Edge poloidal rotation drive for ITER

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*Flight cancellation prevented actual presentation

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ICRF waves from a slightly modified ICRF antenna strap can be used for adding edge poloidal rotation to the ITER plasma. Wave currents excited by the top poloidal segment are used to add momentum to the edge plasma from the lower strap B-fields that are phased differently. Both power and momentum can be added independently. Adding momentum in the right direction (Er>0) would eliminate ELM-ing and would allow for the required ash flow. Antenna design and wave field calculations will be presented, along with the results of a rudimentary transport model with radial diffusion and pinch. Our model is partly validated on ET plasmas.
Content

• Poloidal and toroidal rotation damping times for ITER plasmas
• Poloidal torque requirements
• Pinch velocity $\sim D_{n\text{ci}}E_r/T_i$ and Er generation
• Time evolution of density for fueling rates
• Controlling Er at the edge with ICRF antenna
• Core poloidal rotation control discussed in my TTF talk (Thursday, 11 AM).
Slow down physics

• Poloidal rotation slow down due magnetic pumping in the inhomogeneous B-field.
• Toroidal rotation slows down on electrons (in 2D) and magnetic turbulence (in 3D).
• Toroidal rotation shear effects D’s weakly
• Poloidal rotation effects Chi’s weakly
• Poloidal rotation effects V’s strongly < focus
Poloidal rotation cost down time


\[ t_{\text{pol}} = \frac{4R}{p^{1/2}qv_{\text{ti}}} \] (phase mixing)

\( v_{\text{ti}} = \) thermal ion velocity

The problem is that rotation is forced by non-ambipolar currents. All ion transport is assumed to be non-ambipolar in this exposition!
Density evolution equation

\[ \frac{\partial n}{\partial t} + \nabla \cdot G = \text{source} \leftarrow \text{continuity equation} \]

The particle flux is given by:

\[ G = -D \frac{\partial n}{\partial r} +nv_r \]

where \( D \sim c_i \) from measurement and theory.

\( v_r \) is a radial pinch velocity related to poloidal rotation

\[ v_r = v_q \frac{n}{w_i} ; \quad v_q = \frac{E_r}{B} \quad (= 1e4/5 =2 \text{ km/s}) \]

\( v_q = \text{poloidal velocity}, \quad n = \text{collisions}, \quad w_i = \text{banana poloidal gyro frequency} \)
V_r needed during burn in ITER

\[ v_r = \frac{I_{\text{mass low}}}{(n*e*S)} \]

\[ I_{\text{mass flow}} = 320 \text{ Amps (10\%He ash plus D and T)} \]
\[ n(\text{edge}) = 1e19/\text{m}^3 \]
\[ e = 1.6e-19 \]
\[ S = 2*\pi*a*2*\pi*R = 400 \text{ m}^2 \]

\[ v_r = 1/2 \text{ m/sec} \]

This IS a very high rate of transport and it will rotate the plasma the wrong way due to \( j_r \times B \). We need to rotate against it!
Physics comes from edge bias experiments in ET and from enhanced neoclassical theory (Shaing)

- Electrode current for rotation agrees with non-ambipolar “banana orbit transport” ideas.
- The electron current required to stop the rotation at the edge is 10-20 amps in ET and Shaing.
- The inferred ion current agrees with the ion current given by the neoclassical ion mobility (mobility = $D_{nci}/T_i$).
Numeric density time evolution in ET limited by MHD driven crash

\[ \frac{\partial n}{\partial t} + \nabla \cdot G = \text{source} \iff \text{continuity equation} \]

\[ G = -D \frac{\partial n}{\partial r} + n v_r \]
Numeric density time evolution in ITER

ITER pinch in 1000 seconds
The pinch mitigation in ITER close to the edge (Er>0)

• Base on poloidally segmented ICRF antenna it is possible to drive against 10% of the radial transport driven torque at 10 MW. (Rough number). If we are wrong about the H-mode physics then it may be ok.

• Otherwise a new rotation drive is needed, somewhat like in the proposed RWM control, to make Er>0. (Anti H-mode).
Summary and Conclusions

• We observe a persistent poloidal rotation profile in ET at Mach number of 0.1-0.2. This generates a radial electric field greater than $T_i/a$. $E_r < 0$.

• In MHD free regimes the ion orbits are close to neoclassical and the electrons are close to 3D and relax to the ion transport. $\Rightarrow$ Ambipolarity is violated.

• The pinch rates can be explained from radial electric field and collision.

• Refueling ITER will be enhanced by this pinch but ash removal will remain a bigger problem for it. We need $E_r > 0$ in ITER through forced poloidal rotation.