Fast Ion Doppler Spectroscopy Measurements During Magnetic Reconnection in a Compact Torus

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Abstract / Motivation
The Prairie View (PV) Rotamak is a toroidal plasma device that can operate in field reversed configuration (FRC) and spherical tokamak (ST) regimes. As a new diagnostic, an ion Doppler spectroscopy (IDS) system is installed to have high temporal ion temperature and flow measurements. This development will help understanding our plasma for the future experiments which include magnetic reconnection, MHD instability studies, and plasma shape control (via feedback). The measurements are a tunable temporal resolution and can perform measurements as fast as 0.1 µs time steps.

Experimental Setup
The PV-Rotamak is a compact torus configuration, which employs two pairs of external rotating magnetic field (RMF) to non-inductively drive a steady state toroidal plasma current. The RMF is produced by two 90°-dephased rf generators. Each generator can feed 400 kW of power to one pair of coils at 500 kHz. Another two coils provide a maximum external equilibrium (vertical) magnetic field (B0) of 230 Gauss (at the vessel’s center). The RMF and vertical magnetic field windings embrace a cylindrical chamber. The chamber is an 80-cm long Pyrex™ vessel with 40 cm ID. A Pfeiffer Balzers TPU 510 turbo pump maintains a background pressure of 10^-10 Torr throughout the experiments. In the ST configuration, a steady toroidal magnetic field (Bt) is produced by discharging a capacitor bank through six wires that are pulled through the central axial stainless steel pipe (covered with a quartz tube). The RMF is applied for 40 ms period; during this period, B0 and Bt remain constant within 5%. A 650/113/50 rf generator, pre-ionizes hydrogen gas (flowing continuously into the chamber) for 13 ms, it has 7 ms overlap with the RMF. Five sets of magnetic shape control coils are wound close to the chamber’s surface at z = 5 (eight turns), z = 8 cm (four turns) and z = 30 cm (four turns). For the experiments reported here the middle coil was used. A Keppco ATE 6-100M provides a maximum current of 900 A to the middle coil.

Emission Lines
A BWTeK™-irometer spectrometer was used to identify the impurity emission lines. Since the Pyrex™ vessel is not transparent to the wavelengths below ~360 nm, the spectrometer was helpful to identify carbon, oxygen, and silicon lines between 400-800 nm.

The IDS System
Ion Doppler spectroscopy is a non-invasive diagnostics to measure ion temperature and flow speed, in a line-of-sight, in plasmas, the main broadening mechanism of the impurity emission lines is the Doppler broadening. The impurities whose emission lines are investigated in this diagnostics, are mainly present in the plasma due to the plasma-wall interactions. A Maxwellian velocity distribution function can be assumed for a plasma with the motion of its particles having purely a thermal nature. For moving and rotating plasma particles with different velocities, there is Doppler shift for emitting lines. The shift depends on the direction of motion of the particles with respect to the observer and the amount of shift is given by

\[
\Delta \lambda = \frac{v}{c} \lambda
\]

The temperature can be calculated as

\[
T_{\text{IDS}} = \frac{\Delta \lambda}{\Delta \lambda_{\text{com}}}
\]

A Jarrell-Ash 50 monochromator with a ruled diffraction grating of 1188 g/mm was used for these experiments. The light was collected through a telescope that can pivot to perform measurements for different plasma chords. Another optics was designed to have an optimum light coupled into the monochromator. The PMT signal was amplified with a gain of 10^5 Volts/A, and it was recorded by a PDI-5112 NI-Scope. An Hg-Cd lamp was used for the monochromator calibrations. The motorized gears of the monochromator allowed wavelength resolution of 0.01 nm. The instrument temperature for carbon lines is 1.35 eV.

IDS Results
Furthermore, the measurements are extended to the case in which the middle coil was charged high enough, to severely disrupt the plasma. The measurements were performed for 5 different chords:

- \(B_0 = 25\) G
- \(I_t = 2.5\) kA
- 180 SCCM gas flow
- With shaping coils
- Middle coil current \(I_m = 250\) A at 20 ms for 3 ms

Summary / Future Work

- An ion Doppler spectroscopy system was successfully installed for ion temperature and flow speed measurements on the PV-Rotamak. The measurements can be performed as fast as 0.1 µs.
- Carbon, silicon, and silicon impurities were identified for the IDS measurements, by using the i-Trometer spectrometer.
- Two different carbon III lines exhibit consistent temperature and flow measurements.
- The measurements were performed for the case in which the plasma was severely disrupted and recovered. The measurements show ~100% increase of ion temperature due to enhanced confinement.
- The IDS measurements will be performed for the lines below 360 nm, by installing a quartz window.
- A new monochromator lines the ability of multi-wavelength measurements will be employed.

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