

The Fiber Optic Multiplexed Upgraded Thomson Scattering Diagnostic for the ISTTOK Tokamak

M. P. Alonso¹, L. A. Berni²

¹Associação EURATOM/IST, Centro de Fusão Nuclear, Instituto Superior Técnico, 1049-001, Lisboa, Portugal

²Laboratório Associado de Plasma (LAP), Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, São Paulo, Brasil

An upgrade of the ISTTOK Thomson Scattering Diagnostic is being developed aiming at the simultaneous measurements of twenty-point radial profiles of the electron temperature and density in the same tokamak discharge, using a single laser pulse and a single polychromator.

1. Introduction

This paper describes the design details and the results of numerical simulation of an upgrade of the ISTTOK Thomson scattering diagnostic [1, 2].

The new configuration of this diagnostic aims increasing the spatial resolution radial profiles of the electron temperature and density, in the same ISTTOK discharge ($T_e = 200$ eV and $n_e = 2 \times 10^{19} \text{ m}^{-3}$) using a single laser pulse (30 nano sec., 10 J) and a single spectrometer (with 3 avalanche-photodiodes and interference filters).

This multipoint Thomson scattering diagnostic is based on a specially designed light collecting system and a time-delay technique provided by different length optical fibers used to relay the scattered light to a single spectrometer.

2. Thomson Scattering Diagnostic at ISTTOK

The Neodymium: glass laser beam ($\lambda = 1054$ nm, 30 ns pulse duration, up to 30 J) is driven by four flat mirrors up to the tokamak where is focused to the plasma center by a 1 m focal lens. The flight tube and the laser dump (made of glass) have specially designed black anodized inserts to reduce laser stray light. This noise has also been decreased by using one view-dump mounted inside the vacuum vessel and opposite to the collection lenses. Figure 1 shows the present two fiber optic Thomson scattering system [2].

The 90° scattered light is collected by a duplet made of a plan-convex and aspheric lens and relayed to the spectrometer by two optical fibers with different length. This collecting light set-up has a magnification of 4 times with 0.4 numerical aperture (NA) fiber optic.

The spectrometer is based in a combination of spherical and aspheric lenses that has been optimized to achieve the maximum light throughput everywhere in the system, keeping constant the etendue. This spectrometer avalanche photodiodes

have 3 mm diameter of sensible area that allow the multiple optical fibers insertion in a single spectrometer. The second optical fiber has plus 15 m length to allowed the non simultaneous arriving of the light scattered pulse to the avalanche photodiode sensible area. Then the spectrometer output signals are given to a digital oscilloscope (1 Giga Sample per second sampling rate) through three different length coaxial cables connected to a passive addition electronic circuit.

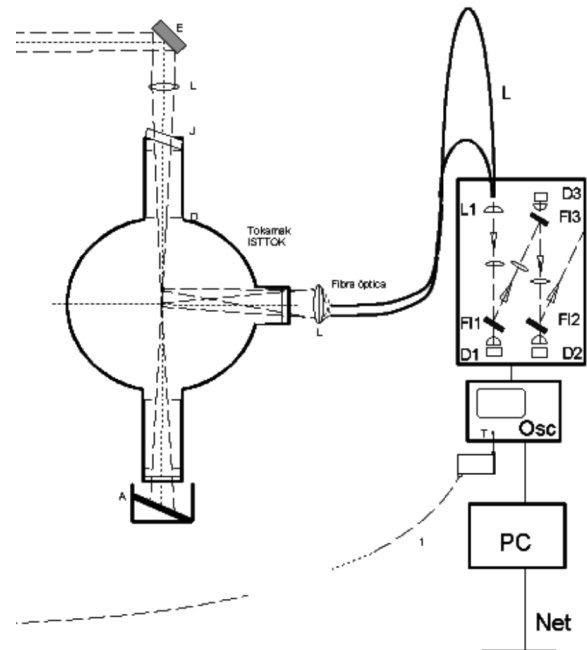


Fig. 1: Present Thomson scattering on the ISTTOK tokamak; In the left side the E means mirror's place; L for lens; J for window; D for diaphragm; A for laser dump; L symbolize the fiber optic delay; the L1, FI1, D1 stand for the spectrometer's component; and T for trigger cable signal.

3. Multipoint Thomson Scattering Diagnostic

A new multipoint Thomson scattering diagnostic is being proposed to upgrade the present system. This diagnostic upgrade is based on the same fiber optic time-delay technique [2] and on the increase of the number of fiber optics. Taking in account the 16 mm² that the ISTTOK spectrometer has of effective input area for the fiber optic, then is possible to introduce up to 20 fibers in the spectrometer to measure 20 spatial channels if each fiber has 0.8 mm diameter (Figure 2). For this setup the estimate lengths of the fibers optics are unchanged and monotonous increasing with 20 m length difference.

