Performance of the Thomson Scattering Diagnostic on HSX

K. Zhai, F.S.B. Anderson, K. Willis, K. Likin, and D.T. Anderson

HSX Plasma Laboratory
University of Wisconsin-Madison,

We report the design and the performance of the 10-point Thomson scattering system installed on Helical Symmetry Experiment (HSX). Based upon the design of the GA Thomson scattering system, the HSX Thomson scattering system covers the complete plasma cross section, providing a 10-point plasma parameter profile measurement during a single plasma shot. The system consists of a commercial 1J- 10nsYAG laser, 10 polychromators form GA, the specially designed collection optics, a CAMAC data acquisition unit, and a controlling computer. The high throughput collection optics enables the measurement even at a plasma density of $0.5\times10^{12}cm^{-3}$. The system configuration, the spectral response calibration, the Raman calibration of the system, and the operational results will be presented.

1. Introduction

Thomson scattering experiment is a conventional diagnostics in fusion plasma research to provide measurement of the electron temperature and density [1-3]. In HSX plasma lab, a Nd:YAG Thomson scattering system has been established and is now in operational. The HSX Thomson scattering system uses the polychromator that is originally designed by General Atomics [1]. Large collection optics are used in the system to get enough scattered photons from the HSX plasma with a typical density of $1\times10^{12}/cm^3$. The system is capable of 10-point profile measurement. Ten identical fiber bundles with a transmission rate of 0.6 couple the collected photons to ten polychromators that disperse the collected light. Four wavelength channels in each of the ten polychromators are optimized for temperature measurement range from 10 eV-2 keV. A dedicated CAMAC system is used to record the data. The system has been spectrally and absolutely calibrated, which can provide routine profile measurement of the electron temperature and density.

2. System Description

Physically, the HSX Thomson scattering system can be divided into several major elements. These are: laser system, beaming transportation and stray light control, collection optics of the scattered light, spectrum dispersion system, detection and signal handling, and control system. Each of these subsystems is interdependent, and the respective designs are dependent upon each other.

The HSX Thomson scattering system use a commercial manufactured Nd:YAG laser. This laser consists of an oscillator section and an amplification stage. The oscillator compartment is Q-switched by means of a Pockel cell and a Brewster polarizer. The beam from oscillator passes through a telescope and then enters into the amplifier compartment. The system being in service can deliver a pulse of energy 1 J with a 10 ns pulse width. The laser is located in a dust free air-conditioned room on an optical table. The pointing direction changes within 100 micro-degrees for 3 months test.

Beam from the laser head is guided by three laser mirrors and then focused to the HSX vessel with a f = 3m focus lens. The focus spot size is around 1 mm in plasma region of measurement of vertically 20 cm extending form the geometrical center to the edge. In addition, a ½-

waveplate located in front of the laser head is used to adjust the beam polarization to enable maximum scattered light flux going into collection optics. Entrance and exit tubes are specially designed with baffles to control the stray light. Entrance and exit windows are Brewster angle orientated fused silica windows to reduce the stray light and ensure maximum laser transmission. There is a silicon detector to monitor the reflected power from the entrance window. To accomplish the Brewster condition, we adjust the ½-waveplate to minimize the reflected power from the entrance window. There are two CCD cameras, one is located after the 3rd mirror just before the beam getting into the vessel and the other is located before the beam dump just after the beam getting off the vessel. These two cameras provide daily monitoring of the beam alignment with the collection optics. For safety reason the beam is totally enclosed in a solid opaque material for this class four laser device.

Since the electron density in HSX is relatively low at typically around $1\times10^{12}/cm^3$, it requires the special design of the collection optics to obtain enough signal level. We use ZEMAX to design the collection optics, which fully accomplish the measurement requirement for the HSX experiment. The collection optics consists of two doublets made of BK7 and SF1 glass with AR coating for the wavelength from 800-1070 nm. This collection lens collects scattering laser light from ten radial locations and image on ten individual fiber bundles. A 10 cm entrance pupil diameter of the collection lens provides a collection of about 20000 photons at the density of $1\times10^{12}/cm^3$. The image space NA is 0.23, enabling a perfect coupling to the fiber optics. The spot size on the image plane at the fiber bundle surface is less than 100 micrometers as shown in Fig. 1. The collection lens is installed in a 5-dimension adjustable holder, which is supported from the HSX lab ground without any physical contact with the vessel to ensure relative stable with the beam.

