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The Fiber Optic Multiplexed Thomson Scattering Diagnostic for the ETE Tokamak

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Introduction

The ETE (Experimento Tokamak Esférico) [1] is a medium-size spherical tokamak with an aspect ratio of $A \leq 1.5$, major radius $R_o = 30$ cm, toroidal field $B_o = 0.4$ T and plasma current $I_p = 0.22$ MA. To measure the electron temperature and density profiles a Thomson scattering diagnostic system with a 10 J ruby laser was implemented. A new Thomson scattering diagnostic is being developed for ETE aiming at the simultaneous measurement of the profiles at up to nineteen spatial points in the same discharge using only one polychromator. This work describes the present system and the details of the proposed multiplexed Thomson scattering diagnostic based on a fiber optic time-delay technique [4].

Present Thomson Scattering Diagnostic

Figure 1 shows the present one-channel Thomson scattering (TS) system [2]. The ruby laser beam ($\lambda = 694.3$ nm, pulse duration: 30 ns) is driven by three flat mirrors and is focalized at the center of the plasma by a 3 m focal lens. A 1.3 m flight tube and a dump with special black painted inserts were designed to prevent the stray light. An f/6.3 collection lens [3] allows to measure up to 22 spatial plasma points (shot by shot) with a resolution of 15 mm along the laser line. The lens images the scattered light on a 7 m fiber-bundle (f/1.75 and cross-section of 4.5x1.5 mm^2), that is spectral analyzed by a five-channel filter polychromator [3]. The present polychromator was optimized to measure electrom temperatures from 20 eV to 2 keV and densities greater than 1×10^{19} m^{-3}. The overall transmission of the system is calculated to be 31%. The signals are acquired by a four-channel high speed oscilloscope. Figure 2 shows the ray-tracing of the objective simulated by the ZEMAX code and table 1 describes each optical element of the objective.

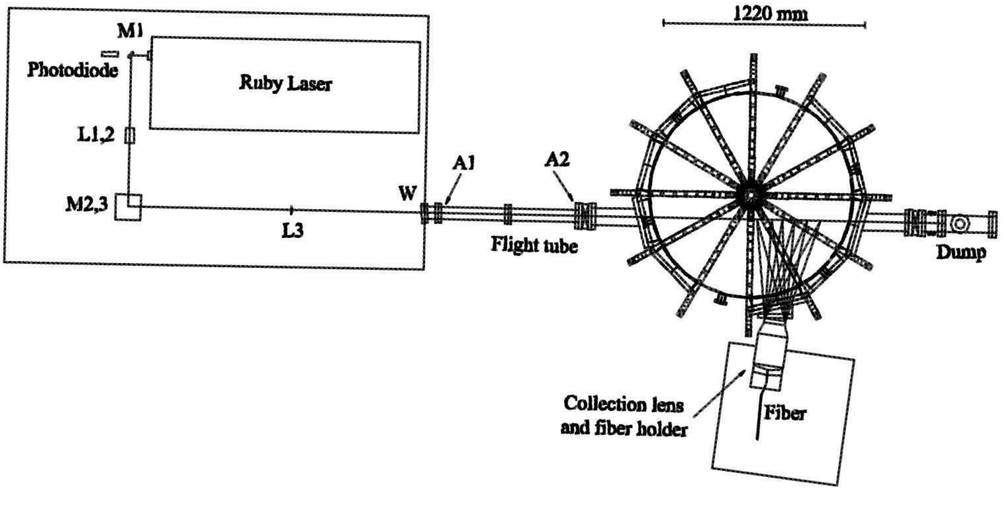

Figure 1: *Thomson scattering on the ETE tokamak. M1,2,3: flat mirrors; L1,2: beam expander; L3: focusing lens; W: entrance window; A1,2: apertures.*

