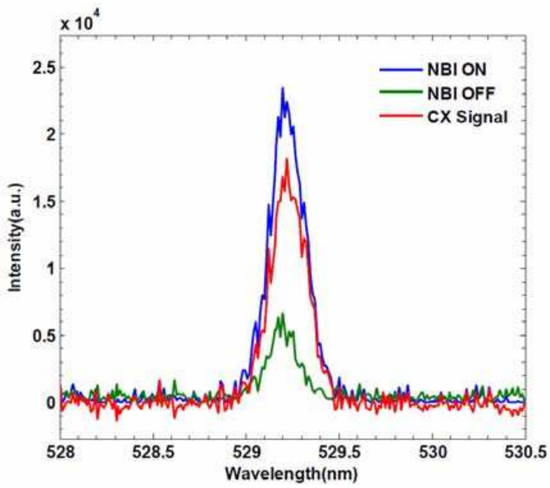

Fig. 3 Typical CXRS signal

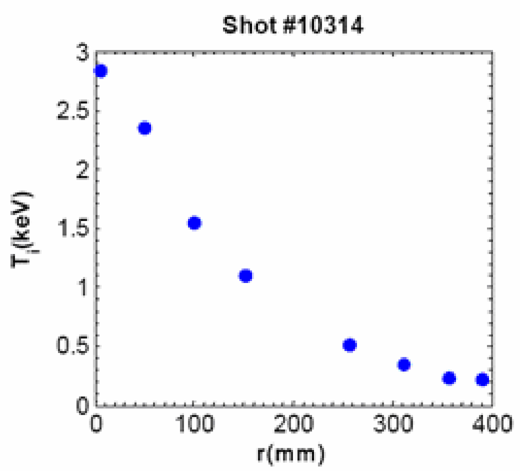

Fig. 4 Ion temperature and profile

The CVI used for analysis is in hydrogen-like ions, though the observation line is actually made up of a number of closely spaced fine structure components, but the fine-structure is completely unresolved, one has to consider further splitting of these components due to the Zeeman effect, so the ion temperature can not be obtained directly from the measued pectrum by one Gaussian fitting [6, 7] . A code that intends to be fast and reasonably accurate have been developed to perform a fitting analysis of the measured spectrum. And this method takes into account both Zeeman and fine-structure effects. According to this way, the total broadening can be represented by the sum of three Gaussians of different intensity but with the same width. The intensity ratios are determined by the angle between the magnetic field and the line of observation, the fact that parameterization model has linear dependence on the magnetic field amplitude extensively facilitates the data analysis procedure. Given the three parameters and the intensity ratios, the three polarizations- each one a Gaussian---components can be constructed. When these are summed together, the Zeeman profile is reproduced. Thus to include the entire Zeeman pattern in the analysis, one only requires three components, instead of several hundred, and the free fitting parameter will be the true temperature. Fig.4 is the ion temperature and profile on HL-2A obtained by this way.

4. **Conclusions**

A new CXRS system was successful designed and installed in HL-2A tokamak during 2008 experimental campaign, and through this system we can get the CX signal with enough SNR, the ion temperature and profile also can be got.

In order to get higher reliability and better time-resolved results, the system optimization is essential. On HL-2A, the feasible way can achieve is to increase the collection efficiency of optical system rather than raise the neutral beam density in the beam-spectrometer line-of-sight intersection volume. A complete analysis of the CXRS optical system has identified modifications to the optical system that will increase the collection efficiency [3]: (1) A new mirror with higher reflectivity will be used. (2) The optical fibers (200μm) will replace by larger diameter optical fibers (600μm). (3) A higher aperture ratio of spectrograph also will be used, so a new lenses system which matches the fibers and spectrometer will be developed respectively. Together, these changes will result in a signal level increase greatly, improving the S/N of ~6.

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