Ten identical fiber bundles are used to couple the collected scattered laser light to polychromator. Each bundle is a 7 m long with a rectangle-to-circle shape and consists of 126 200/220-core/cladding-silica/silica low OH fibers with a NA between 0.24-0.25. Figure 2 shows the rectangular end of the fiber bundle of 0.8 mm × 7 mm, which matches the image of the laser beam through the collection optics. We have tested the transmission efficiency of each individual bundle, showing that the transmission is equal to or great than 60%. Ten identical polychromators manufactured by GA are used to disperse the scattered laser light. There are four wavelength channels in each polychromator. The filters differentiating individual wavelength channels are optimized for the measurement of the electron temperature ranging from

10 eV to 2 keV, appropriate for the measurement in both the edge and core region on HSX. The detector and amplifier are attached to the polychromators. The detector used is EG&G C30956E avalanche photodiode, which has a quantum efficiency great than 40% around 1.06um and an avalanche gain of 50-100. The output from the amplifier provides a signal in the range from 0.0 to –1.0 volt. The signal is recorded by gating Leroy Model 2250 charge integrating digitizer. The data acquisition system is a computer GPIB controlled CAMAC system dedicated for HSX Thomson scattering experiment.

A HeNe laser is used for the alignment adjustment of the collection optics. This alignment laser can be aligned with the YAG laser in the laser room. An in-vessel target is designed to align the collection optics with the HeNe laser beam. The target is moved along the beam path and the scattered light is imaged on a 3-fiber bundle. We maximize signal collected by the center fiber to optimize the alignment of the collection optics with the laser beam.

There are two timing components in the system. A NI 6602 timing card is used to set the time when the laser is fired at the time during plasma discharge and the time for taking background data. This provides an accuracy of 12.5 ns. Another timing component we used is the Stanford DG535 unit, which provides the gate to the digitizer synchronizing with the laser signal. This timing component provides a higher accuracy of about 1.5 ns.

3. Calibration

In order to evaluate the measured signal quantitatively, the spectral sensitivity of the 10 polychromator has to be calibrated in a proceeding calibration procedure with relatively high wavelength resolution. For this purpose we use a tungsten lamp as the light source which passes through a ¼-m monochromator. The output from the exit slit is then splitted into two beams with a beam splitter, one of which is monitored with an absolutely calibrated InGaAs detector and the 2^{nd} beam is monitored with a silicon detector. Then we scan the wavelength from 850 nm to 1070 nm to calibrate the monitor silicon detector. After that we scan the wavelength again with the 2^{nd} beam from the monochromator exit fed into the polychromator. The result is shown in Fig. 3. We also include in the figure the scattered light spectrum at three electron temperatures of 50 eV, 200 eV, and 2000 eV.

Since the stray light contribution to the first wavelength channel makes the Rayleigh scattering troublesome, we use rotational Raman scattering for the density calibration [4, 5]. For safety reason, we choose nitrogen gas rather than hydrogen gas. We find the strongest lines from Raman scattering lie in the 2nd wavelength channel extending from 1050 nm to 1060 nm. We fill the HSX tank with nitrogen gas and change the gas pressure from 10 torr to 90 torr. At each pressure we fire the laser and collect the scattered light the same way as we do Thomson scattering experiment. The Raman scattering result is shows in Fig. 4.

4. Experimental Results

Figure 5 shows a typical temperature and density profile measured by the HSX Thomson scattering for Quasi-Helical-Symmetry mode at 50 kW ECRH power. We also carried out an ECRH power scan to study the plasma temperature response with different ECRH heating power. Figure 6 shows the results of the power scan for QHS mode. The line-averaged electron density of the central channel is fixed at about $1.5\times10^{12}cm^{-3}$. It is shown that the whole temperature profile increase with the heating power. The central temperature increases from about 500 eV to 950 eV while the heating power increases form 37 kW to 150 kW.

