THE ISTTOK THOMSON SCATTERING DIAGNOSTIC

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This article describes the Thomson scattering diagnostic that has been develop for multipoint measurements of the electron temperature and plasma density in the tokamak ISTTOK. The design is based on a single laser pulse, two multi-input fibre optic interference filter spectrometer one digital oscilloscope and a time-delay technique. Special collection optics, optimised detectors and high transmission singe fibres with large numerical aperture are used to increase the sensitivity and spatial resolution. The number of measurement points can be extended by increasing the number of fibres without altering the collection optics or light relay system.

1 Introduction

The Thomson scattering diagnostic is the most used technique to determine the temperature (T_e) and density (n_e) of the plasma electrons. It is based on the scattering of laser photons by the free electrons in the plasma. From a Maxwellian distribution of the electron velocities is obtain a Gaussian distribution of the scattered photon wavelengths. The electron density and temperature are, respectively, proportional to the area and width squared of the Gaussian distribution. New designs of the diagnostic have been proposed aiming at the increase of the temporal and spatial resolution. High temporal resolution, important for the study of L-H transitions, edge localized modes and disruptions, can be obtained using a multi-pulse high repetition laser. High spatial resolution, important for understanding the transport of particles and heat as well as for the study of plasma non homogeneities (such as filamentation) has been achieved by spatial multipoint analysis. There is also an increasing need to extend the n_e and T_e measurements to the edge and to the divertor where the problems of plasma parameter determination at low densities and temperatures, as well as high background light, must be overcome.

This article presents a 90º Thomson Scattering Diagnostic (TSD) that has been develop for the tokamak ISTTOK aiming at multipoint measurements in a low density and low electron temperature plasma.

This diagnostic includes several innovations such as the use of special collection optics, large numerical aperture single fibres, and a very high throughout compact spectrometer with avalanche silicon photodiodes with a multi fibre input, an electrical time-delay device and a digital oscilloscope for data acquisition. This technique allows each spectrometer to cover up to three spatial points in the plasma and to use a single input channel of the oscilloscope to record all the nine output signals of the spectrometer.

2 Description of the Diagnostic

The TSD (Fig. 1) has been developed to provide simultaneous multipoint n_e e and T_e measurements along one laser vertical chord in the ISTTOK plasma, located at 5 mm off the tokamak centre.

2.1 The Laser

The Nd-Glass laser was manufactured by Quantel (reference PG38) for this diagnostic. Its main components are: (i) the oscillator, composed by a cavity mirror, an active medium, the electro-optic trigger based on a Q-switched Pockels cell, and a Glan-Taylor polarizer; and (ii) two amplifiers. The amplifying components are phosphate-glass rods doped with neodymium and surrounded by linear flash lamps. In between the two amplifiers there is a Faraday rotator isolator to prevent damages due to the amplification of backward reflected light.

