Symmetric Mirror Experiments
Neutron Sources and Basic Fusion Science

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Introduction
- Mirror plasma has a natural magnetic dumper that sends the radially escaping plasma particles with their high kinetic energy out the two ends through two expanding magnetic nozzles.

- Mirror plasma is a neutron source with advantages described in Ryutov et al. (1998), Post et al. (1973) and Ivanov (2000, 2003). Mirror group at the Budker Institute is designing a mirror machine to produce a 14 MeV neutron source for the determination of the lifetime of wall materials exposed to the neutron and plasma fluxes and to augment the thorium based Fusion Reactors with lower radioactive waste production.

- Linear geometry device is simpler to build, diagnostics, and feedback control. Neutron source is concentrated at the mirroring point. External control with Real-Time control [robots] from diagnostics to injectors of power, plasma and electrode biasing is relatively simple.

Nonlinear pde’s waves and convective cells
\[ \partial_t \Delta \varphi + \nabla \cdot (\nabla \varphi, P) = H \cdot (\varphi - \varphi_w) + \kappa (P, r^2) + \nu_\ell \Delta \varphi - \nu_i \Delta \varphi - U \Delta S_v, \]
\[ \partial_t P + \nabla \cdot (\varphi, P) = \nu_\ell \Delta P - \nu_i \Delta P + Q, \]
\[ \Phi : \text{stream function for the velocity of the plasma} \]
\[ P : \text{is the normalized pressure of the plasma} \]
\[ b = \delta B_z(x, y, t) : \text{is the normalized magnetic fluctuation of the plasma} \]

H is the strength of the plasma-wall coupling
Angular velocity and rotational shear parameter \( \kappa(r,z) \) is the magnetic curvature \( \sim r \partial^2 \ln B/\partial z^2 \)
Axi-Symmetric magnetic field with \( r < a << L_z \)
U gives the FLR stabilization to small scales
3D nonlinear simulations show vortex confinement

Voltage Profile from End Cell Active Probes

Real-Time, Reconfigurable I/O (RIO) Plasma Control System

Input: Thomson scattering; magnetic probes, Langmuir probes central cell; voltage/currents from end cells; expansion tanks.

Acuators: Control of NBI injection, gas puff, and ECH heaters

Architectures of New Steady State Robotic Mirror Machine

Trapping condition: The ExB rotation number is the ratio of the vortex rotation rate \( \Omega_B \) to the linear frequency \( \omega_k \)

\[ R_B = \frac{\Omega_B}{\omega_k}_+, R_B \geq 1 \]
The dispersion of vortex structures dominates

\[ R_B < 1 \]
The rotation of vortex structures traps the waves and the plasma

Conclusions
- Nonlinear simulations of the coupled fast and slow waves show the onset of nonlinear convective cells with m=1 to m=3 components. Nonlinear vortex structure is formed with rotation and axial flows Helicity vector precesses and is tilted helicity vector owing to the axial outward flows. The 3D vortex states with sheared flows provide a stable nonlinear convective cell for the plasma confinement.

- The maximum electron thermal energy approaches the 1keV due to the improved confinement. The ECH heaters are a dominant control mechanism for improved plasma confinement and heating.

- The solitary 3D vortex structure is a natural state in the ionospheric and magnetospheric plasmas. Such structures will be studied in the proposed new mirror trap.

References

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