Design of a Permanent Magnet System for the Production of Closed Resonance Surfaces in Microwave Discharge Ion Sources

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1. Introduction

- The production of high current beams of **high charge state ions** has many possible applications.
- For example, **alpha particles** are used in the accelerator based production of **Astatine-211 used in targeted alpha therapy** of cancer.
- There are two common types of electron cyclotron resonance ion sources:

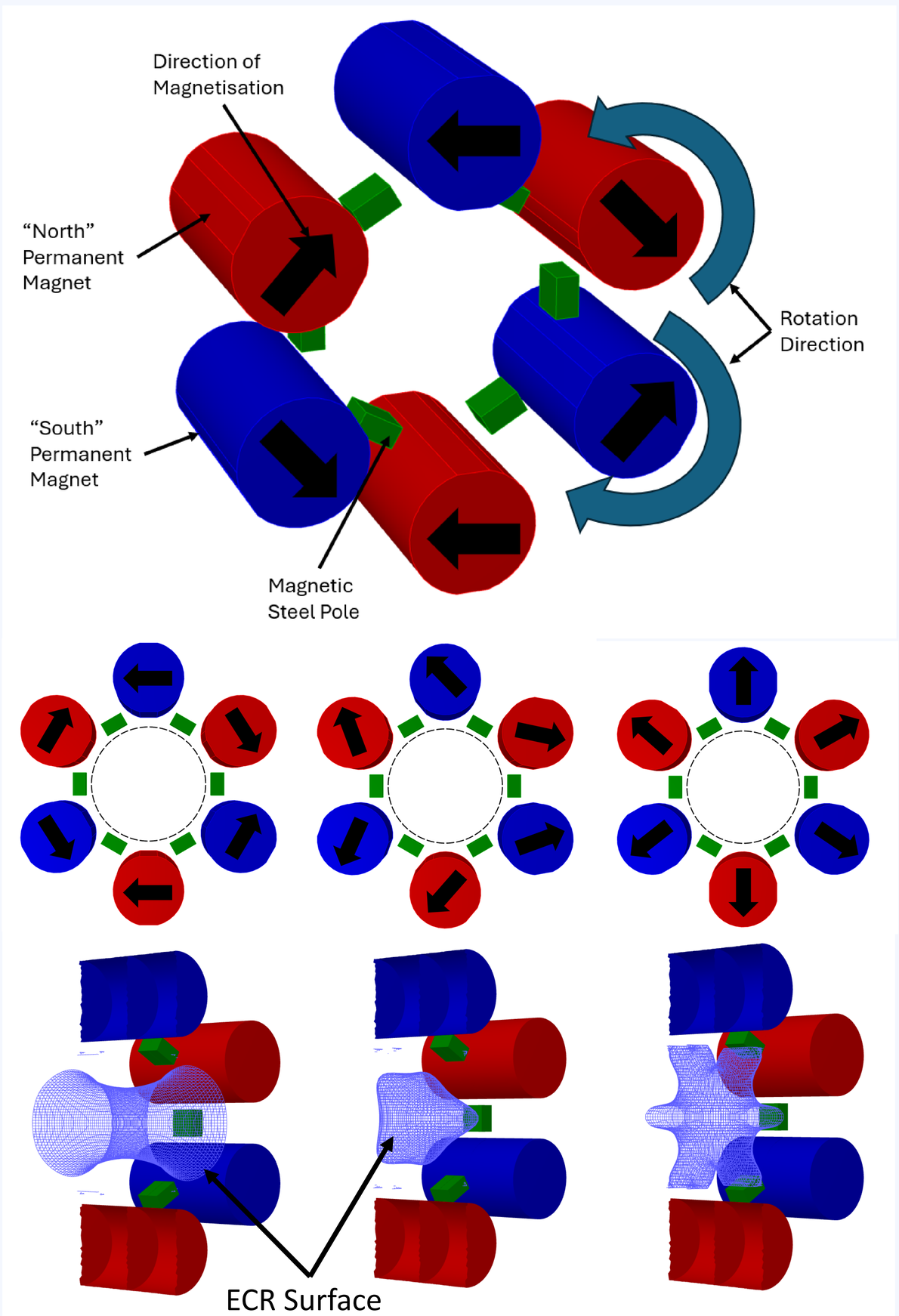
ECRIS:
- **Complex** combination of solenoid and hexapolar fields.
- Forms closed resonant field surface.
- High confinement giving high charge states.
- Limited to **low currents**.

