The design of a MSE polarimetry diagnostic for the measurement of radial electric fields on the HSX stellarator

T. Dobbins, S. T. A. Kumar, D. T. Anderson, F. S. B. Anderson HSX Plasma Laboratory, University of Wisconsin, Madison

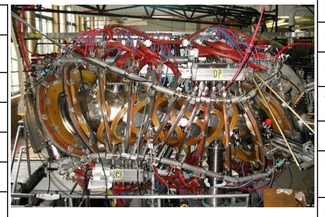
Overview

Abstract

- Neoclassical codes estimate a large positive radial electric field (40-50 kV/m) near the core of HSX
- Impurity ion flow measurements could not resolve this large electric field.
- A MSE polarimetry diagnostic has been designed for the HSX stellarator to directly measure the radial electric field near the core of the plasma
- The design has been optimized to get a maximum change in polarization angle from a radial electric field with good spatial resolution.
- The diagnostic design and initial characterization are presented

HSX & Beam Parameters

HSX	
<R>	1.2 m
<a>	.12 m
$<n_e>$	1-4*10^{18}/m^3
T_e	0.5-2.5 keV
T_i	30-60 eV
B_0	1 T
ι	1.05-1.12

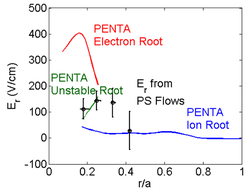


HSX Neutral Beam	
E_b	30 keV
I_b	4 A
Time	3 ms
Species	Hydrogen
Full energy component	~80-90%
Beam radius	~1.5 cm

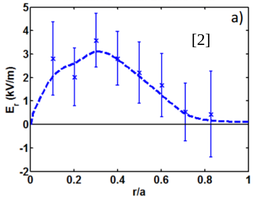
HSX Radial Electric Field

- Neoclassical modeling with the PENTA [1] code indicate a large radial electric field in the core
- The large predicted core $\vec{E}_r$ was not measured with CHERS [2]
  - CHERS measurements of $\vec{E}_r$ are usually done in methane plasmas
  - Large spot size limits on core resolution
    - From beam size and optical design
- New CHERS views have increased resolution and measure higher $\vec{E}_r$
  - Still lower $\vec{E}_r$ than PENTA calculations

E_r from new CHERS Views & PENTA Calculations

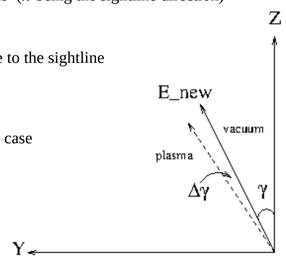


E_r from CHERS Views

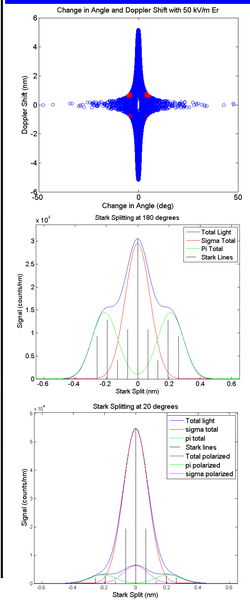


MSE Polarimetry Overview

- The beam particles feel an effective electric field from $\vec{E}_{vxB} = \vec{v}x\vec{B}$ & plasma $\vec{E}_r$
- $\vec{E}_{tot} = \vec{E}_{vxB} + \vec{E}_r$
- The total field is transformed into the sightline coordinates ($\vec{x}$ being the sightline direction)
- $\vec{E}_{new} = T \cdot \vec{E}_{tot}$
- The polarization angle, γ, of the light is measured relative to the sightline
- $\tan\gamma = \frac{\vec{E}_{new}\cdot\vec{y}}{\vec{E}_{new}\cdot\vec{z}}$
- $\Delta\gamma$ is the difference between the vacuum case and plasma case
- $\Delta\gamma$ arises from $\vec{E}_r$ and/or bootstrap current
  - $\Delta\gamma_{bs}$ is negligible in the core of HSX
  - Near the edge the effects are comparable



