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Thomson Scattering Measurement in Heliotron J

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Abstract

Thomson scattering system has been developed for Heliotron J. Two-dimensional measurement is required at least since plasmas of Heliotron J are fully three-dimensional. For this purpose, a movable collecting mirror system and a movable bending mirror system have been developed. Using this system, the electron temperature and density in the range of 0.3 m in the z (vertical)-direction and 0.2 m in the R (major radius)-direction can be measured. The spectrally and spatially resolved light scattered by electrons is injected into a image-intensifier tube and recorded by a CCD camera. An image of about 0.1 m in z-direction and 80 nm in the wavelength is obtained in one discharge.

Keywords:

Thomson scattering, electron temperature, Helioron J, two-dimensional measurement, camera system

1. Introduction

Heliotron J is a helical-axis heliotron device with local quasi-omnigeneous field [1]. The Heliotron J device was designed to produce a wide variety of the field configurations to study the optimization of the helical-axis heliotron field configuration. Along this purpose, Thomson scattering device has been developed. The spatial profile data of plasma temperature and density with sufficient spatial resolution are important for the local transport analysis. Two-dimensional measurement is required at least in Heliotron J since the plasma is fully three-dimensional.

The injection port and the scattered-light detection port for the Thomson scattering system can be arranged in the same poloidal plane in Helioron J since Heliotron J has a L = 1 helical coil instead of L = 2 helical coils. Therefore, the sampling point can be changed by moving the injection optical system and the detection optical system in the same direction. These two optical systems are separately installed and designed to change the positions by the same distance within the sufficient accuracy for the reduction of the structure material. The optical image fiber bundle connects the collecting optical system to the spectrometer followed by the detector system in order to make it easy to align the system components.

2. Experimental Setup

The overview of the Thomson scattering system for Heliotron J is shown in Fig. 1. This system is composed of a ruby laser injector with an energy of 4–5 J, the injection optical system, the collecting optical system (a spherical mirror and an image fiber bundle), a spectrometer, a framing camera and CCD camera system. A fast framing camera with an S-25 photocathode surface is used as the front end of the detector since the background plasma light can be also obtained with several hundred-nanosecond intervals. The readout device is a cooled CCD, which has 1000 × 1000 pixels each of which corresponds to 0.1 mm (spatial length) and 0.2 nm (wavelength). For practical purposes, the

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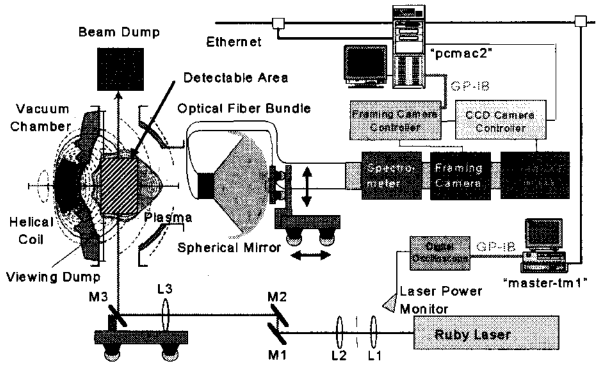

Fig. 1 An overview of the Thomson scattering system.

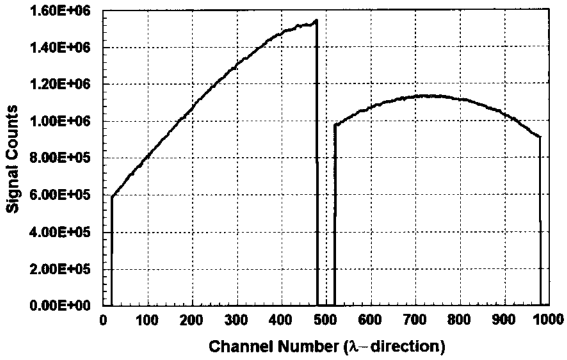

Fig. 2 Relative calibration data using a tungsten lamp (Toshiba, 8V10cd). The left part is the signal frame (0–500 channel) and the right part is the background frame.

spatial resolution is restricted by the diameter of the laser beam (about 2 mm) and the scattered light intensity. The reason that the spatial resolution depends on the intensity is that a lot of signals must be summed along the sampling volume to increase S/N ratio when the signal is weak.