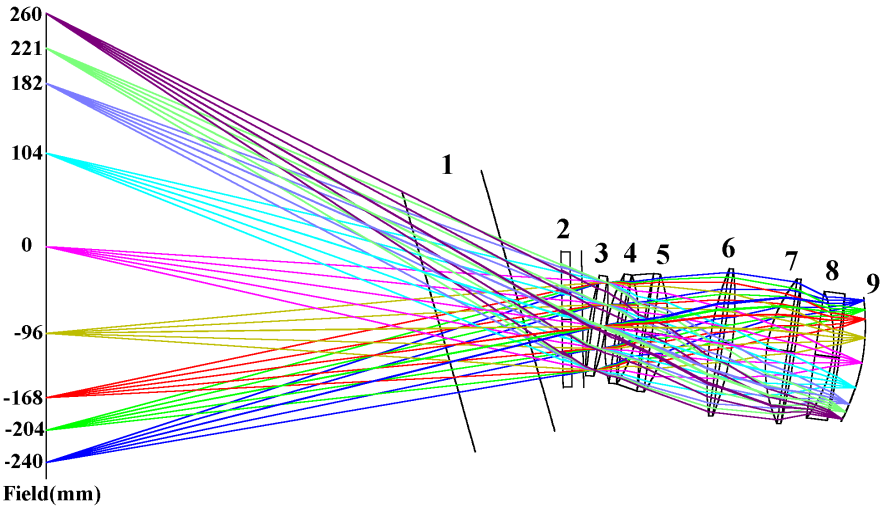

Figure 2: *ZEMAX ray-tracing of the objective. 1- Vessel port of the ETE; 2- CF150 window; 3 to 8 - Lenses of the objective; 9- Objective focal plane.*

Lens	**R1** (mm)	**R2** (mm)	**R3** (mm)	**ϕ** (mm)	**Thickness** (mm)	**Glass**	**Coating**
3	429.0	-285.0		112.0	18.0	SK5	HEAR1
4	175.0	469.9		122.3	15.0	SK5	HEAR1
5	-140.5	719.7	-145.9	122.3 132.0	6.0 26.0	SF6 SK5	AR HEAR1
6	350.0	-350.0		165.0	24.0	BK7	HEAR1
7	160.0	-848.0		162.0	30.0	BK7	HEAR1
8	-145.0	-719.7		142.0	7.5	SF6	AR

Table 1: *Optical elements of the objective.*

Multipoint Thomson Scattering Diagnostic

A multipoint Thomson scattering (MTS) diagnostic is being proposed to upgrade the present system. This new diagnostic is based on a time-delay technique by using different-lengths optical fibers to relay the light signals to the same polychromator [4]. The proposed system uses large core monofibers (0.6 or 0.8 mm) of NA = 0.39 with an average attenuation of 7 dB/Km in the spectral range from 694 nm to 880 nm. As the amplification of the present collection lens is about 3.3 times, it is necessary to use micro-lenses (ϕ = 3 mm) in front of each fiber to enlarge the observation region inside the plasma to 4 mm.

In the case of fibers of 0.8 mm and micro-lenses of f = 15 mm it is possible to introduce up to 10 fibers (to measure 10 spatial channels) in the polychromator, because the effective allowed area in this diagnostic component is 7 mm^2. For this MTS setup the estimate lengths of the fibers are monotonous increased with 14 m length difference. The first fiber has a length of 8 m and the last one (fiber number 10) of 134 m. The overall transmission is estimated to be 52% for the first fiber and 42% for the last one. With fibers of 0.6 mm is possible to have 19 spatial channels. The last fiber has a length of 260 m and the transmission is reduced to 35%. For this system is considered micro-lenses of f = 9 mm which increases the amplification of the collections optics to 6.6 times. Figure 3 shows a ray-tracing detail of the MTS setup for fibers of 0.8 mm diameter.

