Development of High Temperature Superconducting ECR Ion Source Using REBCO Coils

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MOP006

HTS-ECR

High Temperature Superconducting ECR ion source (HTS-ECR)

- ECR ion source with **magnetic field induced only by iron-less REBCO coils**.
- **Key technology development of iron-less electromagnet** for Skeleton Cyclotron, an iron-less cyclotron under development in RCNP.

$REBa_2Cu_3O_{7-x}$ (REBCO, RE=rare earth)

- Critical temperature T_c > 90K.
- **High critical current density** under perpendicular magnetic field component.
- J_c > 400 A/mm^2 under 20 T of external $B_\perp$ field.

→Ideal material for **iron-less electromagnet** of cyclotron / ion source.

Particle type	p^+, d^+ and He^{2+}
Cooling	GM cryocooler
Operation Temperatur	20～30 K
Extraction Voltage	50 kV
Operation Frequency	2.45 GHz and 10 GHz

→ Produce beam to Skeleton Cyclotron for RI production, BNCT, Targeted Alpha-particle Therapy, etc.

→ Large thermal margin for stable operation.

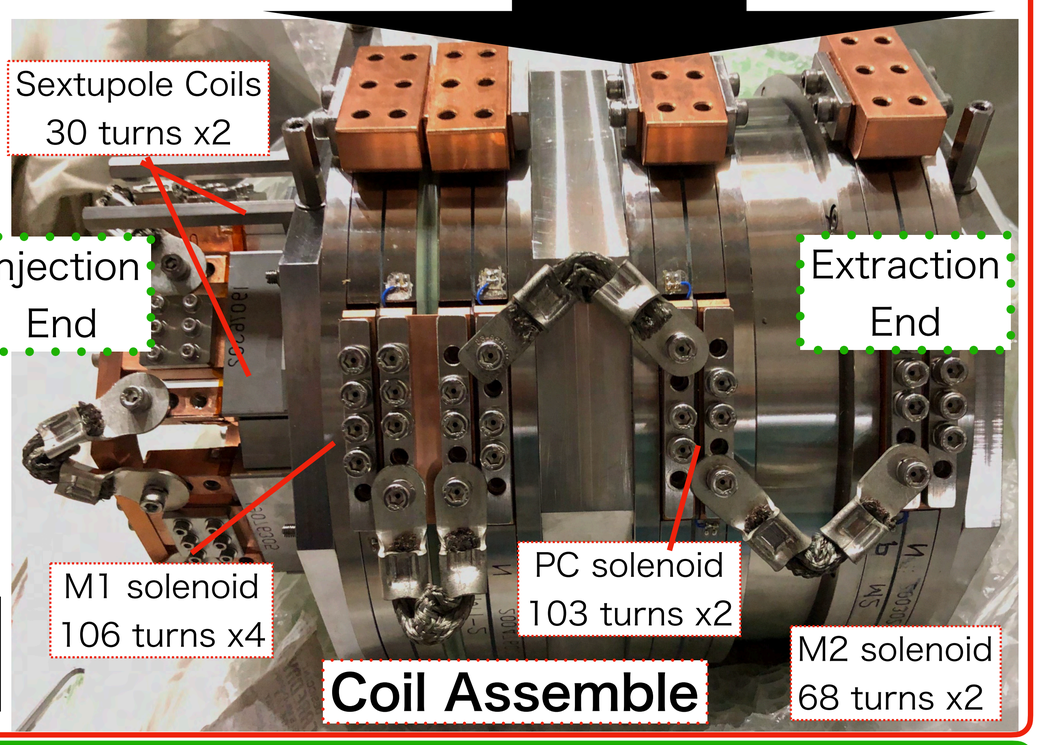
→ To examine the linear-adjustability of magnetic field induced by REBCO coils.

REBCO sextupole coil

- I_c > 250 A at 30 K

REBCO solenoid

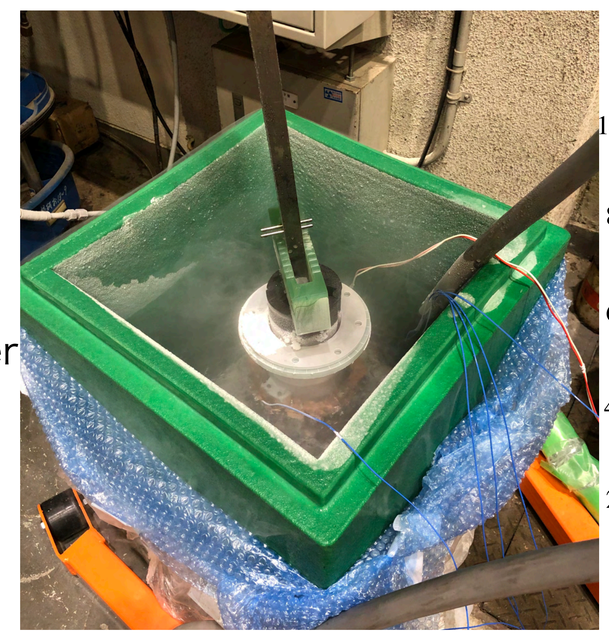
- I_c > 500 A at 30 K



Low temperature performance test (77 K)

Performance test apparatus

- REBCO coil assemble putted inside **liquid Nitrogen (77K)**.
- Currents are applied, while **3 solenoids are in series**, and **6 sextupole coils are in series** respectively.
- Voltages of each coil are recored, to examine the coils' stability under external magnetic field.