The beam injection point and the detection point can be moved horizontally in the major radius direction to any positions in the range of 0.2 m with an setting error of 0.2 mm so that the various configurations of Heliotron-J plasma can be measured. The detectable area is shown in Fig. 1. About 0.1-m sampling volume along the laser beam can be measured by 1000 detector elements in one shot. The spherical mirror of 0.5-m in diameter is used for the collecting optics. The solid angle of the collecting optics is 0.09 Sr, which is increased by three times larger than that of Heliotron E [2,3]. The light guide system from the collecting optics to the spectrometer is also changed from the lens system to the imaging fiber bundle. The collecting optics and the detector could be aligned separately by using the fiber system.

3. Calibration of the System

The framing camera and the CCD camera had the wavelength sensitivity and the sensitivity profile on the detector surface. Other optical components such as the spectrometer and the optical fiber bundle also had sensitivity dependence on the wavelength and surface position. The relative calibration of the whole system was carried out with a tungsten lamp (Toshiba, 8V10cd) whose radiation dependence on the wavelength was well known. The lamp was placed at the edge of the optical fiber to calibrate the whole system. The image of the lamp is shown in Fig. 2. There were two frames in the CCD camera, the left side of which was used for the Thomson scattered light detection, and the right side of which was used for the background light detection. The framing camera attached in front of the CCD camera made the change of the exposure side. The channel number from 20 to 480 on the each side corresponded to the wavelength from 790 nm to 710 nm. The dependence of the signal on the wavelength was caused mainly by reason that the tungsten radiation had the dependence on the wavelength and the central region of the camera tube had better sensitivity.

The Rayleigh scattering measurement was carried out to estimate the coefficient for converting the measured signal of Thomson scattering to the photon number. The Rayleigh scattering with nitrogen gas was selected since nitrogen is non-flammable. The measured signals with the various nitrogen pressures by the manometer are shown in Fig. 3(a). The intersection of $P = 0$ line and the data line corresponds to the stray light strength and the slope of the data line corresponds to the sensitivity of the detector system. The sensitivity of the system was determined from the linear fit of the data up to 71 Torr. It was found that the detector signal was saturated beyond 71 Torr.

From this sensitivity, the Thomson scattering signals were estimated for the various plasma parameters in Fig. 3(b). Each data point corresponded to the summed signal within 10 nm in the wavelength and 0.01 m in the real space. In this figure, the data counts for S/N ~ 1 was 1000. This noise was caused by the statistical error. We thought that S/N > 2 are needed for the determination of the temperature. This means that the signal counts from the four-time larger number of

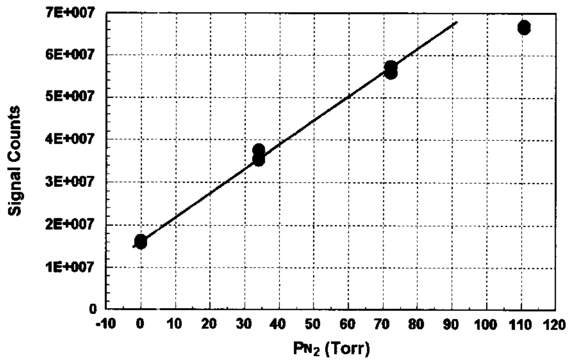

Fig. 3 (a) Rayleigh scattering signals for various nitrogen pressures.

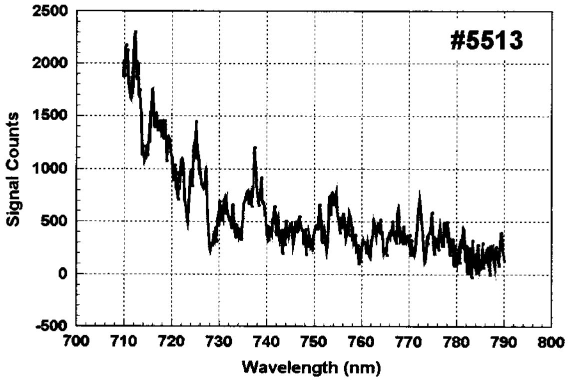

Fig. 4 (a) Raw signal of the shot number 5513. The signals are summed in the range of 0.05 m.

