Effects of Toroidal Rotation on Hybrid Scenario Plasmas

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with
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The ITER hybrid scenario and hybrid plasmas:

ITER definition:
An advanced (better than standard H-mode) scenario;
long pulse inductive, with “substantial” noninductive current drive;
producing high neutron fluence.
Intermediate in performance between standard H-mode and AT steady-state noninductive scenarios.

There is no more precise definition.
(You know it when you see it.)
DIII-D hybrid plasmas:

- bootstrap fraction ~ 0.3-0.5
  - \( q_0 \approx 1 \)
  - completely relaxed, stationary profiles (\( J, n_e, T_e, T_i, V_\phi \))

- broader current profile than standard H-mode
  - \( \Rightarrow \) less susceptible to \( m/n = 2/1 \) NTM
  - \( \Rightarrow \) higher \( \beta \)
  - reduce or eliminate sawteeth
  - \( \Rightarrow \) better confinement
  - \( \Rightarrow \) remove trigger for 2/1 NTM

- modified current profile is definitely due to presence of stationary MHD activity – almost always a 3/2 NTM;
  - no definitive identification of mechanism

- hybrids have excellent confinement
  - possibly due to combined effects of better rotation profile and better \( q \) profile.
Toroidal rotation effects:

✧ Most of the tokamak experience base is limited to plasmas with strong toroidal rotation (thanks to NB heating).

✧ There is significant concern that ITER (& DEMO & reactors) will have low rotation.

✧ And that low rotation reduces ExB shear, increasing turbulence levels and the resulting transport.

✧ And that low rotation may reduce the β thresholds for NTMs and RWMs.

DIII-D experiments:

Use the recently (2005) modified NB configuration (2 of 7 NB sources in the counter direction) to study the effect of rotation on the performance of hybrid plasmas.
Summary of observations:

We performed systematic scans of rotation at several values of density and q95

- Central Mach number has been reduced by up to a factor of 5, to $M_0 \approx 0.1$, maintaining stationary conditions.

- Confinement is reduced.
  - Fusion performance parameter $G (= \beta N H_{89}/q_{95}^2)$ is reduced by 10-30%, but remains above ITER level for $Q_{fus} = 10$ operation at low $q_{95}$. I.e., The overall performance drops from “excellent” to “very good”.

- 3/2 NTM island width increases with a noticable but minor effect on confinement.

- Primary confinement effect appears to be via reduction of ExB flow shear.
Outline:

➔ Examine the changes in properties of a single discharge when the input torque is reduced.

➔ Briefly look at the relationship between torque and angular momentum.

➔ Examine the changes in confinement and MHD behavior as a function of angular momentum.
begin dominant n=2
begin dominant n=3
begin ELMs, NTMs
turn on 2 counter beams

Ip (MA)
P_nb (MW)
P_rad (MW)
neutrons (10^{15}/s)
\langle n_e \rangle (10^{20}/m^3)
n_e(0) (10^{20}/m^3)
T_e(0) (keV)
T_i(0) (keV)
V_\phi(0) (km/s)
M_\phi(0)
\beta_N
\beta_p
\ell_i
H_{89p}
D_\alpha
q_0–q_{min}
\tilde{B}_{n=1,rms} (G)
\tilde{B}_{n=2,rms} (G)
\tilde{B}_{n=3,rms} (G)
f_{n=2,rms} (kHz)
V_{surf} (V)
t (s)
125499
q_0–q_{min}
gas rate (arb)
integrated gas (arb)
drsep (m)

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turn on 2 counter beams

begin dominant n=2

begin dominant n=3

begin ELMs, NTMs

Ip (MA)

P_{nb} (MW)

D_\alpha

M_\phi (0)

B_{n=2,\text{rms}} (G)

B_{n=3,\text{rms}} (G)

f_{n=2,\text{rms}} (kHz)

H_{89P}
Reducing torque by factor $\sim 3$ reduces rotation by a similar factor and leads to large reduction in ExB flow shear at mid-radius.
Density and temperature profiles change little (both $\beta_N$ and $\bar{n}_e$ are controlled).
Current and $q$ profiles change very little ($J_{\text{NBCD}}$ is a small fraction of the total current).
Angular momentum is proportional to torque, except for some indication of inherent rotation at low torque.
\[ \tau_\Omega \approx \tau_E, \text{ except for very low torque points} \]
Mach number is proportional to angular momentum, except near edge, where $v_\phi \rightarrow 0$ at finite total angular momentum. (Related to locking?)
Three ways of looking at confinement as a function of angular momentum.
GLF23: ExB shear flow is needed to match Te and Ti profiles at high rotation, but not at low rotation. ⇒ change in ExB flow shear is responsible for most of confinement change.
Change (increase) in NTM island width accounts for an ~5% change in $\tau_E$. Small compared to ~30% overall reduction.
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  → Fusion performance parameter $G (= \beta_N H_{89}/q_{95}^2)$ is reduced by 10-30%, but remains above ITER level for $Q_{fus} = 10$ operation at low $q_{95}$. I.e., The overall performance drops from “excellent” to “very good”.

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