Multipoint Thomson Scattering Diagnostic For The TCABR Tokamak With Centimeter Spatial Resolution

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Abstract. This paper describes a multi-point Thomson scattering system that is being developed for the TCABR tokamak based on a signal delay technique, which allows the determination of the electron temperature and plasma density radial profiles, with approximately 1 cm spatial resolution, employing just one spectrometer.

Keywords: Thomson scattering, Tokamak, Electron temperature, Electron density.
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INTRODUCTION

TCABR is a limiter, rectangular cross section tokamak, with major radius $R_0 = 0.61$ m, minor radius $a = 0.18$ m, toroidal magnetic field $B_0 = 1.1$ T, plasma current $I_p \leq 100$ kA, line average plasma density $n \approx 1 - 3 \times 10^{19}$ m^{-3}, and central electron temperature in ohmic discharges $Te_0 \leq 650$ eV [1].

The TCABR Thomson scattering diagnostic has been developed aiming at providing simultaneous multipoint ne and Te measurements along one vertical chord, passing at the centre of the plasma column, with approximately 1 cm spatial resolution. The design, based upon signal delay techniques already tested on ISTTOK and ETE [2, 3], has been optimized using commercial software for optical ray-tracing.

GENERAL HARDWARE DESCRIPTION

This diagnostic [4, 5] is composed of a high-power laser, a laser beam delivery system, a light detection assembly and a data acquisition system (Figure 1).

The Laser

A Neodymium doped phosphate glass laser, producing a single laser pulse with one Hertz repetition rate is used. Each laser pulse has up to 30 J, with 20 ns pulse duration (the time duration of the laser pulse depends on the flash lamps voltage) and 1.5 mrad divergence (for a multimode laser pulse), and near 25 mm diameter at the laser box output.

The high power (1 GW) laser pulse is produced using two optical amplifiers and an optical Faraday isolator over a granitic table. The laser emission has central wavelength $\lambda = 1.054$ µm and 2 nm spectral width at half height.

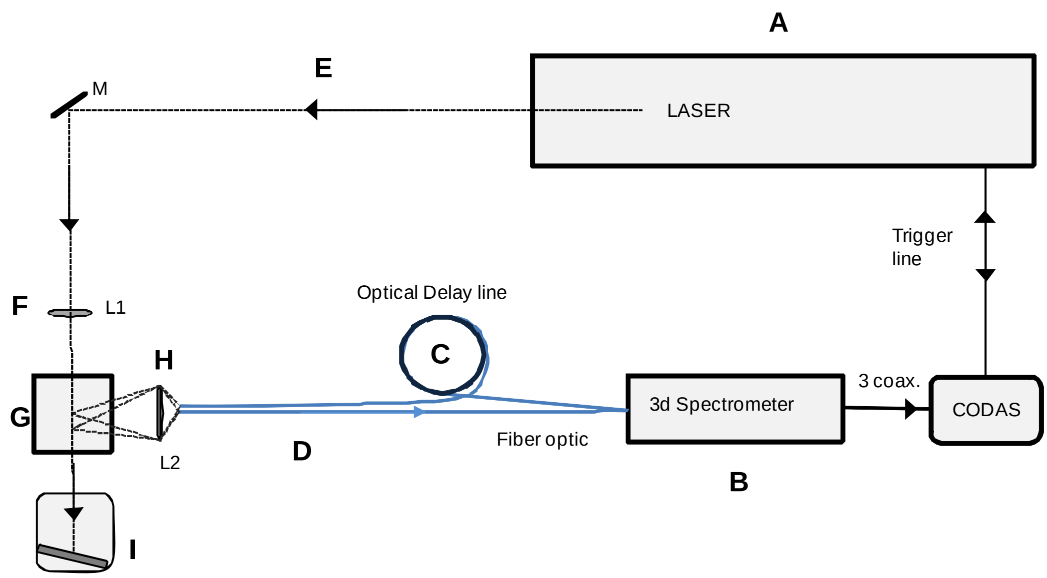

FIGURE 1. Lay-out of the TCABR Thomson scattering diagnostic. (A) Nd:Glass laser (PG38), (B) board with the spectrometers, oscilloscope and data acquisition PC, (C) optical delay lines, (D) optical fiber, (E) laser delivery system, (F) lens and input window to the vacuum vessel, (G) section of the tokamak, (H) collecting lenses, (I) main laser absorption dump.

This laser (Figure 2) comprises an oscillator, two amplifiers, an optical Faraday isolator, two laser beam Galileo expanders and a polarization rotation plate. The laser operates on a 4I11/2-4F3/2 transition within the 4f3 configuration of Nd3+, which is induced by the electric field of the host material. The neodymium ions have been doped into the host material (phosphate glass) of the oscillator rods and in the amplifiers rods. Linear flash tubes excite the neodymium ions and an inverted population is produced through non-radiative decay in the 4f3 4F3/2 level.

