Comparison of neoclassical flow theory with CXRS velocity measurements from Alcator C-Mod

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1. First-order neoclassical predictions for velocity on a flux surface

The total flow on a flux surface can be written as the sum of two flux surface dependent components. [-1-3]

\[ \nabla \times \mathbf{v} = \nabla \times \left( \mathbf{v}_{\text{pol}} + \mathbf{v}_{\text{tor}} \right) \]

where a denotes species, \( n_0 \) is defined below, and

\[ \mathbf{n}_0 = \left( n_0 \, \mathbf{e}_r \right) \]

where the electric potential (\( \psi \)), density (\( n \)), and pressure (\( p \)) are all functions of the flux, \( \psi \). The component directed along the magnetic field can be calculated for the various regimes based on the collisionality of the plasma:

- For impurity or edge, \( \psi_r \) and main axis, \( \psi_0 \), in the Pfirsch-Schlüter (PS) and banana (\( B \)) regimes we get

\[ \mathbf{v}_{\text{pol}} = \mathbf{v}_{\text{pol}}^{\text{bs}} + \mathbf{v}_{\text{pol}}^{\text{bn}} \]

\[ \mathbf{v}_{\text{pol}}^{\text{bs}} = \frac{1}{q^2} \left( \mathbf{v}_T \times \nabla \psi \right) \]

\[ \mathbf{v}_{\text{pol}}^{\text{bn}} = \frac{1}{q} \left( \mathbf{v}_T \times \nabla \psi \right) \]

where \( \beta = (\psi/\psi_0)^{1/2} \), temperature, \( f_p \) mapped particle fraction, and \( f_c \) the circulating particle fraction. In these calculations we assume

\[ T_r = T_T \quad \text{and} \quad \mathbf{n}_r = \mathbf{n}_T \]

\[ f_p = 1.44 \frac{\beta^2}{\sqrt{\beta - 1}} \quad \text{and} \quad f_c = 1 - f_p \]

The impurity and temperature and density profiles are derived from the CXRS diagnostic. (See Figure 1.)

The electron temperature and density profiles are derived from the Thomson Scattering diagnostic and mapped to the midplane. Magnetic field structure calculations are done using EFIT.

2. CXRS Diagnostic

The neoclassical model described above along with CXRS (Diode Array) obtained charge exchange recombination from the low-field side (LFS) of the plasma.

The component directed along the magnetic field is the neoclassical flow where the electric potential (\( \psi \)) are all functions of the flux, \( \psi \). We assume \[4\] the plateau regime to the Pfirsch-Schlüter (PS) surface) in both these regimes. Examining how the neoclassical flow correlations correlate with the measured profiles, we probe the validity of first-order neoclassical flow theories at the plasma edge for Alcator C-Mod.

3. Poloidal velocity comparison with neoclassical flow predictions

The calculated profiles reproduce the poloidal velocity peak commonly seen in the steep gradient region of the pedestal.

The PS profile shows the same approximate magnitude of the measured peak but typically the position and width of the peak differs.

Calculating the poloidal peak height over several time slices for multiple shots we obtain Figure 3. Diamonds are data from EDA-Bruins. The highest poloidal velocities measured in the ELM free high confinement (HC) pedestal regime are not co-current positive. Any deviation from this has remaining effects.

The maximum difference in velocity may be a function of collisionality but more data at higher collisionality should be examined.

The ELM-free H-mode data has <10 lower collisionality than the ELM driven HC shots.

5. Toroidal velocity comparison with neoclassical flow predictions

Examining the toroidal velocity peak to the measured peak but tends to be larger, especially at higher collisionality. The peak of the PS calculated velocity is usually found at larger radii than the measured velocity peak. (See Figure 2a.)

The PS calculated peak width is usually larger than the measured width, but shows no specific trends. (See Figure 2a.)

The PS peak velocities are generally well matched to the measured but tend to be larger, especially at higher collisionality.

6. Temperature Dependence

The dependence of \( T_r \) to \( T_T \) for the neoclassical model is a function of collisionality. (See Figure 6.)

Thus, the poloidal velocity should scale with the gradient of the pedestal.

The ELM-free H-mode data has ~x10 lower collisionality than the ELM driven HC shots.

Summary and Conclusions

The flows in the pedestal region at the LFS of the plasma can be roughly described by first-order neoclassical theory.

- In the steep gradient region, the Pfirsch-Schlüter regime calculations match the measured data in magnitude but not position and width.
- Collisionality does not have a strong effect on the toroidal velocity.
- Further into the plasma the banana regime calculations are a closer match than the PS calculation.
- Additional effects to consider in the calculations would be induced \( E_T \) and poloidal density variation on a flux surface.

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