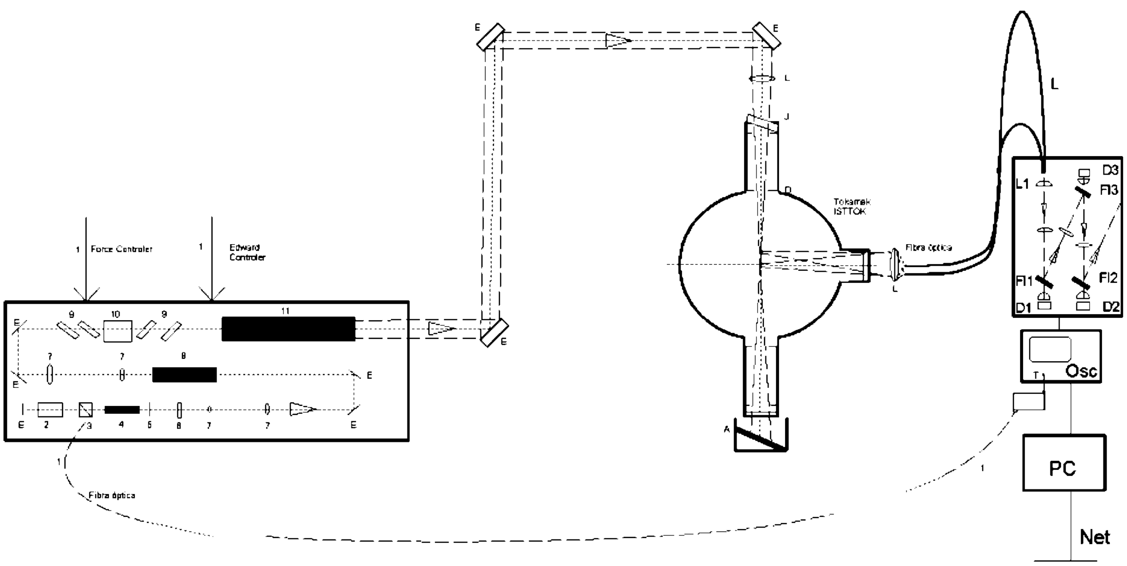


Fig. 1: Lay-out of the Thomson Scattering Diagnostic at the ISTTOK. In the left side it's the Nd:Glass laser, in the right side it's the spectrometer and the digital oscilloscope.

The PG38 laser has the following characteristics: central wavelength at 1054 nm, spectral width of 2 nm, pulse duration 16 ns, the maximum energy per pulse is 30 J, the beam divergence is 1.5 mrad, the bean diameter is 25 mm, with linear polarization and maximum repetition rate of 4 laser shots per minute.

2.2 Laser beam delivery system

The laser beam is delivered into the tokamak plasma by a set of four dielectric coated mirrors. They have two “v” shape reflectivity. One with 99.7 % reflectivity for the main 1.054 μm wavelength and a second “v” shape with 50% reflectivity for the He-Ne green laser line. These reflectors are all operated at a nominal 45° incidence angle and have a damage threshold higher than 8 J/cm^2 at 1.054 μm.

The laser pulse must travel 15 m path inside PVC tubes, each located between two consecutive mirrors and a 0.8 m length stainless steel pipe, placed between the last reflector and the top port of the vacuum chamber. This pipe has inside of it another aluminium pipe with two diaphragms to reduce the stray light. Its internal face was coated by two layers of, respectively, black electrolytic oxide and graphite, aiming at reducing the stray-light inside the tokamak chamber. Stray-light has also been decreased by using one view-dumps mounted inside the vacuum vessel and opposite to the collection lenses. The laser beam is focused inside the plasma into a chord of 2 mm width by a 1 m focal lens. The two tokamak ports have a BK7 glass window with antireflection coating and titled at 2°. After the interaction with the plasma, the laser beam is absorbed by a thick black glass tilted at 5º at the end of another 0.8 m long stainless steel pipe connected to a bottom port of the vacuum chamber. Over the thick black glass there is an uncoated optical fibre that allow the instantaneous laser energy measurement.

The alignment of the laser beam delivery system it’s made using a coaxial CW He-Ne green laser. For this purpose a set of transparent films, with a mark, are inserted mechanically centred in each mirror and in the two windows. At the bean delivery end a set of shadows are obtain when the He-Ne laser is on. When all the shadow’s marks are concentric the laser bean delivery it’s aligned.

2.3 Collection optics and scattered light transmission

The 90° scattered light is collected by a combination of a plan convex and an aspherical lens and relayed to the spectrometer by two optical fibres. These lenses have a diameter of 50.8 mm and a focal length, respectively, equal to 200 and 53 mm. The set-up has a magnification of about 4 times. The large etandu provided by the aspherical lens allowed to use up to five large fibres (1.5 mm diameter) instead of fibre bundles, leading to a 30% increase in transmission. The TSD "anhydroguide" optical fibres have large numerical aperture (0.4), with a minimum of 10 m length and fine mechanical polished ends.

