High-Beta Plasma Confinement and Inward Particle Diffusion in the Magnetospheric Device RT-1

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- RT-1 is a magnetospheric configuration generated by a levitated superconducting (Bi-2223) magnet.
- High-β hot-electron ECH plasma is generated and stably sustained in RT-1.
- The maximum local β is 70% and pressure profiles have steep gradient near the levitated magnet.
- Electrons of high-β plasma typically consist of 70% of hot (~50keV) and the rest of cold populations.
- Confinement time of the hot-component high-β plasma $t_\beta \sim 0.6s > 10^3t_\text{Bohm}$.
- Inward particle diffusion to strong field region was confirmed by pure electron plasma experiment.

Introduction

- Stable high-β plasma confinement is essential for realizing advanced fusion burning D-D and D-T.
- Dipole fusion was proposed by taking a hint from the Jovian magnetosphere, where high-β plasma is stably confined.
- The mechanism of high-β state is theoretically explained by hydrodynamic pressure of fast flow (double Beltrami state).
- Study of high-β flowing plasma is important for understanding the fundamental physics of self-organization of magnetized charged particles, as well as for the realization of advanced fusion concept.
- Diversity of plasma structures can emerge by two-fluid effects.

Experimental Setup: Ring Trap 1 (RT-1)

- Dipole field magnet: Bi-2223 high-temperature superconducting coil, 250kAT (116A), 112kg.
- Plasma is generated and heated by electron cyclotron resonance heating (ECH) with 2.45GHz magnetron (20kW, 2s) and 8.2GHz klystron (25kW (~100kW in the future), 1s).
- Diagnostic system consists of: 75GHz interferometer, visible light spectroscopy, magnetic loops, and radial and 2d profile of electron density, of non-neutral (pure electron) plasma.

Improved High-β Stable State

- Magnetospheric plasma near Jupiter.
- Right-hand rule for current direction.
- Right-hand rule for helicity.
- Right-hand rule for pressure.

Confinement Properties

- Injection power of 2.45GHz microwave and (b) temporal decay of line density after the termination of microwave at times with different neutral gas pressures. (c) Ratio of slow decay component electrons and (d) time constants of decay times in variation of neutral gas pressure.
- Electrons consists of hot (~50keV) and cold (~10eV) populations, and hot-component has relatively long lifetime due to its small cross section of Coulomb collisions.
- Line density signals have two different decay times, corresponding to two components.
- By optimizing neutral gas pressure, increase in the ratio of hot component (~80%) and decay time ($\tau_\text{dec} = 0.6s$) was observed. $c_f \tau_{\text{peak}} = 1.4 \mu s \tau_{\text{decay}} = 3000s$.
- Energy confinement time $t_\text{E} = \frac{\tau_\text{dec}}{(1+ \frac{\tau_\text{dec}}{\tau_\text{E}})}$ suggests that temporal variation is of relatively small in afterglow phase.

Peaked Density Profiles

- Coefficient of n(r)/n(r)* and estimated radial density profiles with and without coil levitation.
- When the superconducting coil is levitated, plasma has peaked density profiles.

X-ray Measurements

(a) Visible light image and typical x-ray images of plasmas generated by 2.45GHz and (b) 8.2GHz ECH from port1. (c) X-ray image from port2.

Diamagnetism and maximum local β, and (b) line density in variation of gas pressure.

- High-β (maximum local β~70%) and high density (n~10^24 cm^-3) possibly due to EBW plasma is generated.
- Parameter ranges are designated as high-density (4mPa<P_e<20mPa), high-β (0.4mPa<P_e<4mPa), and unstable states (P_e<0.4mPa) according to the filling neutral gas pressure.
- High-β state is characterized by large stored energy, strong x-ray, and depression of visible light strength.
- In phase (i), thin plasma has large electromagnetic fluctuations, which are stabilized in steady state in (ii).

Experimental Results: Plasma at RT-1

- Magnetic field $B_0=1T$.
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*1987 Hasegawa, CPTCF 15. 147. RT (Tokyo) and LDX (MIT/Columbia) are operating dipole fusion experiments.


Decoupling of ion and electron fluids causes many interesting phenomena, for example strong ion flow due to ion diamagnetism, which are not treated by MHD.

β state is theoretically explained by hydrodynamic pressure of fast flow (double Beltrami state).

Improved High-β Stable State

Cross sections of RT-1*, visible light image of plasma, and construction of superconducting magnet.

Proto-RT (1998-)

Mini-RT (2003-)

RT-1 (2006-)

Superconducting Magnet (50kA)

X-ray Measurements

(a) Visible light image and typical x-ray images of plasmas generated by 2.45GHz and (b) 8.2GHz ECH from port1. (c) X-ray image from port2.

Temperature and density of hot electrons in variation of filled neutral gas, and hot electron pressure $P_e=\frac{n_e}{\tau_\text{in}}$ variation of diamagnetic signal.

High-β plasma pressure is mainly resulted from hot electrons.

Plasma has hot component electrons of $T_e=50keV$.

Strong correlation between $P_e=\frac{n_e}{\tau_\text{in}}$ and diamagnetism suggests hot component is the main component of electrons in high-β cases.

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