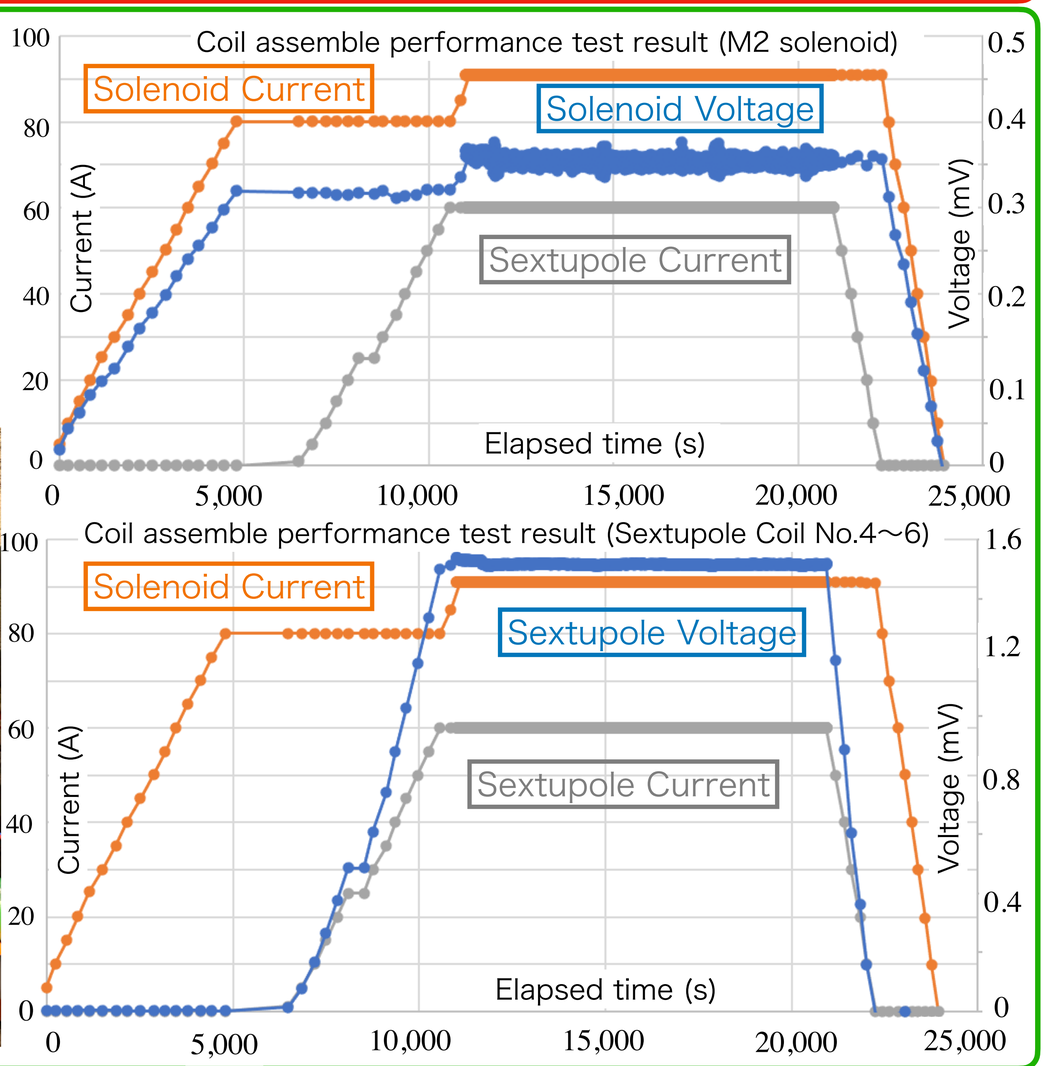


Test results

- Figures on the right show the applied current and voltages of M2 solenoid and 3 sextupole coils. Similar results obtained from other coils.
- **No normal conducting state transition** under 90 A in solenoids and 60 A in sextupole coils.

→Coils performance **remain the same under external magnetic field**.

→**High stability** under hours of operation.



