Parameter scalings of ICRF mode conversion flow drive in Alcator C-Mod plasmas

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ICRF mode conversion flow drive (MCFD) has been demonstrated in Alcator C-Mod D(^{3}He) plasmas [1,2]. The observed rotation is in the co-current direction, and velocities as large as 100 km/s have been observed with an imaging x-ray spectrometer system. Detailed scans of plasma and ICRF parameters have been carried out in order to optimize the driven rotation in the core, in both L- and H-mode plasmas. Parameters include the toroidal magnetic field, ^{3}He concentration, plasma current, electron density, and ICRF power, phase and frequency. An empirical scaling of the rotation velocity dependence on these parameters has been developed.

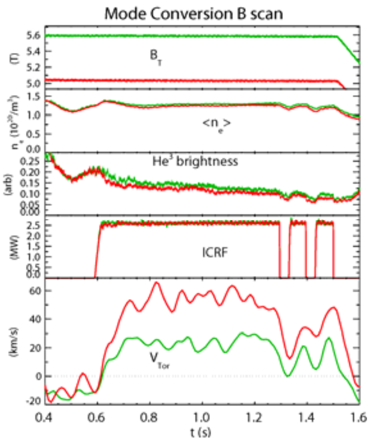

Fig.1 Parameter time histories at two different magnetic fields.

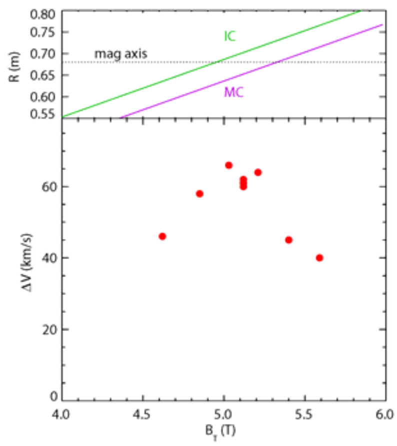

Fig.2 Velocity as a function of magnetic field.

Shown in Fig.1 is a comparison of the time histories of two otherwise similar deuterium discharges at 5.60 and 5.04 T, with 2.5 MW of ICRF power at 50 MHz and a ^{3}He concentration of about 10%. The core toroidal rotation velocity (bottom frame) was higher in the 5.04 T case. From a shot to shot scan of B_T, shown in Fig.2 is a plot of the change in the core rotation velocity (difference between during and pre-ICRF) as a function of toroidal magnetic field, at fixed density, ICRF power (50 MHz) and ^{3}He concentration. For these conditions, there is a maximum in the rotation velocity around 5.1 T, with the mode conversion surface (D-^{3}He hybrid layer, top frame in purple) on the high field side and the ^{3}He ion cyclotron layer (green) on the low field side, but both near the magnetic axis. In Fig.3 is presented a comparison of the time histories of two discharges, similar except for different ^{3}He concentrations, and in Fig.4 are shown the velocities for a shot to shot scan of the ^{3}He level (with all other parameters held constant), varied by different gas puff lengths. The brightness of the hydrogen-like He line at 4686 A was used to monitor the ^{3}He concentration. The maximum velocity was found for a concentration of about 10% (corresponding to a line brightness of about 0.13), which was estimated by comparing TORIC simulations to the observed mode-converted wave from the phase contrast imaging diagnostic [2].

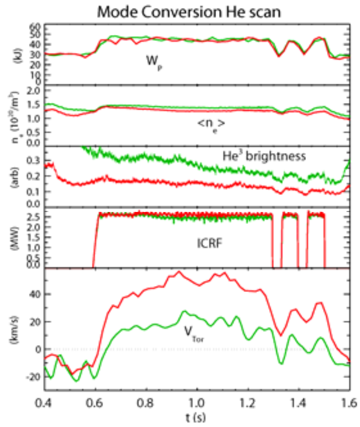

Fig.3 Parameter time histories with different ^{3}He levels.

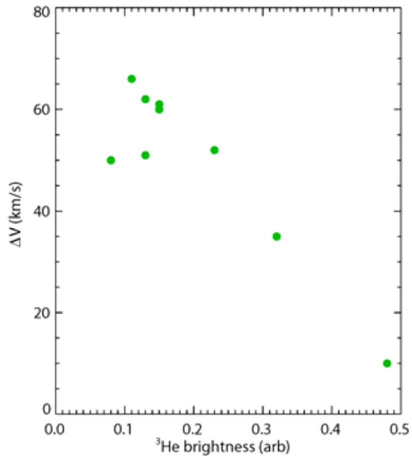

Fig.4 Velocity as a function of ^{3}He brightness.

A comparison of two discharges with similar parameters (including steps in the ICRF power) at different plasma current is shown in Fig.5. The rotation velocity is larger for higher plasma current, which is the inverse of the intrinsic rotation current scaling using ICRF minority heating [3]. There is also an increase in the velocity with ICRF power (although there is an apparent saturation of the velocity at the highest power). Shown in Fig.6 is the change in the rotation velocity as a function of plasma current, for two different power levels. A comparison of time histories of two discharges with different electron densities is shown in Fig.7; the rotation is much higher in the lower density case. Fig.8 shows the results for a shot to shot

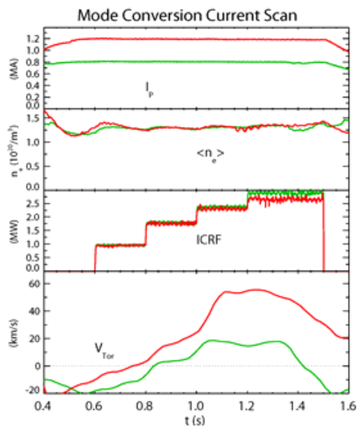

Fig.5 Parameter time histories for two different plasma currents.