MDIS 2.45 GHz:
- Solenoid field only.
- **Open resonant field surfaces** at plasma chamber ends.
- Can achieve high currents > 100 mA.
- Limited to **singly charged ions**.

- We present here the design of a **simplified magnetic array** capable of generating the **closed resonant field surface** required for the plasma confinement and multiple ionisation using a MDIS.

2. Magnetic Design

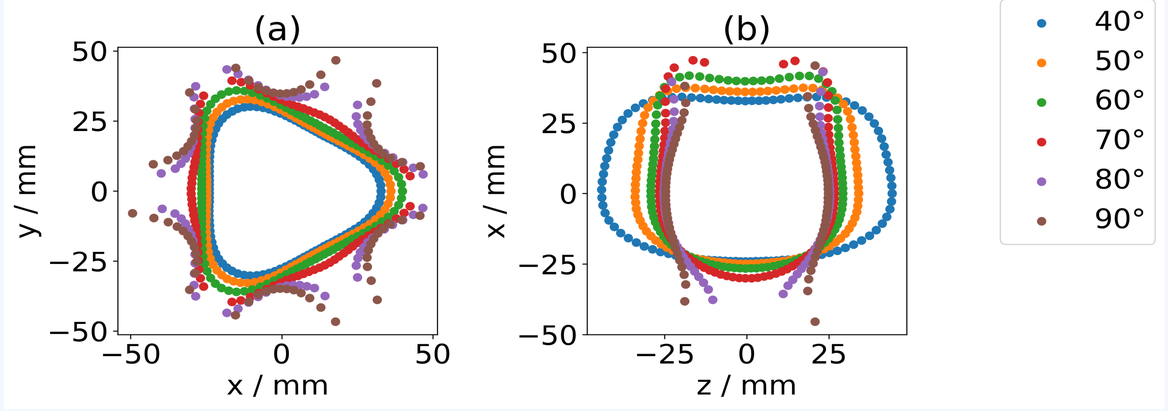
- Magnetic array named the CLosed ECR surface Permanent magnet with Tuning Options (**CLEPTO**).
- Example design for **2.45 GHz** Microwave Discharge Ion Source.
- Resonant field surface where **B_{ECR} = 87.5 mT**.



- Six **diametrically magnetised permanent magnet rods** and **6 ferromagnetic pole pieces**.
- Permanent magnets are **rotated to alter the shape** of the ECR field surface.
- "North" and "South" magnets rotated in opposite directions.
- At some angles, **the ECR surface forms a closed shape**.
- Scan the QR code to view an **animation** of the tuning of the resonant field shape.

