Study of Intrinsic Rotation in Tokamak Plasmas

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Introduction

Controlling Nuclear fusion reactions in nuclear fusion is one of the most challenging tasks for humankind. The Tokamak is at present the most promising device for the magnetic confinement fusion as it has confined fusion plasmas for longest time [1]. Rotation and rotational shear are very useful and advantageous for the plasma transport and to increase plasma stability. Currently, NBI is the most effective way to rotate the plasma. In future, fusion devices like ITER, it will not be possible to rotate the plasma through NBI. Thus, the study of intrinsic rotation becomes the utmost relevance. Parra, Barnes *et al* [2, 3] proposed a gyrokinetic model to explain the intrinsic rotation. The new momentum transport model is being implemented in the code GS2. In this PhD project the modified GS2 code will be benchmarked with other codes as well as experimental data. The code will also be extended to include the study of impurity effects on rotation with second order correction.

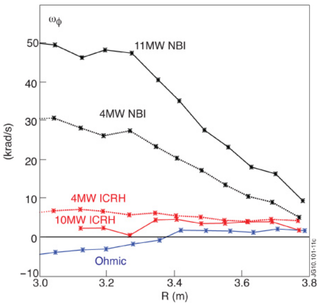

Figure 1: Toroidal rotation profiles of intrinsic rotation measured in plasmas with ICRH and in plasmas with Ohmic heating, is compared with the measured toroidal rotation by NBI [5]

.Theory

Current theories for intrinsic rotation suggest that it can be self-generated from microturbulence [4]. The model proposed by F. I. Parra, M. Barnes et al. [2,3], investigates the second order fluctuations of density *n* and temperature *T* profiles along with heating sources of plasma where the fluctuations are anisotropic with respect to equilibrium magnetic field. Expanding the distribution function

$$f = f_0 + f_1 + f_2$$

where $f_1 = \delta f$ and $f_2 = \delta^2 f$, by implying the condition to hold local gyrokinetic model is:

$$\rho_* = \frac{\rho}{L} \sim \frac{\omega}{L} \sim \frac{\delta f}{f} \sim \frac{f_2}{f_1} \ll 1$$

Where ρ is Larmor radius, L is characteristic length scale of machine, ω is plasma frequency.Corresponding rotation in plasma from gyrokinetic model gives

$$\delta_r \Omega_\zeta = F(\Omega_\zeta, n, T, \delta_r n, \delta_r T, \delta_r^2 n, \delta_r^2 T, heating(r, \theta, V))$$

Where Ω_ζ is angular velocity in toroidal direction, V is the velocity vector, n is the density, T is the temperature, δ_r is the gradient of the quantities, δ_r^2 is the second derivative of quantities , Thus $\Omega_\zeta = \frac{V_\zeta}{R}$. gradient of the quantities Figure 1 shows the measurement of toroidal rotation using different heating sources

Preliminary results

Linear gyrokinetic simulations were performed to get familiar with the GS2 code. Only first order gyrokinetic model is used to obtain preliminary result before understanding the second order gyrokinetics. In figure 2 for DIII-D discharge using a simplified magnetic equilibrium known as Cyclone base case [6]. This is a high confinement shot (#81499) at time t=4000 ms, r=0.5a,

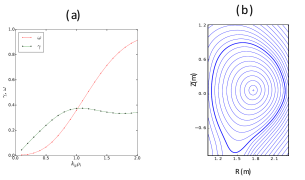

Figure 2: a) Growth rate and frequency of ITG of DIII-D shot #81499 b) Flux surface of DIII-D shot #81499 (x-axis is R in meters and y-axis is Z in meters). It is a poloidal cross-section of tokamak

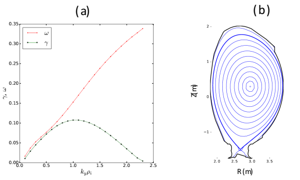

Figure 3: a) Growth rate and frequency of ITG of JET shot #74758 b) Flux surface of JET shot #74758 (x-axis is R in meters and y-axis is Z in meters). It is a poloidal cross-section of tokamak

a is the minor radius of last closed flux surface label. It is one of the most used confinement shot for benchmarking of gyrokinetic codes [7]. Temperature gradient is 6.93 and density gradient is 2.2 .

Similarly figure 3 is the ITG eigenmode scan of a JET shot #74758 at time t=53.265 ms. This specific shot shows the intrinsic rotation by ohmic heating. The linear gyrokinetic simulation were performed at r=0.5a, temperature gradient is 2.2 and density gradient is 1.5.

The DIII-D shot has NBI heating whereas JET shot has Ohmic heating. As in figure 1, it shows that the rotation is higher by NBI heating while intrinsic rotation from Ohmic heating is low, thus DIII-D shot will have higher rotation. Density and temperature profiles of DIII-D and JET shot are taken from experiments. However, for the DIII-D case, simplified magnetic equilibrium called Cyclone Base Case is used. The simplified magnetic equilibrium makes gyrokinetic equation easier to treat analytically, which is advantageous for benchmarking purposes. On the other hand, actual equilibrium from magnetic measurements has been used for JET shot.

Conclusions and Future work

Linear gyrokinetic simulations were performed for a DIII-D shot #81499, the cyclone base case (CBC) and a JET shot #74758 using the experimental equilibrium. ITG modes were obtained for both the DIII-D CBC and the JET shot. For the JET shot the observation of ITG together with counter-rotation in the plasma-core is consistent with observations of intrinsic rotation in the tokamak Alcator-CMOD [7].

The JET shot still require further investigation to determine if Trapped Electron mode (TEM) exists. Another approach to obtain the TEM is by using initial value solver instead of eigenvalue solver. Further analysis of other parameters like collisionality, impurity type and impurity density will be performed in future.

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