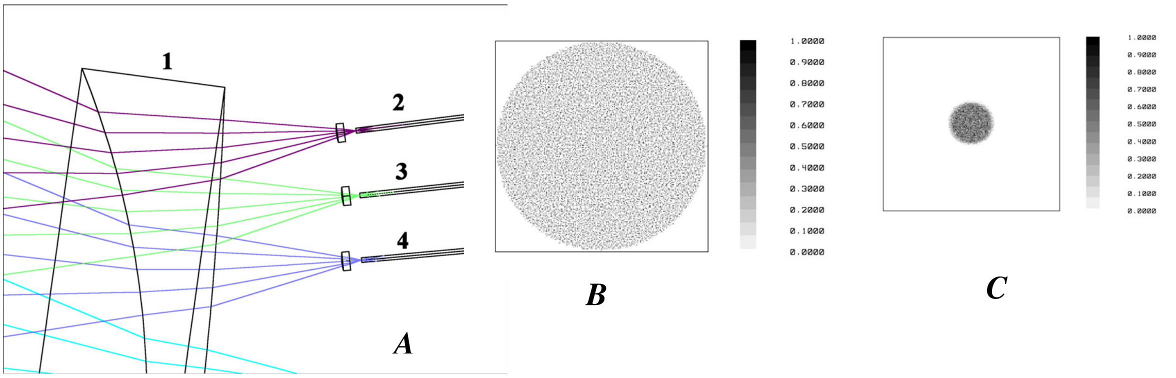

Figure 3: *Details of the MTS for fibers of 0.8 mm core diameter and micro-lenses of f = 15 mm. (**A**) Ray-tracing: **1**- Last lens of the objective; **2** to **4** - Micro-lenses and fibers for fields at -240, -204 and -168 mm. (**B**) Spot diagram of a test object (ϕ = 4 mm) put at the field -168mm. (**C**) Spot diagram of the imaged object from (B) on the fiber 4.*

Simulation Results

Simulations were performed using MATHEMATICA aiming at estimating the signals of the two proposed MTS systems and to compare with the present TS signals. Tables 2 to 4 summarize the results. Simulations were performed for three different values of the parameters T_e and n_e. The number of scattered photons in the collection solid angle (Ω) was calculated by using Adrian Selden equations. The number of photons that reach each channel was estimated taking in account the transmission of the optics and the polychromator spectral response. The output signals were estimated considering the gain of the polychromator electronics.

T_e (eV)	**n_e** (10^{19} m^{-3})	**N of scat. photons** in plasma and Ω	**N of photons** at detector	**Estimated signals** (output in mV)
40	1	454 159	ch2: 19 240	64
			ch3: 24 407	80
			ch4: -------	------
150	2	90 8317	ch2: 22 456	74
			ch3: 54 629	178
			ch4: 18 895	60
300	5	2.3 x 10^6	ch2: 40 581	134
			ch3: 113 212	370
			ch4: 92 562	290

Table 2: *Present ETE Thomson Scattering Diagnostic parameters (with laser energy of 4J, objective NA 0.0833 and 31% light transmission)*

T_e	**n_e**	**N of scat. photons in Ω**	**N of photons and estimated output signals at detector**						
				fiber 1		**fiber 5**		**fiber 10**	
(eV)	(10^{19} m^{-3})	at plasma	Ch	N	mV	N	mV	N	mV
40	1	123 915	2	8 933	(30)	8 164	(27)	7 292	(24)
			3	11 332	(37)	10 356	(34)	9 251	(30)
			4	----------	-----	---------	-----	--------	-----
150	2	247 831	2	10 426	(35)	9 529	(31.5)	8 511	(28)
			3	25 365	(83)	23 180	(76)	20 705	(68)
			4	8 773	(28)	8 017	(25)	7 162	(22)
300	5	619 577	2	18 842	(62)	17 219	(57)	15 381	(51)
			3	52 565	(172)	48 039	(157)	42 910	(140)
			4	42 977	(135)	39 276	(123)	35 083	(110)

Table 3: *Planned parameters for MTS with 0.8 mm diameter fibers (using laser energy: 7J, objective NA: 0.07113 and ligh transmission: 42 - 52 %).*

T_e	**n_e**	**N of scat. photons in Ω**	**N of photons and estimated output signals at detector**						
				fiber 1		**fiber 10**		**fiber 19**	
(eV)	(10^{19} m^{-3})	at plasma	Ch	N	mV	N	mV	N	mV
40	1	176 397	2	10 380	(34)	8 472	(28)	6 915	(23)
			3	13 168	(43)	10 747	(35)	8 772	(29)
			4	--------		--------		-------	
150	2	352 795	2	12 116	(40)	9 888	(33)	8 072	(27)
			3	29 475	(96)	24 055	(79)	19 637	(64)
			4	10 194	(32)	8 320	(26)	6 791	(21)
300	5	881 986	2	21 895	(72)	17 870	(59)	14 587	(48)
			3	61 083	(200)	49 853	(164)	40 695	(133)
			4	49 942	(156)	40 760	(128)	33 272	(104)

Table 4: *Proposed MTS with 0.6 mm diameter fibers (using laser energy: 10J, objective NA: 0.0488 and light transmission: 35 - 52%).*

As a preliminary conclusion, the MTS system with 0.8 mm fibers was chosen, which means 10 channels per polychromator. This choice is to prevent the possible increase of the optics elements damage due to the high laser power and because of the time dispersion of the light signals inside the fibers, not yet considered.

Acknowledgements

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