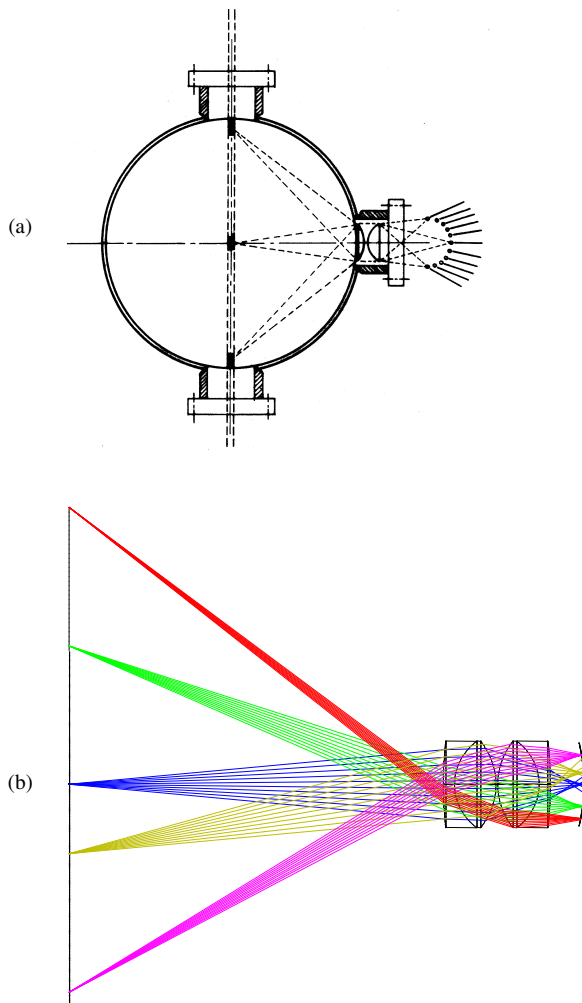


Fig. 2 : (a) Tokamak ISTTOK cross section and proposed Thomson Scattering collecting lens made with a duplet and a set of micro lens. (b) ZEMAX ray-tracing of the collecting lens.

The proposed system will use smaller core monofibers (0.8 mm and NA = 0.4) and if the magnification of the collection lens is 4 times, then

this implies the necessity of introduce a sphere or a micro-lens (with $\phi = 1.5$ mm) in front of each fiber optic to enlarge the observation volume inside the plasma up to the former 5 mm.

4. Numerical Simulations Results

Simulations have been performed using optical ray tracing software aiming at increasing the diagnostic spatial resolution by a definition of a new optical collecting systems. Numerical results have shown that a spatial resolution near 5 mm (equivalent for the T_e and n_e) for measurement at 20 points of the ISTTOK plasma-laser chord will be achievable by using a new collecting lens set that offer space for up to 20 fiber optic input (with a reduced diameter) that are compatibles with the spectrometer input size. The new light collecting lens assemble (figures 3 and 4) can be made using (i) a lens assemble that focusing (the first lens) at the laser chord and (the last lens) to the fiber optic input, or with (ii) the referred lens sequential set and including a tinny sphere or a micro lens adjacent to each fiber optic.

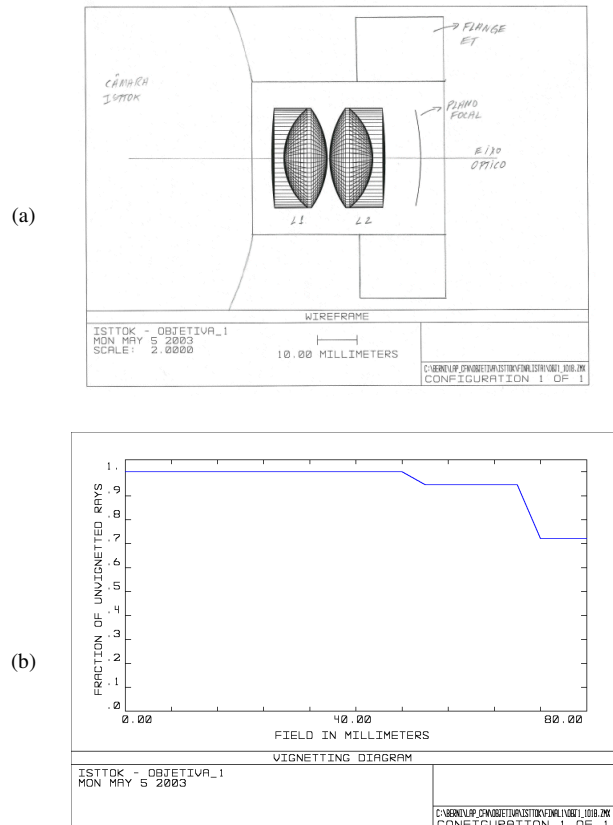


Fig. 3 : (a) Tokamak ISTTOK viewing window and 3D proposed collecting lens made with two standard lenses. (b) Results of the vignetting made by the (3.a) collecting lens using an array of 0.8 mm diameter fiber optics.