5. Summary and Future Work

In HSX plasma lab, a Nd:YAG 10 channel Thomson scattering system has been established and is now in operational. It provides daily routine measurement of the electron temperature and density. Since the operational density in HSX is relatively low, the signal to noise ration is of much importance for this particular case. Future work will be concentrated on reducing the noise level and developing new data analysis techniques.

6. Acknowledgement

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FIGURE CAPTIONS:

1. Spot size on image plane, which shows the image size is less than 100 micrometers for all ten spatial channels for wavelength ranging from 650nm to 1060 nm.

2. Laser beam image on fiber surface. The 10 rectangles of $0.8mm \times 7$ mm indicate 10 fiber surfaces on image plane. A margin of about 0.3 mm is for misalignment.

3. Spectral response of the four channels of the polychromator. The 90-degree Thomson scattering spectra at electron temperatures of 50 eV, 200 eV and 2000 eV are also shown.

4. Raman scattering signal changes with gas pressure. The calibration factor is defined by the slope of the fitted line.

5. Typical temperature and density profile measured for QHS central heating mode at 50 kW ECRH power (Shot 33 on Feb. 12).

6. Electron temperature profile changes with the increasing of the ECRH heating power. These are QHS central heating shots at fixed density of $1.5\times10^{12}cm^{-3}$.

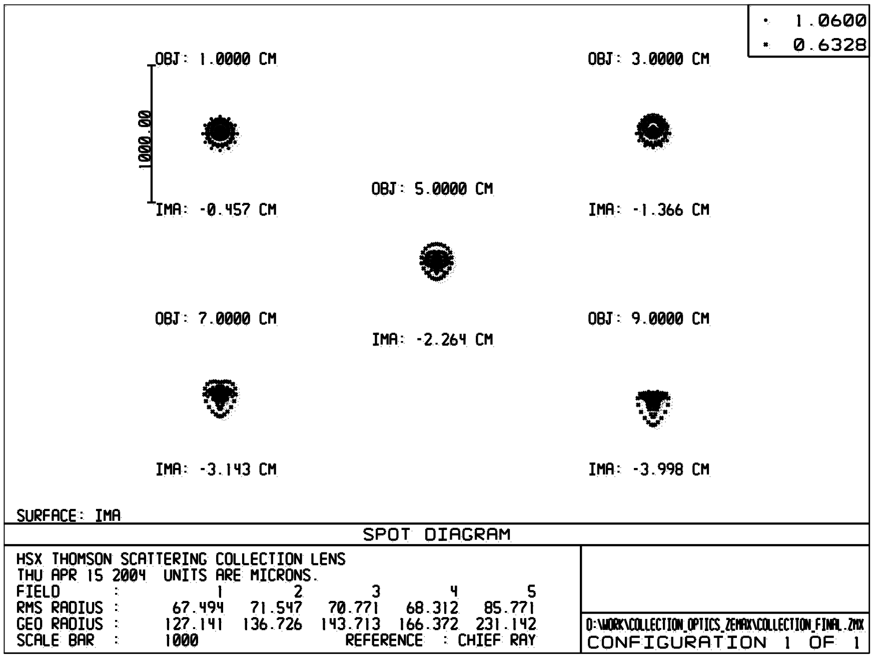

Figure 1
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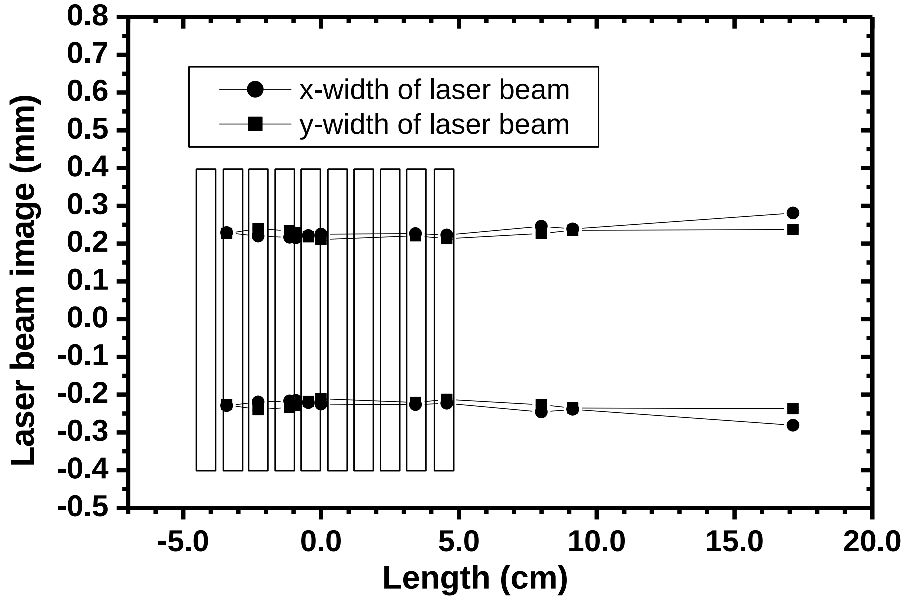

