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Measurements of Rotational Velocity Profiles in the Maryland Centrifugal Experiment

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Introduction

The Maryland Centrifugal Experiment (MCX)[1,2] studies the concepts of centrifugal plasma confinement and stabilization of MHD instabilities by velocity shear. We report measurements of ion rotational velocity profiles obtained from high resolution Doppler spectroscopy of impurity lines. Parabolic type radial profiles of rotational velocity are obtained and clearly demonstrate shear in the plasma rotation that exceeds the critical value for shear stabilization. Further measurements of the velocity profile also show the plasma may not be undergoing isorotation (constant angular velocity along a magnetic field line), which is a departure from ideal MHD.

Experimental Setup

The magnetic configuration of MCX is a long solenoid with axisymmetric mirror end-fields with mirror field up to 2T and mirror ratio of 1-20. A solid core runs down the axis and acts as the high voltage electrode. Biasing of the core drives E×B azimuthal rotation. The high voltage is provided by a capacitor bank, now upgraded to 20kV. MCX had yielded supersonic rotating plasmas in routine operation (ion thermal Mach number $M_s \sim 2$-3) with densities in the range 0.8–8 10^{20} m^{-3}. Plasma rotation was consistent with ExB/B^2, with respect to the signs of both E and B[3]. The plasma was quiescent for up to ~1000's of MHD flute instability times, with no major disruptions observed[4]. We discovered that MCX operates in two discharge modes[5], a lower performance ordinary mode ("O mode") and a higher rotation mode ("HR mode") with improvements in confinement time and Mach number in the range 2-3.

A five channel multichord high resolution Doppler spectrometer system was employed on MCX. The system measures impurity emission lines in the visible along five chords radially through the plasma and the spectra are measured using either a 1m or 2m high resolution spectrograph. All five channels are recorded simultaneously on a high speed, high sensitivity digital camera. Inversion of the chord data to obtain radially resolved ion velocities and temperatures has been accomplished using two independent analysis schemes. A variety of impurity lines can now routinely be investigated, with emphasis on C+,C2+,C3+. For the data in this paper midplane B field 0.24 T, mirror ratio 7, bank voltage 7-9 kV, fill pressure 5mT.

Results

The data in Figure 1 shows the profile of the angular frequency of the rotation as a function of the radius for HR mode conditions. Dashed lines are inner and outer boundaries of the annular plasma in Figs 1 and 3. Three Carbon lines are shown (charge states 1, 2, and 3) as well as the neutral hydrogen line (green). We note that the profiles are parabolic-type; the carbon lines are close to each other within 20%; the neutrals lag the Carbon.

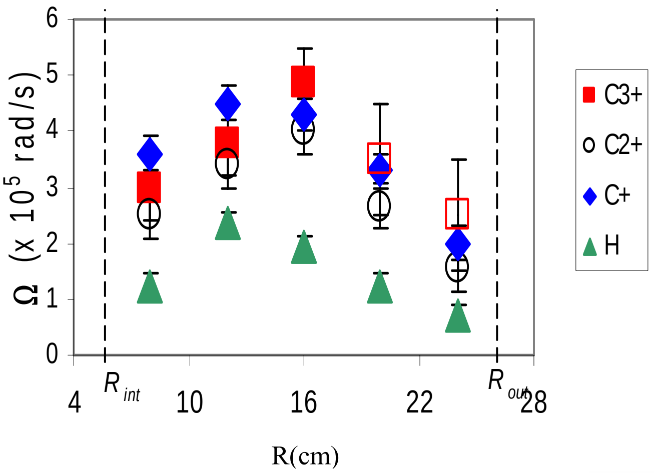

Fig 1. Radial profiles of angular velocity

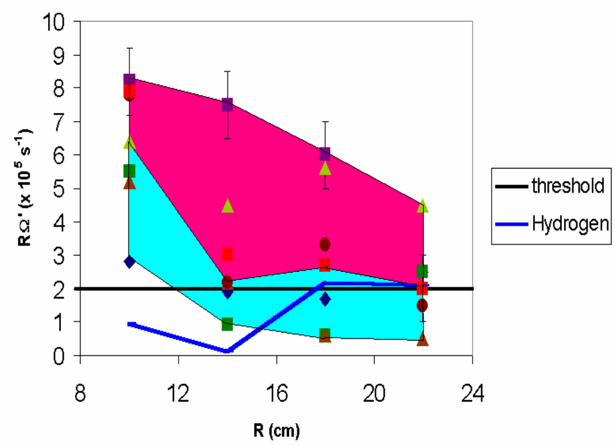

Fig 2. Shear in angular velocity

From the data in Figure 1 we calculate the local radial shear in omega, RΩ'. This is shown in Figure 2 for several discharges.