The adjacent micro lens allows us to increase the overall optical magnification and, then, producing a bigger observation volume at the plasma focusing point with the same fiber optic diameter that, by his way, has the maximum desired diameter allowed for the spectrometer input (figure 5).

We have two possible light collection assemble, one made with two standard lenses and the other made with three specially designed lenses.

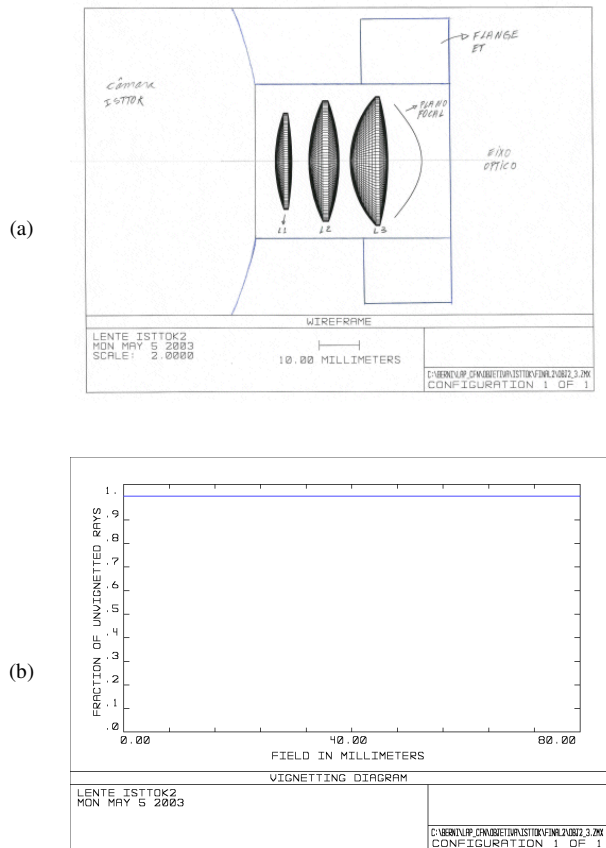


Fig. 4 : (a) Tokamak ISTTOK viewing window and 3D proposed collecting lens made with non standard lenses. (b) Vigneting results from the non standard collecting lens using an array of 0.8 mm diameter fiber optics.

The first collection lens assemble (figure 3) has two achromatic lenses with 25 mm diameter and 30 mm focal length. This duplet is at 100 mm to the laser chord, with a Input NA of 0.08; observing 160 mm of the minor tokamak diameter; with a 6 times magnification; using a 0.8 mm fiber optic; analyzing a plasma volume diameter of 4.8 mm; having a output NA of 0.42 and a $1 \cdot \Omega = 9.6 \times 10^{-5}$.

The second collection lens assemble (figure 4) has three Silica lenses with: L1 = 24 mm, L2 = 30 mm e L3 = 32 mm diameters. This lens assemble is at the same 100 mm to the laser chord, and with a Input NA of 0.08; observing 160 mm of the minor

tokamak diameter; but with a 4.9 times magnification; using a 0.8 mm fiber optic; analyzing a plasma volume diameter of 4,0 mm; having a output NA of 0.36 and a $1 \cdot \Omega = 8.0 \times 10^{-5}$.