Figure 2
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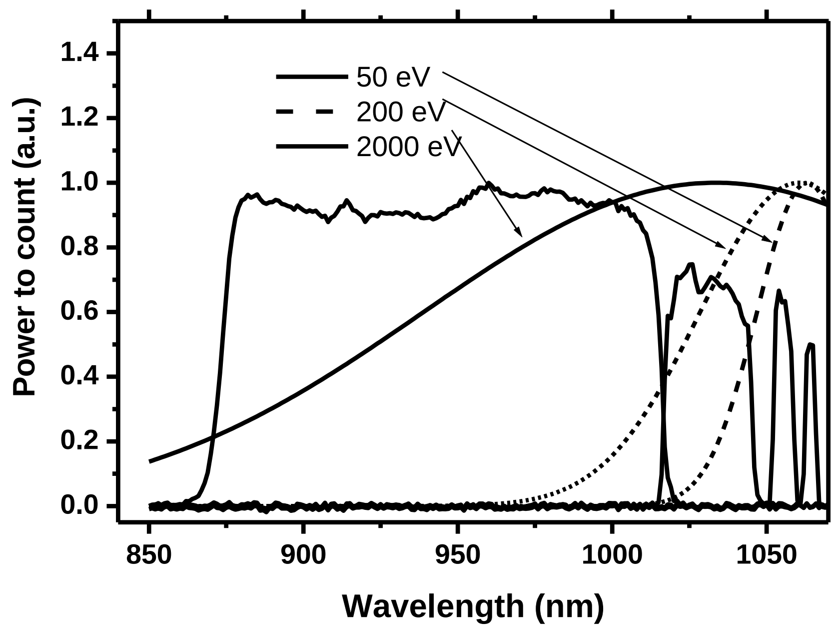

Figure 3
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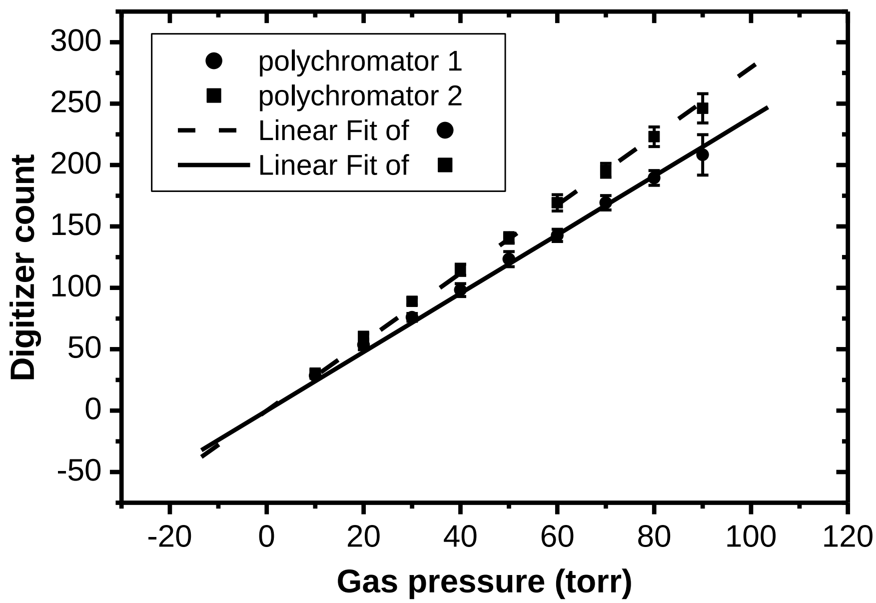