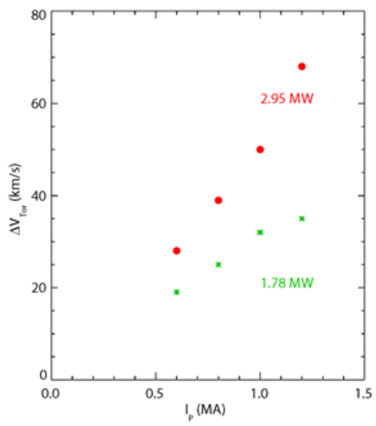

Fig.6 The rotation velocity as a function of current, for two power levels.

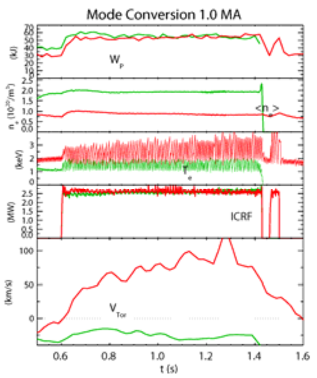

Fig.7 Parameter time histories for different electron densities.

scan of electron density. The driven rotation strongly increases as the electron density is lowered. This observation, coupled with the increase in the rotation with ICRF power, suggests a simple power per particle scaling. MCFD has also been observed at higher magnetic field and ICRF frequency. Shown in Fig.9 is a comparison of the time histories of two plasmas with the same current, electron density and ^{3}He concentration, but with different magnetic field and ICRF frequency. The

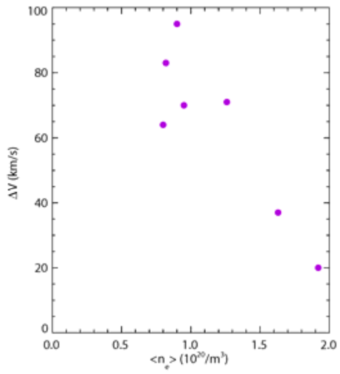

Fig.8 Rotation velocity as a function of density.

discharge at 5 T and 50 MHz (green) exhibited higher rotation than the 8 T, 80 MHz (red) discharge, even at lower power. This is suggestive of an inverse frequency dependence. A database of MCFD rotation velocities has been assembled from a wide range of plasma operating conditions and ICRF parameters, including the phase. The results of a regression analysis are shown in Fig.10, the observed MCFD rotation as a function of the scaling law proportional to $P_{rf}^{1.3}$ $I_p^{0.5}$ $n_e^{-1.0}$ $f^{-1.0}$. The rotation scales with the power delivered per particle, is inversely proportional to the ICRF frequency and increases with plasma current.

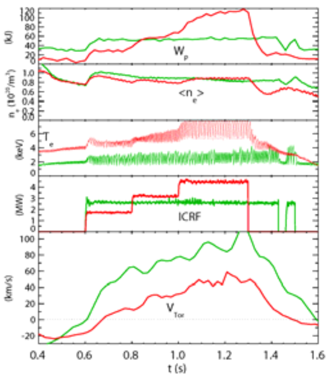

Fig.9 Parameter time histories for 8 T/80 MHz (red) and 5 T/50 MHz (green).

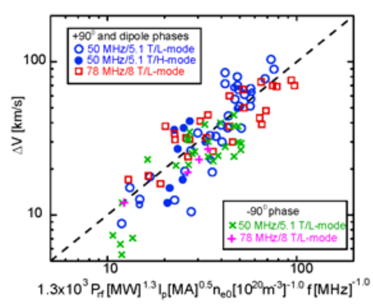

Fig.10 The observed rotation as a function of the scaling.

While certain aspects of the observed rotation are consistent with the MCFD picture (the dependence on magnetic field and ^{3}He concentration), the independence on phase (as shown in Fig.10) and the fact that the observed rotation in JET plasmas is in the *opposite* direction [4] suggest that other mechanisms are at work and need to be considered. In the absence of a comprehensive theory for ICRF MCFD, a scaling relation such as in Fig.10 is useful.

Another possible technique for providing rotation without external momentum input is to take advantage of the intrinsic rotation that has been observed on many devices [5]. The intrinsic rotation velocity is found to scale with the plasma stored energy and inversely with the plasma current. A comparison of intrinsic rotation and MCFD on C-Mod is shown in Fig.11. The levels of rotation in the two cases are very similar, but on this scale the MCFD is favourable, largely because of the different dependence on plasma current.

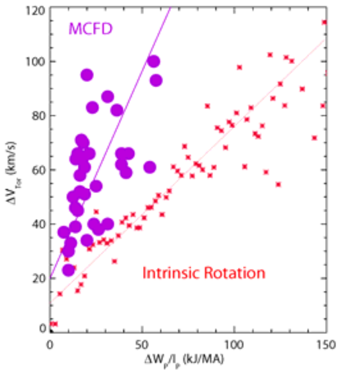

Fig.11 A comparison of MCFD and intrinsic rotation scaling.

References

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