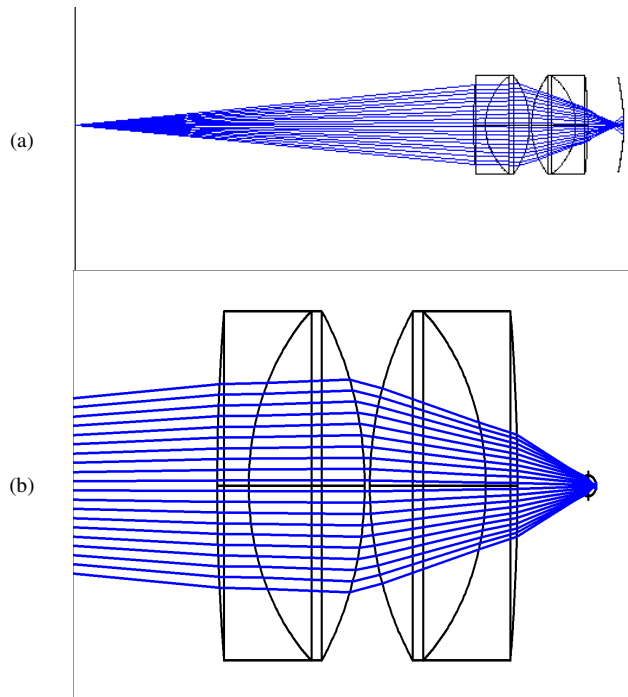


Fig. 5 : (a) Central Ray Tracing of the first collecting light assemble, showing the laser chord at the left side and the image curved line at the right side. (b) Detail of the same central ray tracing and introducing a micro lens of 1.5 mm diameter to increase the magnification value.

To demonstrated the effect of introducing a adjacent micro lens between the last collection lens and the fiber optic we admit an arbitrary observation volume with 5 mm diameter that is considered inside the plasma and at the intersection with the laser chord (in the figure 6.a).

Them, in the figure 6.b we represent the ray tracing result in a image projection plane of the observation volume defined in figure 6.a and using the second collection lens (in figure 4), in this case we can measure a 6 times magnification, then we will need a 1.5 mm diameter fiber optic.

In the figure 6.c we are at the same image projection plane of figure 6.b and using the same arbitrary observation volume shown in figure 6.a but we have introduced a micro lens with 1.5 mm diameter adjacent to the fiber optic. In this case we will have a 12 times magnification and we can use a smaller fiber optic with down to 0.5 mm diameter.

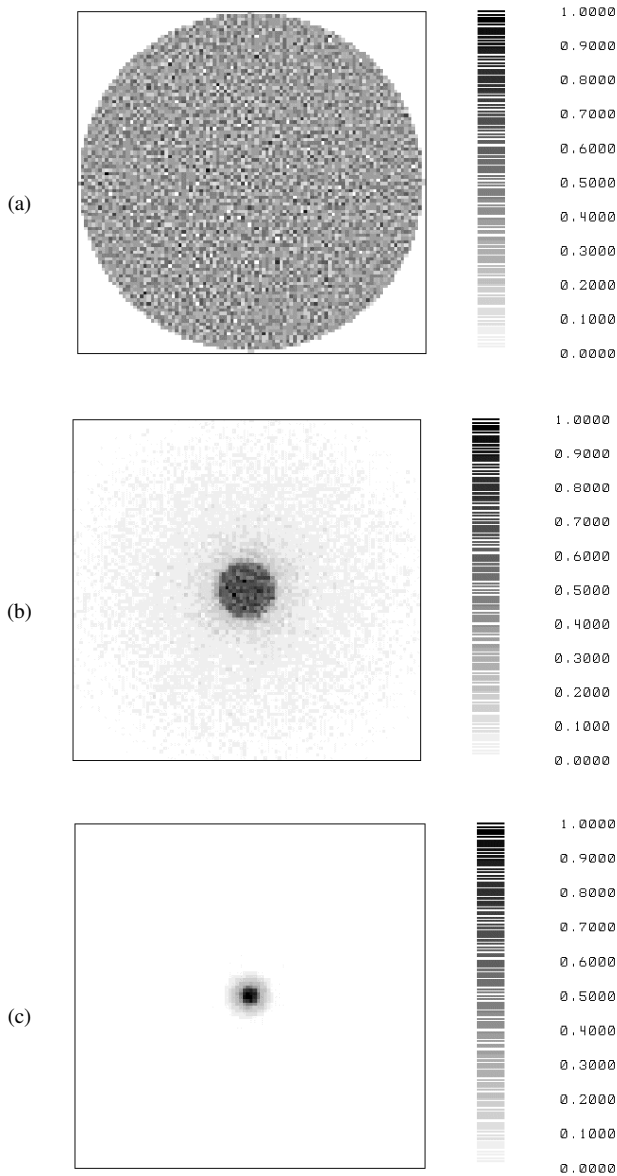


Fig. 6 : **(a)** Arbitrary observation volume with 5 mm diameter; **(b)** Projection image of the observation volume without micro lens; **(c)** Projection image of the observation volume with a 1.5 mm diameter micro lens. Scale 1.0000 : 5.0 mm

5. Conclusions

Numerical results have shown the feasibility of the increase in space resolution using a smaller diameter fiber optic for the ISTTOK Thomson scattering diagnostic and maintaining the high accuracy measurements at low density and low electron temperature plasmas. The use of time delay techniques, multi-input spectrometers and digital oscilloscope will keep reduced the diagnostic size and cost.

6. References

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