Optimization



- A scan of viewing angles was taken for a given measurement location
- The Doppler shift of a view is plotted against the change in measured angle from a 50 kV/m $\vec{E}_r$.
- Doppler shift is needed to avoid the unshifted Halpha line.
- The red points have sufficient Doppler shift and maximize resolution to $\vec{E}_r$.
- Many of these locations are on accessible locations on HSX

Complications from atomic physics:

- Optimal viewing locations make small angles (10-25°) from $\vec{E}_{tot}$
- The viewing angle with respect to $\vec{E}_{tot}$ changes:
  - The polarization fraction of the σ component
  - The ratio of the total π and σ components
- This effects the total signal and the SNR
  - Limiting factor is low signal level
- Need to balance smaller signal levels with increased resolution
- The large non-polarized signal in the sigma component leads to the use of the π component at smaller angles

Design & Testing

Hardware

- Dynamic polarimetry uses two Photoelastic Modulators (PEMs) to measure γ
  - The 2 PEMS operate at two frequencies f_1 & f_2 (42 & 47 kHz)
  - The PEMs change the polarization angle of the light at a frequency f
  - The light is then passed though a linear polarizer and a filter
  - The light is then measured with a avalanche photo diode (APD)
  - Lock in amplifiers are used to isolate the signal at 2f

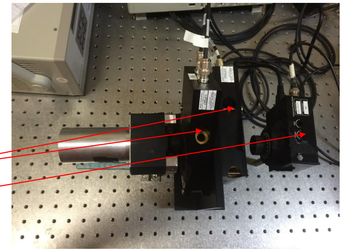
Equations:

$$S_1 = \frac{(I_\sigma - I_\pi)}{\sqrt{2}} J_2(\phi_0)\sin(2\gamma)$$

$$S_2 = \frac{-(I_\sigma - I_\pi)}{\sqrt{2}} J_2(\phi_0)\cos(2\gamma)$$

$$S_1/S_2 = -\tan(2\gamma)$$

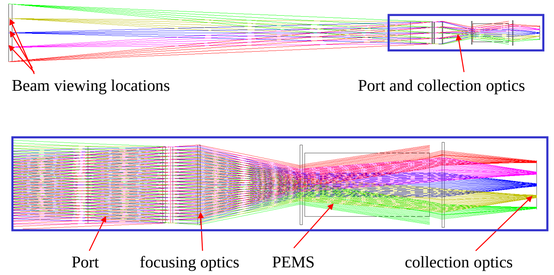
PEMs & APD



Optical Design

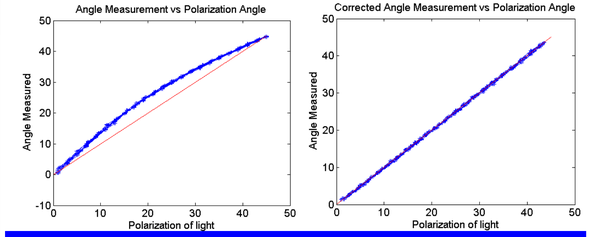
- Several views planned per port (e.g. r/a=.1,.15, .2)
- Only one filter, APD, and pair of lock-ins are currently available
  - limits collection to one view at a time

ZEMAX modeling of the collection optics



Calibration

- Two lock in amplifiers are used to measure the 2f frequencies of the two PEMS
- The relative gain on the lock-in amplifiers is calibrated out
- A known input polarization angle is compared to the output angle
- A linear relative gain factor is applied to the ratio of signals to minimize the deviation from a one to one correlation in angle



Future Plans & Summary

Future Work

1. Complete the calibration of the PEM/lockin system
2. Calibrate the tunable filter used to isolate the π or σ components
3. Machine the new ports
4. Calibrate the complete system using beam into gas shots with the magnets

Summary

- Neoclassical codes predict a large radial electric fields in the core of HSX
- A new MSE diagnostic has been designed to directly measure E_r
- Optimized to measure E_r in the core
- Calibrations are currently in progress

References

[1] D.A. Spong, *Phys. Plasmas* 12 (2005) 056114; J. Lore at al., *Phys. Plasmas* 17 (2010) 056101

[2] Briesemeister, Alexis R. "Measurement and Modeling of the Flows and Radial Electric Field in the HSX Stellarator." (2013).

This work is supported by US DOE Grant DE-FG02-93ER54222