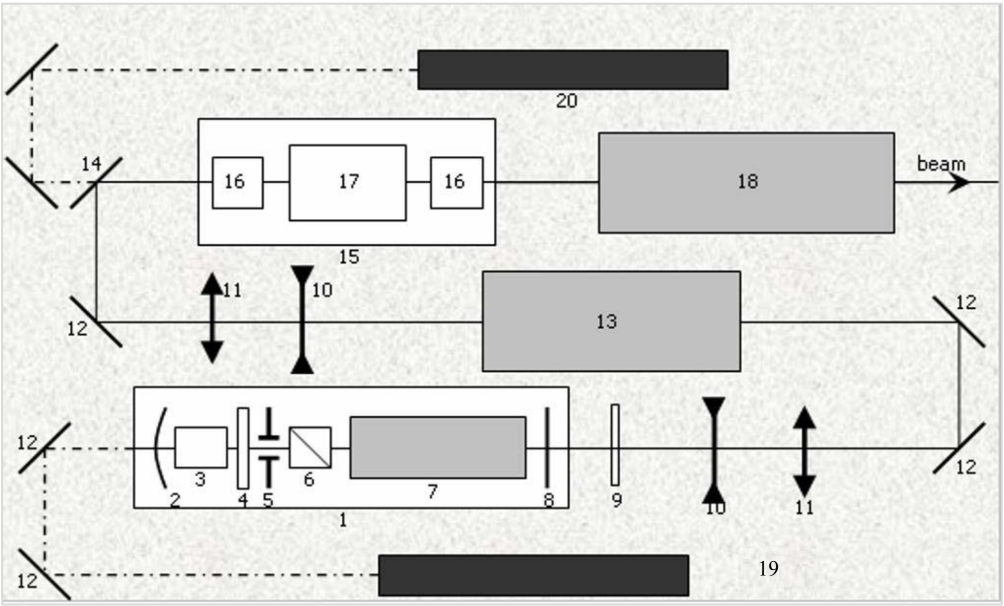

FIGURE 2. *Layout of the PG38 Neodymium:glass laser. (1) Oscillator, (2) Concave mirror, (3) Pockels-cell, (4) λ/4-retardation plate, (5) Aperture, (6) Glan-Taylor prism, (7) Main amplifier, (8) Plane mirror, (9) λ /4-retardation plate, (10) Negative lens, (11) Positive lens, (12) Plane mirror, (13) First amplifier, (14) Plane mirror transparent to the He-Ne green laser, (15) Faraday isolator, (16) Brewster polarisers, (17) Faraday rotator, (18) second and final amplifier, (19) He-Ne red laser, (20) He-Ne green laser.*

This system is a typical Q-switched laser for Thomson scattering diagnostics, which means that the stimulated emission is restrained to one large pulse. The oscillator beam has 0.75 J energy output. The first and second amplifier adds energy to this pulse and the beam leaves the granitic table with an energy up to 30 J. All the optical components are optimized for λ = 1.054 μm. An optical Faraday isolator was installed to prevent the back scattered laser light to re-enter the system backwards and damage the optical components after amplification. The Faraday isolator contains two pairs of Brewster polarisers and a Faraday crystal verded rotator. The laser has also two auxiliary He-Ne lasers (Figure 2), which provide visual beams for alignment of the oscillator (red light) and of the laser beam delivery system (green light).

Laser beam delivery system

The laser pulse delivery system is designed to transport the laser pulse from a laser house to the vacuum vessel (Figure 1), aiming at minimizing the alignment time and the stray-light. It is composed of four mirrors with a dichotic thin-film that maximizes the reflectivity (in transmission v-shape) at 1054 nm and encloses simultaneously a 50% reflectivity for the 543 nm (green alignment He-Ne laser). The reduction of the laser stray light is made using antireflection coating on the vacuum window and on the focusing lens, black anodized aluminum pipes, a viewing dump, and with the critical positioning of few slightly oversized diaphragms made of blue glass. After traversing the tokamak vessel, the laser beam is absorbed by the laser light dump, made by a tilted black glass installed inside a thin hollow black cylinder.