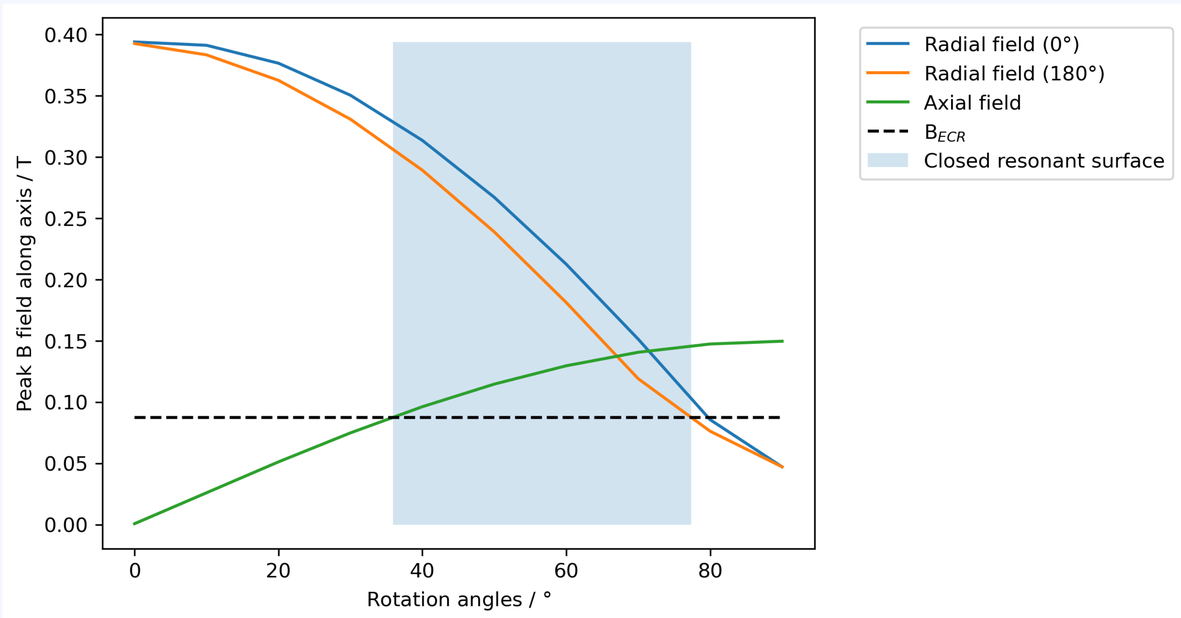
3. Resonant Field Shape

- Shape of resonant field changes as magnets are rotated.
- As rotation angle is increased, **three-lobe closed surface** is formed.
- **Increasing angle increases width and decreases length** of resonant surface.
- At very high angles, openings in surface appear near the poles.



Resonant field contours at different rotation configurations in the (a) transverse (xy) and (b) longitudinal (xz) planes.

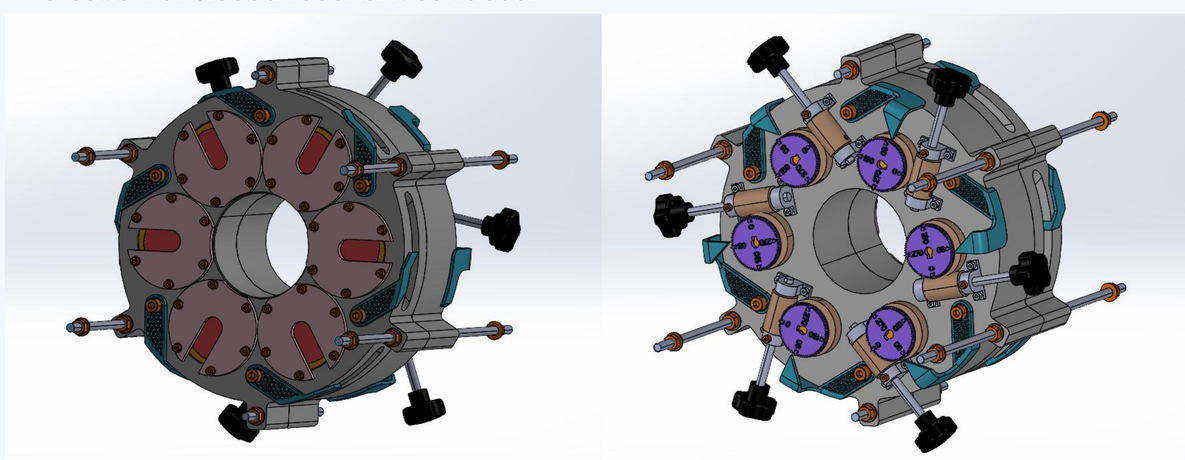
- A closed resonant field surface is formed if **the minimum magnetic field along any line** from the centre of the plasma chamber to one of the ends **exceeds B_{ECR}**.
- Due to symmetry, this **can be simplified to three lines**: two radial lines in opposite directions and one axial line.
- Range of angles over which closed ECR surface is formed can be determined from plot below.



Plot of maximum field along different lines from the magnetic centre, highlighting range of angles where a closed surface is formed.

4. Prototype Design

- Design is complete for a **proof of principle prototype**.
- **Worm gears** are used to manually rotate each permeant magnet and to **manage rotational forces** between magnets.
- Device will be assembled and **fields mapped with a Hall probe** to confirm the creation of closed resonant surfaces.



5. Conclusions and Future Work

- Design of novel permanent magnet system for generation of closed resonant surfaces for application in the generation of multiply charged ions beams in Microwave Discharge Ion Sources- **patent pending**.
- **Prototype magnet will be built as proof of principle** of creation and tuning of closed resonant field surface.
- **Future work to integrate design with a plasma chamber** for plasma density measurements.
- Further developments towards full beam extraction.

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