A 10-channel far-infrared polarimeter for the TCV tokamak

P.Blanchard, R.Behn, H.Weisen, A.Zhuchkova

Ecole Polytechnique Fédérale de Lausanne (EPFL)
Centre de Recherches en Physique des Plasmas, Association Euratom-Confédération Suisse
CH-1015 Lausanne, Switzerland

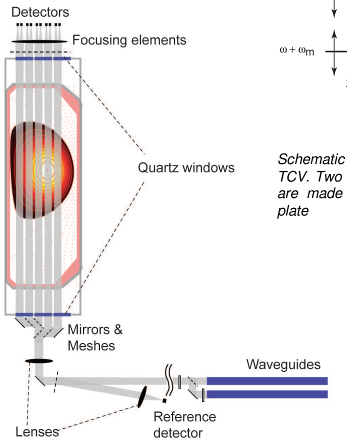
E-mail: **patrick.blanchard@epfl.ch**

Abstract

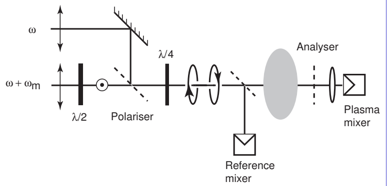
- A new far-infrared (FIR) polarimeter diagnostic for the TCV tokamak is under construction at CRPP
- It uses two FIR lasers at 432.5 microns, optically pumped by a 120W continuous wave CO_2 laser
- The two FIR cavities will be detuned such that the combination of the beams, using a method proposed by Dodel and Kunz[1], produces a single beam with a linear polarization rotating at the difference frequency (set to 750kHz)
- Not influenced by signal amplitude variations. Need only one detector per line of sight. 10 lines of sight to cover the plasma radius
- Faraday rotation angles will be measured by coherent detection
- Designed especially to obtain current density profiles measurements on low n_e, low I_p plasmas

Setup

System description:

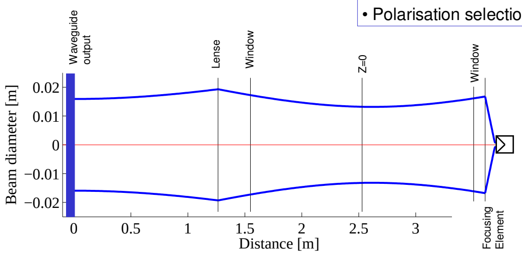


Polarimeter setup on TCV. The grey beams are Gaussian beams. We show the full beam size i.e. its diameter $D=\pi w$, where w is the beam width



Schematic description of the polarimeter technique used on TCV. Two laser beams slightly detuned by an IF frequency are made counter-rotating circular using a quarter-wave plate

- 5 separate laser beams
- Beam waist is 15.8mm located in the middle of the vacuum vessel
- 2 detectors per beam
- Polarisation insensitive meshes used as beam splitters 50%/50% and 70%/30%
- Quartz windows for the vacuum-air interface 7.285mm thick (n=2.1075)
- Schottky diode detectors
- ADC up to 250 kHz
- Pyrex waveguides: 50mm internal diameter
- Polarisation selection after waveguide



- Waveguide diameter is 5cm
- Beam waist is 15.8mm at Z=0

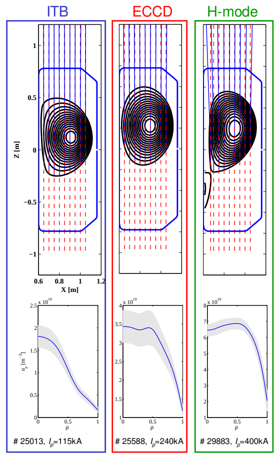
Laser description

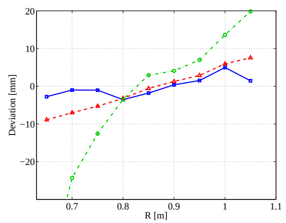
Laser type	CO_2	FIR
Gaz	8% CO_2, 18% N2, re He	Formic acid HCOOH
Nbr of cavities	1	3
Emission line	9.27R20 line (λ=9.27μm)	432.5μm
Output polarization	Linear vertical	Linear vertical
Output power/cavity	120W	30mW

Wavelength selection

- Due to the wide range of plasma shapes, positions and sizes accessible on TCV, optimal polarimeter measurements for all possible configurations cannot be fulfilled by one wavelength.
- Its design has been guided by the need to have valid q profile measurements in low plasma current I_p (<100kA) and electron density n_e ($n_e(0)$<3e19m-3) ITB plasmas. In such discharges, the resolution of the diagnostic has to provide distinguishable Faraday rotation profiles $\Psi(r)$ between monotonic and reversed q profile.