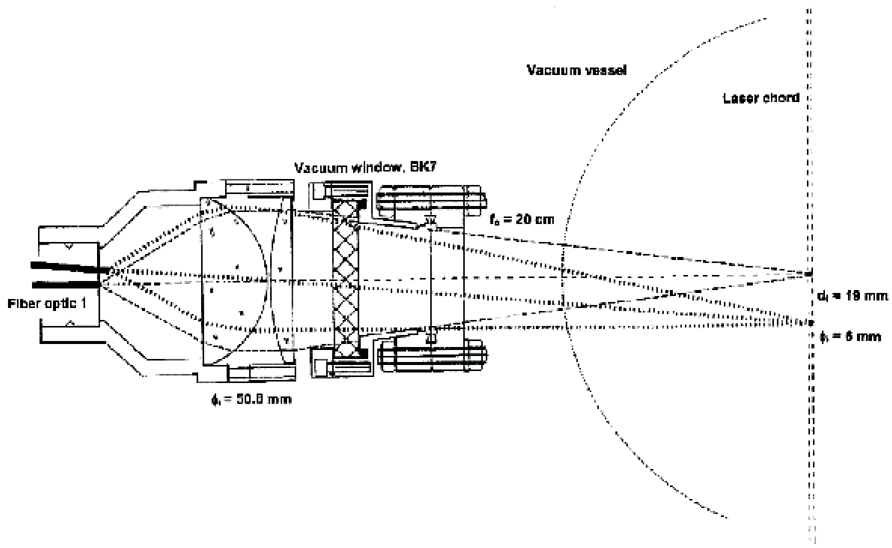


Fig. 2: Collection optics made of plan convex and an aspherical lens and two optical fibre with 1,5 mm diameter.

2.4 Spectrometer

The spectrometer 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 optimised to achieve the maximum light throughput everywhere in the system, keeping constant the etandu. The interference filters, with a clear aperture of 2l mm and 5 mm thickness, were chosen aiming 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 of OD 4 outside. The avalanche photodiodes (C30956E) have 3 mm diameter of sensible area. The preamplifier bandwidth was reduced up to 40 MHz to limit the noise and to match the laser pulse duration. Two optical fibres are inserted in a single spectrometer. The second optical fibre has plus 15 m length to allowed the non simultaneous arriving of the scattered pulse to the avalanche photodiode.

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. The calibration set-up include a focus lens, a monochromator for wavelength selection, a chopper to pulse the light from the tungsten lamp and a glass scatter plate to uniformly illuminate the light collection system of the TSD. This set-up allow to determine the regime of each spectrometer channel due to the wavelength of the input light (Fig. 3) and the relation between the electron temperature with the ratio of the output voltages of any combination of channels.

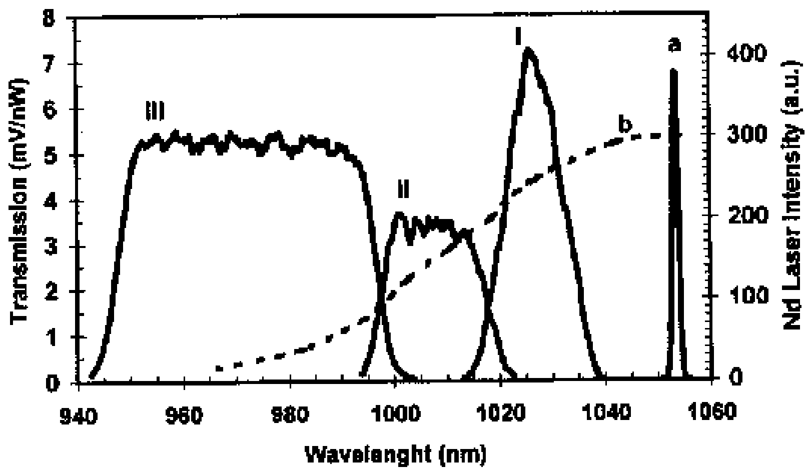


Fig. 3: Spectrometer Calibration. Curves I, II and III are the calibration curves of each interference filter. Curve (a) its the natural broadening of the Nd-Glass laser line. Curve (b) its the Doppler broadening laser line in a plasma with T_e = 250 eV and $n_e = 1x10^{18}$ m^{-3}.