The black straight line is the approximate estimate of the critical shear required for stabilization from V' shear (constant T is assumed)[6]. The data in most cases exceeds the critical limit by up to a factor of 8.

The radially resolved profiles of emission intensity also confirm that the neutral and impurity profiles are hollow, i.e., they are more or less burned out of the center of the annular MCX plasma. (Fig 3).

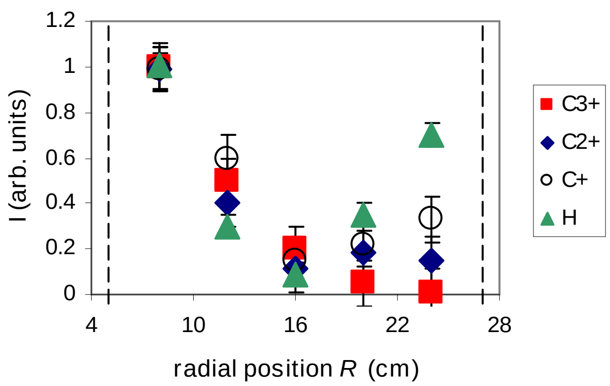

Fig 3. Emission intensity vs radius.

Rotational velocity measurements were also made by Ghosh et al [7] on MCX using the same chords but a higher resolution spectrometer. The results were in very good agreement with those above.

Ideal MHD theory [8] predicts that the angular velocity , $\Omega = \Omega_{ExB} \equiv E/rB$, is a constant along a magnetic field line. However, measurements of the rotational velocity profile have been made at two axial locations(one at midplane and one off midplane at z = 80 cm ; the mirror to mirror distance is 240 cm) and they show deviations from the isorotation condition. The deviations for HR mode and O mode are different and this is shown in Figure 4 . It has also been shown that the deviation increases with magnetic field.

Over the past year it has become evident that as MCX parameters are varied there was an apparent limit to the overall rotational velocity that could be achieved. A database of 957 shots including variations in most parameters showed that all velocities lie below or up to 100 km/s. To understand this limit new end insulators, consisting of nested alumina shells have been constructed and utilized. Recent data shows that these insulators has been very successful in that transitions to O mode have completely been eliminated. We are presently studying increasing the plasma voltage with the new insulator and the results confirm that the MCX rotational velocity is limited from above by the Alfven velocity for all cases. However, a limit at the Alfven CIV velocity [8,9] may also be operating.

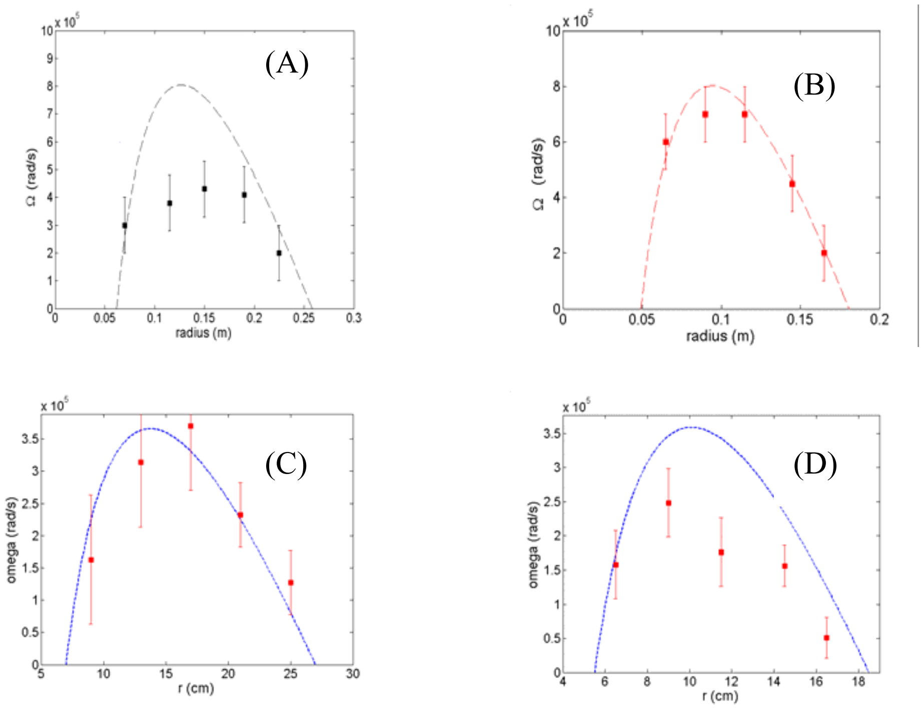

Fig 4. Angular velocity profiles : (A) HR mode midplane, (B) HR mode off midplane, (C) O mode midplane, (D) O mode off midplane. Dotted line are expected values for a parabolic E(r) profile for measured plasma voltage.

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