Light detection assembly

The light detection assembly is composed of collecting optics, optical fibers, and a spectrometer. The Thomson scattered light is analyzed at 90º by a simple collecting optics made with two lenses (a plan-convex and plan-aspherical lens). These lenses have a diameter of 50.8 mm and a focal length equal to 520 and 53 mm, respectively. This collecting lens set-up has a magnification of about 10 times. Optical fibers are used to relay the scattered light to the spectrometer. The large etandu provided by the aspherical lens allows using a plane linear array of large fibers (1.5 mm diameter). One side of the fibers ends is positioned perpendicular to the plane image of the laser chord and the other one is connected to a single spectrometer, with proper matching to the spectrometer's etandue. This arrangement of the fiber optics allows a progressive deliver of the optical signals from the localized plasma electrons to a single spectrometer. These anhydroguide optical fibers have large numerical aperture (0.4) with a minimum of 10 m length and fine mechanical polished ends. Up to five optical fibers can be inserted into a single spectrometer. Each optical fiber received by the spectrometer must have a minimum of 15 m length (a monotonous length increase at each fiber) to allow the non simultaneous arriving of the scattered pulse to the avalanche photodiode. Several devices will be installed inside the vacuum vessel, the flight tube and dump, to reduce the stray-light.

The spectrometer (Figure 3) is based on optical rails, each one containing several lenses, a narrow band optical interference filter, a silicon avalanche photodiode, and a preamplifier. The combination of spherical and aspheric lenses has been optimized to achieve the maximum light throughput everywhere in the system, keeping constant the etandu.

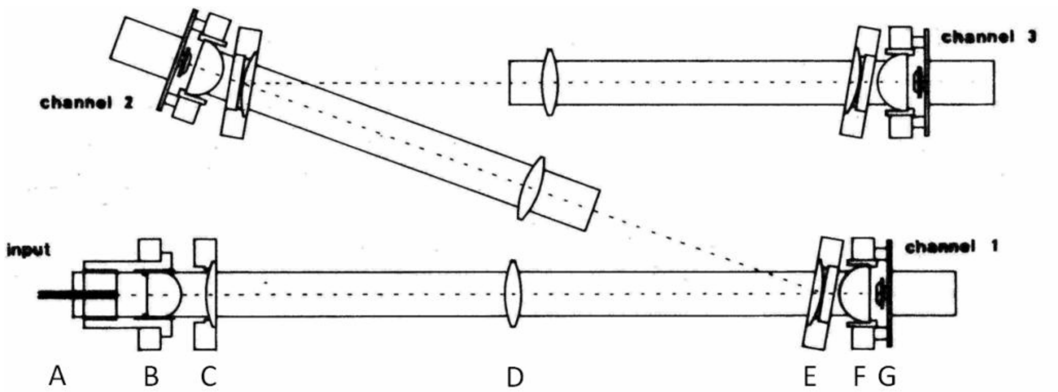

FIGURE 3. *The Thomson Spectrometer Lay-out. Spectrometer made with three equal arms. Each arm has an interference filter that defines the spectral channel. (A) Fibers optic ends. (B) Collimating aspheric lens, (C) long range lens, (D) relay lens, (E) long range lens and interference filter, (F) focusing lens, (G) Si avalanche photodiode.*

The interference filters, with a clear aperture of 21 mm and 5 mm thickness, were chosen aiming at the light analysis in the blue side of the scattered wavelength spectrum, and simultaneously giving the maximum sensitivity for the expected range of the electron temperature. The incidence angle on the interference filter is 10° and they have a 60 % transmission inside the passing band and a blocking band with an optical density of 4. The avalanche photodiodes have 3 mm diameter of sensible area. Then the efficiency of the conversion of photons to electrons in the spectrometer varies between 25 A/W, in the 1060 nm, and 40 A/W, in the 1000 nm up to 800 nm, with an avalanche value of 25. The preamplifier bandwidth was reduced up to 40 MHz to limit the noise and to match the laser pulse duration. The calibration of the spectrometer was made simulating the plasma scattered light by using a stabilized tungsten lamp and a fast response (up to 100 MHz) infrared LED (Figure 4).