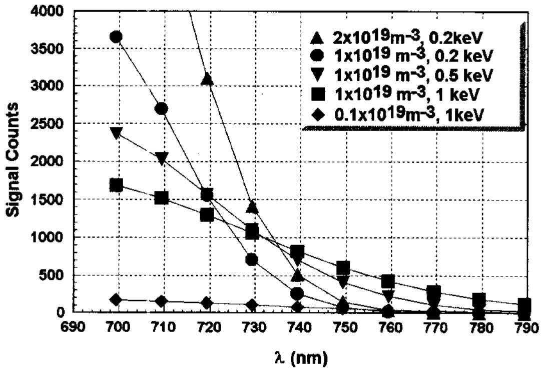

Fig. 3 (b) Estimated Thomson scattering signals for various plasma parameters.

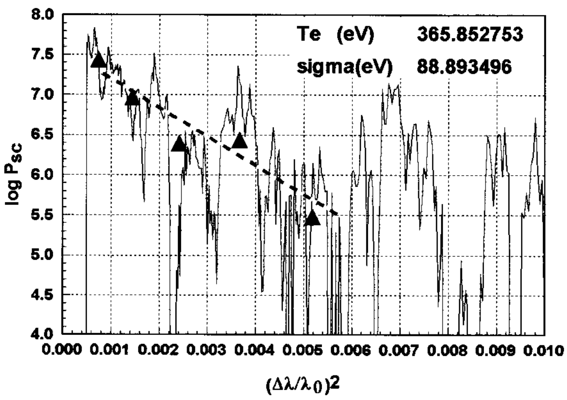

Fig. 4 (b) Electron temperature determined by the calibrated signal. The triangles are averaged values for the 5-nm range. Dashed line shows the fitting for the triangles.

the pixels should be summed. Therefore, the spatial resolution for the electron density of 1×10^{19} m^{-3} was estimated at about 0.05 m.

4. Experimental Results

The raw data from a Heliotron-J plasma generated 53.2-GHz ECH (400 kW) is shown in Fig. 4(a). The exposure time of the framing camera should be as short as possible to avoid the noise of the background plasma light usually. The fire timing of the laser, however, had a jitter about 100 ns against the start trigger. Therefore the exposure time was about 400 ns typically to ensure that the laser pulse of about 50 ns (FWHM) is contained within the exposure time. The interval of the two signals was 900 ns. In this wavelength region and the exposure time, however, there was no significant plasma background light. In Fig. 4(a), the background signals are subtracted only for the offset correction of the ADC of the CCD camera.

From the signal in Fig. 2, 3(a) and Fig. 4(a), the electron temperature is determined. The estimated temperature is 365 eV ± 89 eV at the center of the plasma with the line-averaged density of 2×10^{19} m^{-3} as shown in Fig. 4(b). The spatial resolution of this shot is about 0.05 m determined by the statistical error.

However, the required spatial resolution of 0.01 m under the Heliotron-J plasma condition could not be attained. In the estimation from the Rayleigh scattering experiment, it was found that the detector sensitivity of five times larger than that of our detector is required.

The accuracy of the alignment of the optical system for the two-dimensional measurement were examined using the stainless target in the vacuum chamber of Heliotron J and a helium-neon laser of which the optic axis was coincident with that of the ruby laser of the

Thomson scattering system.

5. Summary

The TV Thomson scattering system was installed and the electron temperature measurement was carried out in Heliotron J. This system covers the detectable area of 0.3 m $\times$ 0.2 m with 0.2 mm setting error. The electron temperature was obtained by this system in the medium electron density region. For lower density plasma or better spatial resolution, the statistical error must be reduced. The signal piling up method should be also effective. A new camera with a GaAs photocathode has been prepared in order to increase photon signals for the next campaign.

Referances

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