Observation of Electromagnetic Fluctuation and Density Decay of Magnetospheric Plasma in RT-1

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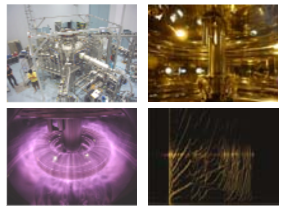
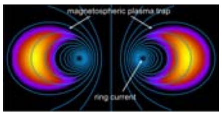
- **In the RT-1 device, a magnetospheric configuration generated by a levitated dipole field magnet, stable confinement of high-β (local β~70%) hot electron plasma has been realized.**
- **When the population of energetic electrons is very large in ECH (electron cyclotron heating) plasma, a high frequency electromagnetic fluctuation was observed by magnetic pickup coils.**
- **The fluctuation rotates in the electron curvature drift direction and has no phase difference along field lines.**
- **The fluctuation can cause rapid loss of plasma especially in a decay phase after RF power is turned off.**



Magnetospheric high-β plasma

- **Magnetospheric configuration enables high-β plasma confinement suitable for advanced fusion**

  - Magnetospheric fusion concept was motivated by spacecraft observation of Jovian high-β (β>1) plasma
  - In strongly inhomogeneous dipole field, MHD modes are stabilized by the effects of plasma compressibility

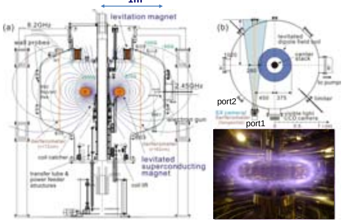


Magnetospheric plasma confinement

  - Mechanism of high-β state is theoretically explained by the effects of hydrodynamic pressure of flow (Double Beltrami state)
  - Realization of ultra high β confinement enables the burning of advanced fusion fuels, such as D-D and D-^{3}He
  - Various structures are self-organized in magnetospheric configuration

The Ring Trap 1 (RT-1) experiment

- **Magnetospheric configuration generated by a levitated superconducting dipole-field magnet**



Cross sections of RT-1 and generated ECH plasma

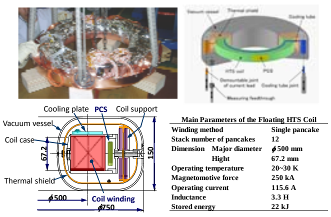
  - Field generated by superconducting coil and levitation coil (pure poloidal config.)
  - ECH system
    - -2.45GHz magnetron 20kW, 2s
    - -8.2GHz klystron 25kW(->100kW), 1s
  - ICH system
    - -1~3MHz 10kW (under construction)

RT-1, Mini-RT (UT) and LDX (MIT/Columbia) are the working magnetospheric devices

- **High-T_c superconductor (Bi-2223) enables 6 hours of magnet levitation operation without cooling**

  - Magnetic dipole with 250kAT (116A)
  - Magnetically levitated (total weight: 112kg)
  - Bi-2223 high-temp. superconductor
  - Operated between 20K and 30K

*2009 Ogawa *et al*., Plasma Fusion Res. **4**, 020.

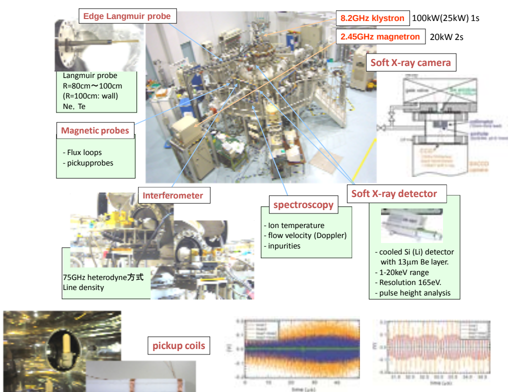


Main Parameters of the Floating HTS Coil

Winding method		Single pancake
Stack number of pancakes		12
Dimension	Major diameter	ϕ500 mm
	Hight	67.2 mm
Operating temperature		20~30 K
Magnetomotive force		250 kA
Operating current		115.6 A
Inductance		3.3 H
Stored energy		22 kJ

Structure of levitated superconducting magnet

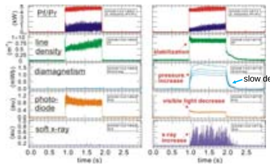
- **Diagnostic system of RT-1 consists of:**
  75GHz (4mm) interferometer, visible light spectroscopy, magnetic loops, Hall probes, pickup coils, Si(Li) and CdTe x-ray detectors, NaI(Tl) scintillators, soft x-ray CCD camera, 4GHz reflectometer, and edge Langmuir probes



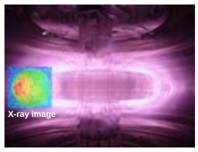
C-coupling between plasma-pickup coil is small, Magnetic signal is measured

Formation of high-β hot electron plasma

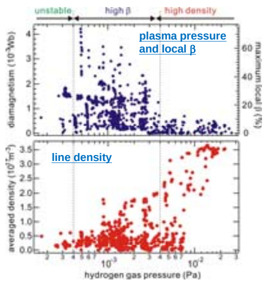
- **Stable high-β (local β~70%) state is realized by optimized operation conditions including neutral gas pressure**



