Upgrade of Far-Infrared Laser-Based Faraday Rotation Measurement on MST

W.X. Ding, D.L. Brower, W. Bergerson, L. Lin, T. Yates

University of California, Los Angeles

B. Chapman, D.J. Den Hartog, J. Reusch, J. Sarff and MST team

University of Wisconsin, Madison

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Introduction

Three key issues

(1) Conservation of circularly polarized wave;
(2) Co-linearity of two probe waves;
(3) Stability of intermediate frequencies between lasers affecting the Faraday rotation measurement

have been resolved experimentally.
MST Reversed-Field Pinch (RFP) is toroidal configuration with relatively weak toroidal magnetic field $B_T$ (i.e., $B_T \sim B_p$)

$q(r) = r \frac{B_T}{R B_p} < 1$

$R_0 = 1.5$ m, $a = 0.51$ m, $I_p < 600$ kA
$B_T \sim 3-4$ kG, $n_e \sim 10^{19}$ m$^{-3}$, $T_{e0} < 1.3$ keV
$\tau_E \sim 10$ ms, $\beta = <p>/B^2(a)=15\%$
\[ \phi \sim \int ndl + \int \tilde{ndl} \]

**Interferometer density fluctuation**

\[ \Psi \sim \int n\vec{B} \cdot d\vec{l} + \int n\vec{b} \cdot d\vec{l} + \int \tilde{n}\vec{B} \cdot d\vec{l} \]

**Faraday rotation magnetic field**

11 chords, separation 8 cm, phase resolution 0.05 degree, time response up to 1\(\mu\)s
New RF-Excited CO$_2$ laser Installed

RF-excited, sealed CO$_2$ laser at 9.27 µm (GEM select 100, Coherent Inc.),

DC power supply for RF source

RF source

Water cooling lines

New CO$_2$ laser has no flowing gas, more stable and easy to operate (key-on)
DC Gas Discharge CO2 Laser was replaced

This home-made CO2 laser is gas-consuming ($5000/year), power degrades fast, unstable after 20 year operation.
Three FIR cavities are pumped by one CO2 laser. The FIR cavities are home-made as well. They provide reasonable FIR power as long as the CO2 laser is stable. The DC motors controlling cavity length will be replaced by pico-motors (PZT control).
Linearly-polarized, orthogonal, co-linear beams are launched.

In laser room, we launch linearly polarized waves instead of circularly polarized waves to avoid the distortion of circular wave due to mesh splitters.
FIR beam profiles away from laser head 155 cm

Divergence is 13.8 mrad, beam waist is 2 cm.

Beam overlapping is NOT distinguished with mm scale.
Lasers are transported toward to MST

Beams transported using over-mode dielectric waveguide, 7.5 cm diameter
Circularly polarized beams are launched just before entrance window.

1/4 waveplates are placed after beams pass meshsplitter to avoid distortion of circular waves.
Circularly-polarized beams can be distorted by mesh.

**calibration curve**

Circularly polarized beam are split into 11 beams by mesh-splitters.

Linearly polarized beam are split into 11 beams by mesh-splitters.

\[ \Phi_L(x) = \Phi(x) + \Psi(x) = c_I \int n_e \, dl + c_F \int n_e B_\parallel \, dl \]
\[ \Phi_R(x) = \Phi(x) - \Psi(x) = c_I \int n_e \, dl - c_F \int n_e B_\parallel \, dl \]

Launching two independent circular waves into plasmas using Dodel and Kunz method (Infrared Phys. 18,1805(1978))
Co-linearity of Two Probing Beams

\[
\Phi_L(x + \Delta x) - \Phi_R(x) \approx \Delta \Phi(x) + 2\Psi(x)
\]

Finite offset between two beams

Error associated with co-linearity of two beam

Faraday Rotation

\[
\Delta \Phi(x) \sim \Phi(x) \frac{\Delta x}{a}
\]

For \( \Delta x=1 \) mm, \( \Delta \Phi(x) \sim 2 \) degree, comparable to Faraday rotation angle!!!

A careful alignment is extremely important!!
Frequency changes during plasma discharge

<table>
<thead>
<tr>
<th>Without discharges</th>
<th>With discharges</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td><strong>Frequency</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Time [ms]</td>
<td>Time [ms]</td>
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Power spectrum three wave system

- Faraday rotation
- L-wave
- R-wave
Phase errors arising from instability of IF

\[ I_{\text{sig}} \sim E_L E_R \cos \left[ 2\pi (f_L - f_R) t + 2\Psi(t) + 2\pi \left( \frac{f_L - f_R}{c} \right) L_1 + \phi_{L0} - \phi_{R0} \right] \]

\[ I_{\text{ref}} \sim E_L E_R \cos \left[ 2\pi (f_L - f_R) t + 2\pi \left( \frac{f_L - f_R}{c} \right) L_2 + \phi_{L0} - \phi_{R0} \right] \]

\[ \phi(t) = 2\Psi(t) + 2\pi \frac{\Delta f}{c} \Delta L \]

Phase errors due to IF is about 0.01 degree in MST FIR system

\[ \Delta f = 20 kHz, \Delta L = 1 m \]
Faraday rotation and density measurements
Simultaneous density and magnetic fluctuations measurement

Magnetic and density fluctuations associated with tearing modes

Density fluctuations associated with tearing modes

Magnetic coils at edge
Summary

Three fundamental technique issues for a successful implementation of Faraday rotation measurements in plasmas have been resolved in a upgraded FIR system on MST.

(1) Distortion of circularly polarized wave;
(2) Co-linearity of two probing beams;
(3) Instability of intermediate frequency.

This will help to build tangential interferometer polarimeter (TIP) system in ITER.