Inter-Machine Comparison of Intrinsic Toroidal Rotation

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Abstract. Parametric scalings of the intrinsic (spontaneous, with no external momentum input) toroidal rotation observed on a large number of tokamaks have been combined with an eye toward revealing the underlying mechanism(s) and extrapolation to future devices. The intrinsic rotation velocity has been found to increase with plasma stored energy or pressure in JET, Alcator C-Mod, Tore Supra, DIII-D, JT-60U and TCV, and to decrease with increasing plasma current in some of these cases. Use of dimensionless parameters has led to a roughly unified scaling with $M_A \propto \beta N$, although a variety of Mach numbers works fairly well; scalings of the intrinsic rotation velocity with normalized gyro-radius or collisionality show no correlation. Whether this suggests the predominant role of MHD phenomena such as ballooning transport over turbulent processes in driving the rotation remains an open question. For an ITER discharge with $\beta N = 2.6$, an intrinsic rotation Alfven Mach number of $M_A \sim 0.02$ may be expected from the above deduced scaling, possibly high enough to stabilize resistive wall modes without external momentum input.

1. Introduction and Background

Rotation and velocity shear play important roles in the transition to high confinement mode (H-mode) [1-5], in the formation of internal transport barriers (ITBs) [6,7] and in suppression of resistive wall modes (RWMs) [8,9] in tokamak discharges. In the current generation of tokamaks, rotation is usually provided by the external momentum input from neutral beam injection. In future reactor-grade devices, this may not be available due to the large machine sizes, high densities and the limitations of beam current. For RWM stabilization in certain ITER operational scenarii, it has been estimated that an Alfven Mach number $M_A = 0.02$ will be required [10,11], depending on the velocity profile and normalized pressure, $\beta_N$. In a particular ITER case with $n_e = 6.7 \times 10^{19}/m^3$ and $B_T = 5.2$ T, this corresponds to a rotation speed of 200 km/s (30 kRad/s), and it remains an open question whether this level of rotation will be generated from neutral beams. The intrinsic (spontaneous) rotation observed in many tokamaks without external momentum input may, however, provide the necessary velocity. Since the mechanism driving intrinsic rotation is not well understood, and in order to anticipate the level of rotation expected in ITER and other reactor devices, a database of observations on several contemporary machines has been constructed. Intrinsic rotation in L-mode plasmas is often found to be in the counter-current direction, and depends very sensitively on the magnetic configuration [12-14] and in a complicated fashion on other parameters, such as the density, plasma current and ion temperature [13-15]. While the study of intrinsic rotation in L-mode discharges is of interest in its own right (e.g. for its relation to the H-mode power threshold [13-14]), these plasmas will not be considered here, since most ignition scenarii in future devices require H-mode confinement. The intrinsic toroidal rotation in H-mode or in other enhanced confinement regimes, which will be the main subject of this