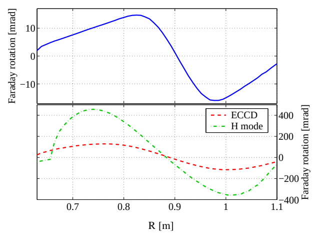
- Refraction effects scale with λ^2





For three different types of TCV plasmas, we represent the laser beam's deviation due to refraction effects at the detector position (Z=1.2m) with respect to ideal non-refracted beams. λ=432.5μm

- Faraday rotation amplitude scales with λ^2



For three different types of TCV plasma, we represent as a function of the radial position R the Faraday rotation calculated for a laser wavelength λ=432.5μm

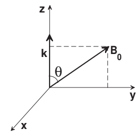
- The expected nominal resolution is about 1mrad[3]
- For the ITB case, it is clear that already at 432.5μm we are close to be marginal. Using the actual FIR at 214.6μm would yield unusable signals in term of polarimetry
- At higher current and density, the Faraday rotation SNR is not expected to be problematic. Refraction effects are going to be more important. In H-mode, the lost of some edge channels is expected

Faraday rotation theory

In the interferometric domain ($\omega > 5\omega_{pe}$, $\omega > 5\omega_{ce}$), the refractive index N is given by a simplified version of the Appleton-Hartree formula:

$$N = \bar{N} \pm \frac{\Delta N}{2} \quad \text{with} \quad \bar{N} = 1 - \frac{1}{2}\left(\frac{\omega_{pe}}{\omega}\right)^2 - \frac{1}{4}\left(\frac{\omega_{pe}}{\omega}\right)^2\left(\frac{\omega_{ce}}{\omega}\right)^2 \sin^2\theta$$

$$\Delta N = \frac{1}{2}\left(\frac{\omega_{pe}}{\omega}\right)^2 \frac{\omega_{ce}}{\omega}\sqrt{\left(\frac{\omega_{ce}}{\omega}\right)^2 \sin^4\theta + 4\cos^2\theta}$$



For each of the two values of N a unique eigenstate of polarization can be associated. Waves can only travel through the plasma in one of these polarization states, experiencing the corresponding N.

For instance, for k // B (θ=0), the eigenstates are left and right hand circularly polarized waves and then the phase shift between the two characteristic waves $d\Psi$ is:

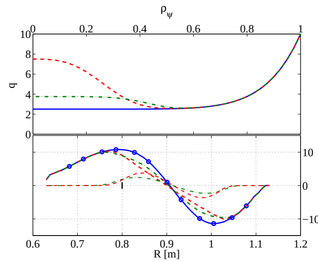
$$d\Psi \equiv \frac{\omega}{c}\Delta N dz = 2.62 \cdot 10^{-13}\lambda^2 n_e(z) B_{//}(z) dz$$

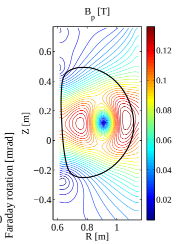
and is commonly called Faraday rotation. In Tokamak plasmas with vertical lines of sight, θ is close to 90º. The Faraday rotation angle will then depends on $d\Psi$ and on $\alpha \equiv -iE_x/E_y$. In case the two waves are conter-rotating circular with a polarisation selection parallel to the x axis, the phase difference between the two waves is given by [2]:

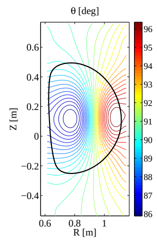
$$\Delta(d\Phi) \equiv \frac{4\alpha}{1+\alpha^2}\frac{d\Psi}{2}$$

Simulations

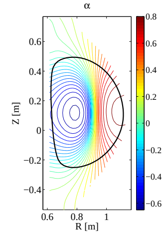
- Very low plasma current I_p=80kA and electron density n_e=1.1e^{19}m^{-3} plasmas
- Compare the Faraday rotation profiles $\Psi(r)$ between monotonic and two reversed q profiles







- In this extreme case, Y was expected to be small
- With a maximum Y=10, the resolution of the system is going to be close to marginal
- Distinctions between the two reversed profiles is going to be difficult
- The slope of Ψ around the plasma axis being proportional to the central current density, the central value of q should however still be both measurable and distinguishable in between the different q profiles.



References

[1] G.Dodel and W.Kunz, 1978 *Infrared Phys.* **18,** 773–6
[2] J.Rommers, Ph.D Thesis, University of Utrecht (1996)
[3] D.L.Brower *et al* 2003 *Review of Scientific Instruments* **74** (3)

Acknowledgements

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