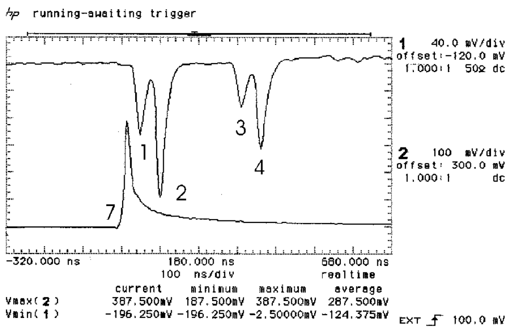
2.7 Control and data acquisition system

The spectrometer output signals are given to a digital oscilloscope (1 Giga Sample per second sampling rate) through three different length coaxial cables and a passive addition electronic circuit. This component is made of a simple resistive impedance of thin film, providing good impedance matching and a fair isolation between inputs. The diagnostic operation is supervised by the ISTTOK control system, which provides signals to start the charge of the laser capacitor banks and to fire the laser. The oscilloscope is triggered by the signal from a Si PiN photodiode located in front of the laser Glan-Taylor polarizer trough a optical fibre with 20 m long. Autonomous safety switches are located in the laser room to prevent accidentally firing the laser.

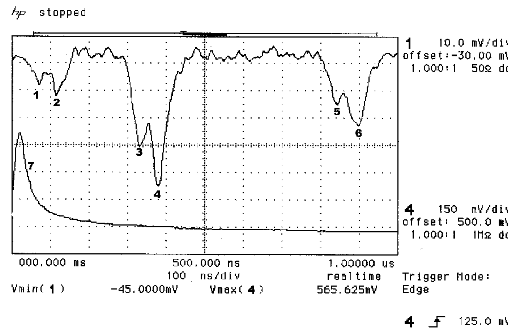
3. Results

The Thomson scattering diagnostic has analysed the plasma at two spatial points of the tokamak in a chord at r=5 mm using a time delay technique. Figure 4 presents two sets of row data obtained in the oscilloscope. The plasma density measurements were made assuming that the value for n_e at r=5 mm are equal to that determined by the heavy ion beam diagnostic. Calibration by Raman Scattering in Nitrogen was not possible due to the big separation between the central laser line and the first interference filter band.

These results allowed to conclude that the TSD has permitted to achieve a resolution of 6 mm for each scattering volume and 19 mm between the two adjacent scattering volumes, with an accuracy for both T_e and n_e measurements of about 15% corresponding to a signal-to-noise ratio of 30.



(a) Low density plasma



(b) High density plasma

Fig. 4: The row data from the TSD. (a) For a low density plasma and (b) for a high density plasma. Positive pick 7 represents the laser energy 10 J. Negative picks 1,3 and 5 are scattered signals from r=5 mm. Negative picks 2,4 and 6 are scattered signals from r=20 mm.

4 Conclusions

Results have shown the feasibility of the design of the ISTTOK Thomson scattering diagnostic to meet the goals of performing high spatial resolution and high accuracy measurements at low density and low electron temperature plasmas. The use of time delay techniques, multi-input spectrometers and a digital oscilloscope has allowed to reduce the diagnostic size and cost. Future work will include calibration of the spectrometer by Raman scattering for absolute plasma density measurements.

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References

1 M.P. Alonso, P.D. Wilcok and C.A.F. Varandas, *Rev. of Scien. Instr.* **70**, n1, (Jan. 1999), p. 783

2 C.A.F. Varandas et al., *Fusion Technol.* **29**, 105 (1996)