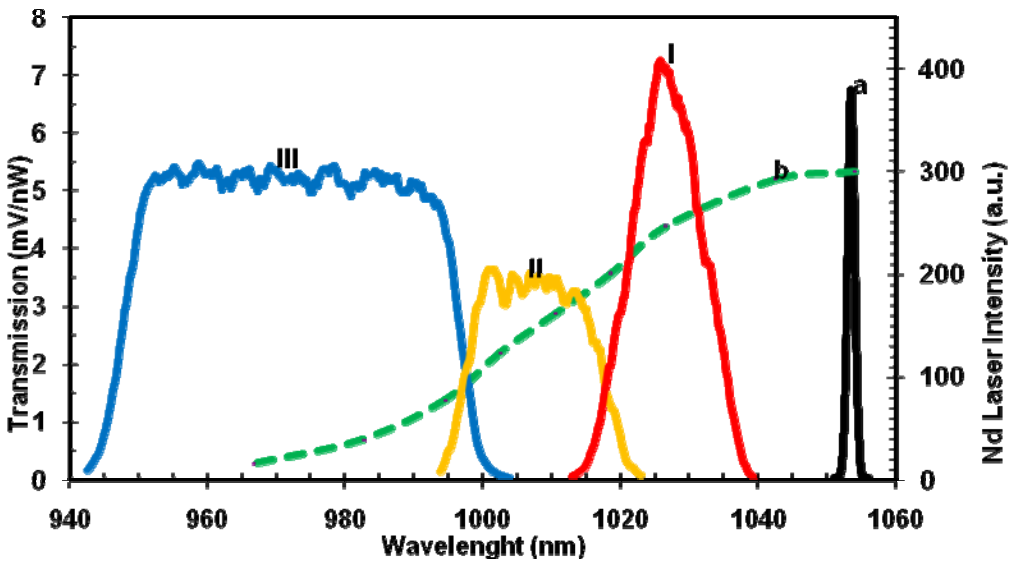

FIGURE 4. *Thomson scattering general view with two vertical axes. Left axes, Optical Transmission: (I, II, III) Spectrometer channels transmissions (corresponding with the 1, 2 and 3 channels). Right axes: Optical emission intensity: (a) natural Nd:glass laser line and (b) typical laser Doppler broadening for 200 eV.*

OPTICAL RAY-TRACING OF THE LASER STRAY-LIGHT

The TCABR Thomson scattering diagnostic was simulated using a commercial ray-tracing program, aiming at assisting in the identification of critical points of the system, such as the origin of the stray light, and to suggest some solutions to these undesirable light intensities. This optical simulation has permitted to clearly identify the need for a light dump in front of the observation window (or viewing dump) and to conclude that the optical assembly of the output tube deserves special attention because of the return of light reflected in the last window. Figure 5 shows the reflections of the laser light inside the TCABR vacuum chamber. These reflections are multiple internal light bounding that have origin on the faces of the last window.

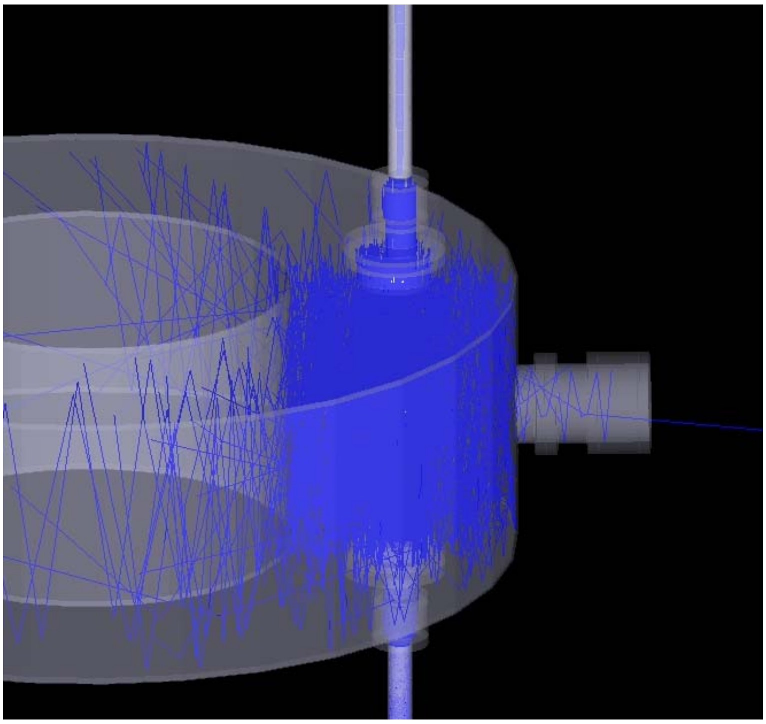

Figure 5. *Ray-tracing of the laser stray-light inside the vacuum chamber.*

DATA ACQUISITION SYSTEM

The three output signals from the spectrometer are connected to a 1 GHz digital oscilloscope, controlled by a Personal Computer. The laser and the oscilloscope are triggered by signals provided respectively by the TCABR central timing system and the laser oscillator. In a second phase, the oscilloscope will be replaced by an on-site developed ATCA transient recorder system.

CONCLUSIONS

The feasibility of the design of the TCABR Thomson scattering diagnostic to meet the goals of performing high spatial resolution and high accuracy measurements at low density and low electron temperature plasmas is being investigated. The Nd:glass laser is on commission testing. The laser pulse delivery system to the tokamak is on the drawing phase. A ray-tracing simulation has allowed preventing few situations of high laser stray-light. The spectrometer is ready to be calibrated. The use of time delay techniques, multi-input spectrometer and a digital oscilloscope will allow reducing the relative complexity of diagnostic. Future work will include calibration of the spectrometer by Rayleigh and Raman scattering for absolute plasma density measurements.

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