Waveforms of low-β and high-β discharges



Visible light and x-ray image of plasma generated by ECH at 2.45GHz

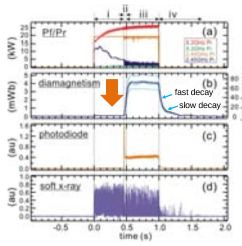


Parameters in variation of neutral gas pressure

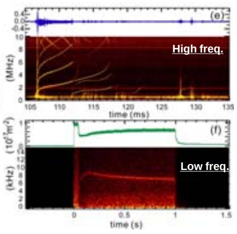
  - Discharge has three typical regimes according to neutral gas pressure P_n
  - By reducing P_n, increase in plasma pressure and x-ray, and decrease in visible light are observed
  - Plasma pressure is mainly attributed to hot electrons generated by ECH
  - X-ray measurements show electrons of ~50keV are the main component of plasma

Onset of electromagnetic fluctuation

- **Two types of fluctuations at ~MHz and at ~10kHz are observed at low neutral gas operation**



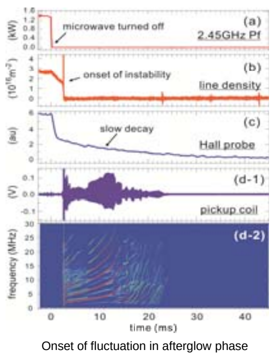
Discharge close to "unstable" state



Fluctuations observed at low P_n

  - By reducing P_n close to ~mPa, coherent fluctuation in kHz range emerges, which does not lead to drastic plasma disruption
  - When P_n is below ~2mPa, electromagnetic fluctuation in MHz range is observed, accompanied by low density state
  - The fluctuation in MHz range is also observed in a decay phase of plasma after turning off microwave (in *afterglow* phase).

- **Onset of fluctuation leads to destructive sudden loss of plasma in the *afterglow* phase**

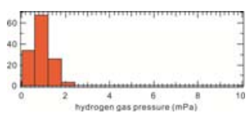


Onset of fluctuation in afterglow phase

  - The hot component of electrons usually has extremely log trap time
  - This is due to small cross section of collisions of high energy electrons
  - As a result, increase in the ratio of hot electron component is expected in the afterglow phase
  - In this phase, onset of fluctuation and rapid loss of plasma were observed
  - Chirping of frequency was repeatedly observed

- **Fluctuation onset and plasma loss appear at low P_n**

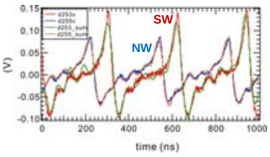
  - The fluctuation during the afterglow phase appears only when P_n is below ~2mPa
  - Strong correlation with the formation of hot electrons



Frequency distribution of fluctuation onset

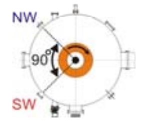
Fluctuation characteristics

- **The fluctuation rotates in toroidal diamagnetic direction of electrons and has no phase difference along field lines**

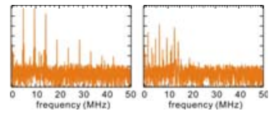


Pickup signals at NW and SW ports on equator

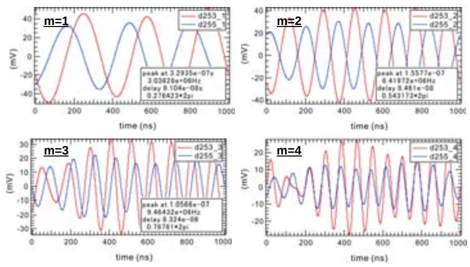
  - Clear phase differences are observed at probes located at different toroidal positions
  - Magnetic fluctuation signals are superposition of modes
  - The rotation direction is in the electron diamagnetic direction



Topview of RT-1

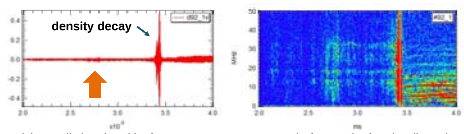


Typical frequency spectra of fluctuation signals



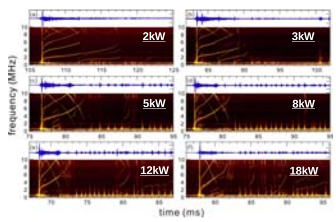
m=1~4 components of pickup coil signals decoupled by FFT method

- **Prior to the destructive fluctuation growth and chirping, plasma has small fluctuations**



Pickup coil signal and its frequency power spectrum before and after the disruption

- **The chirping speed depends on plasma parameters**



Fluctuation evolution in variation 2.45GHz RF power

  - Higher RF input power results fast chirping
  - Similar tendency is observed by changing P_n, fast chirp at low neutral gas pressure

- **Comparison with typical frequencies**

  - For typical field strength of B=0.01-0.1T of the RT-1 device, electron cyclotron frequency f_{ce}=280MHz-2.8GHz ion cyclotron frequency f_{ci}=150kHz-1.5MHz
  - For T_e=30keV, $n_e=1\times10^{15}$ m^{-3}, Λ=n/n'=0.1m (scale length), diamagnetic drift velocity $k_BT_e/eB\Lambda=3\times10^6 - 3\times10^7$ m/s

Conclusion and next step

- **When the population of hot electron component is large in magnetospheric ECH plasma, a burst of electromagnetic fluctuation and rapid loss of plasma were observed/**
- **The fluctuation propagates in toroidal direction, which agrees with the electron diamagnetic direction. The fluctuation frequency is comparable to the toroidal drift frequency of the hot electrons.**
- **The fluctuation is suppressed by neutral gas fueling, realizing stable high β state.**
- **The effects of hot electrons (including kinetic effects) and strong anisotropy of hot electron temperature are possible reasons for the onset of fluctuation; further investigation is needed to identify the fluctuation mode.**