Magnetic field design (for 2.45 GHz and 10 GHz operation)

R-wave cutoff criterion in magnetized plasma[1]:

$$\omega = (\omega_{ce} + \sqrt{\omega_{ce}^2 + 4\omega_{pe}^2})/2$$

cyclotron frequency — plasma frequency

$B_{ECR} \propto \omega$, $\omega_{ce} \propto B$, $\omega_{pe}^2 \propto n$

- $B > B_{ECR}$ everywhere to **avoid R-wave cut-off**.

Electron energy gain from resonance zone[1]

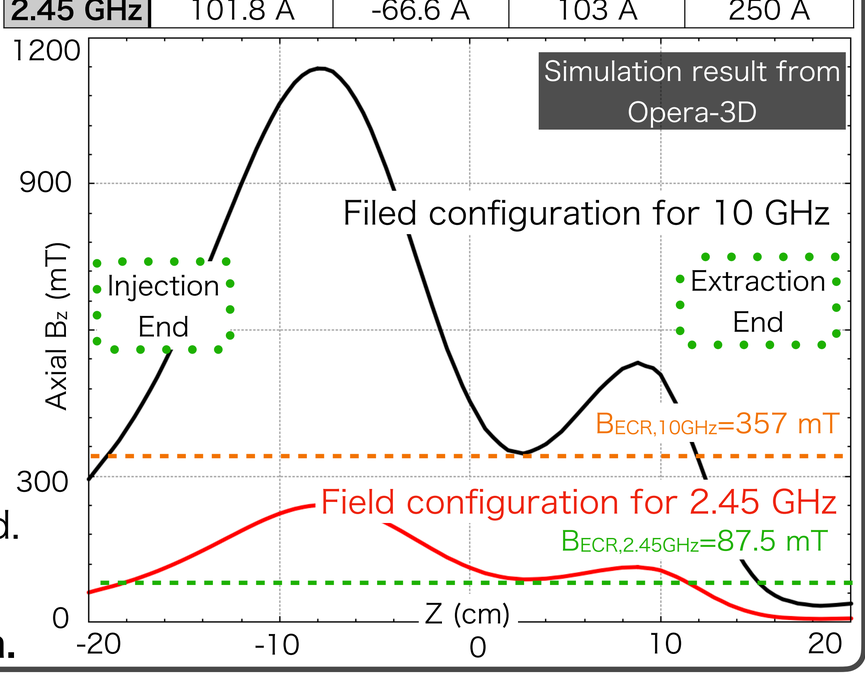
$W \propto E^2/(\Delta B/\Delta z)$

- Put resonance zone at bottom of magnetic field.

→$\Delta B/\Delta z \sim 0$

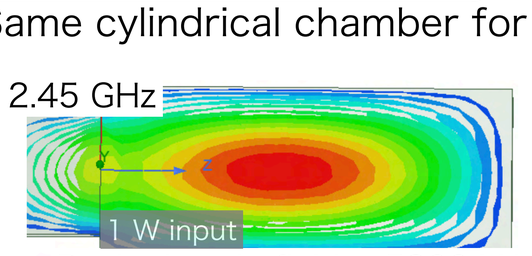
→**Maximize energy gain.**

	M1 current	PC current	M2 current	Sextupole
10 GHz	500 A	-580 A	500 A	250 A
2.45 GHz	101.8 A	-66.6 A	103 A	250 A

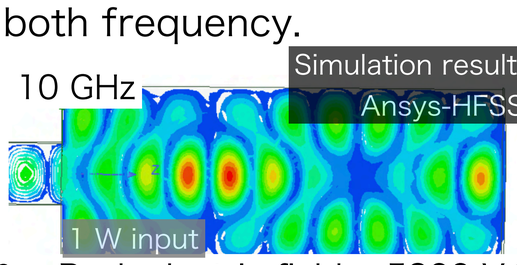


Plasma chamber design

- Same cylindrical chamber for both frequency.



Peak electric field ～5300 V/m



Peak electric field ～5300 V/m

- **38 mm in radius, 184.5 mm in length.**

→Satisfy electromagnetic wave resonance criterion in both frequency.

$$f_{mnp} = \frac{c_0}{2\pi}\sqrt{\left(\frac{j'_{mn}}{r}\right)^2 + \left(\frac{p\pi}{d}\right)^2}$$

- According to Cannobio's Theory[2], with 18 W input, electrons gain 30 keV and 12 keV in maximum, respectively.

→Effective ionization of p^+, d+ and He^{2+}.

Future works

- Coil assemble performance test in 30 K.
- Coil assemble test on magnetic field inducing ability.
- Cryostat is under development. Expected to be completed in next year.

[1]M.A. Liberman and A. J. Lichtenberg, *Principles of Plasma Discharges and Materials Processing* (Wiley Interscience, 2005).

[2]R. Geller, *Electron Cyclotron Resonance Ion Sources and ECR Plasmas* (Institute of Physics Publishing, 1996).