Figure 4
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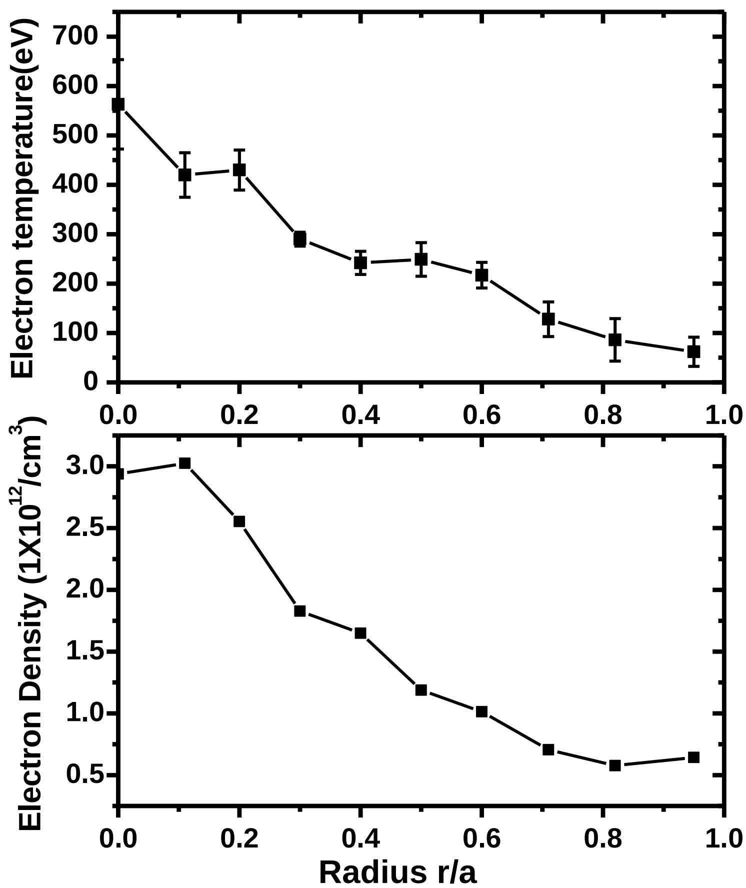

Figure 5
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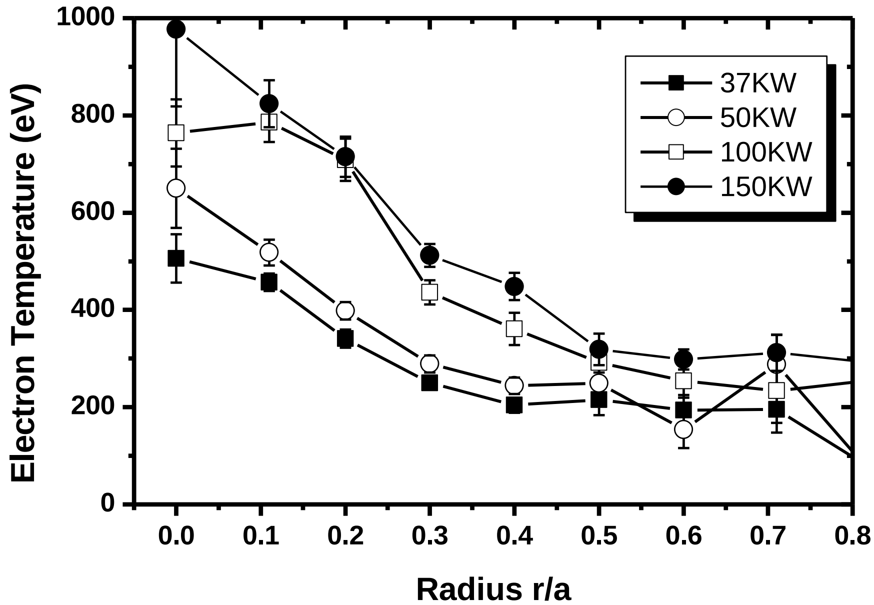

Figure 6
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