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A Novel Design of Superconducting Magnet for ECR Ion Source

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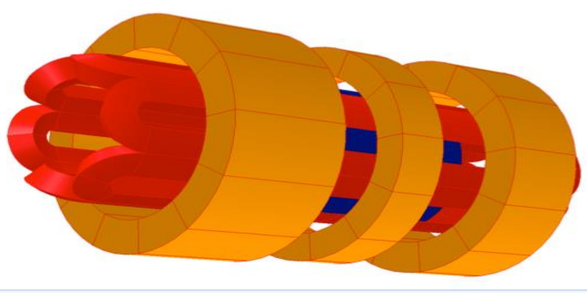
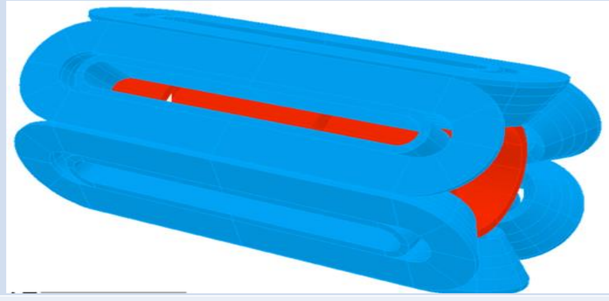
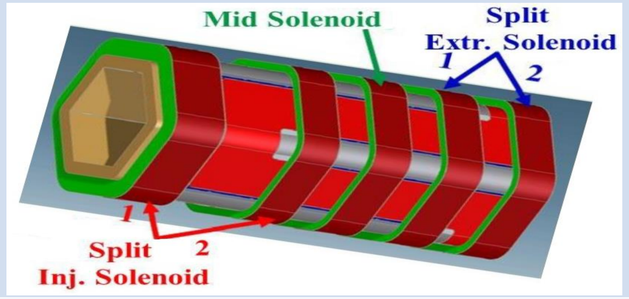
Introduction

This paper proposes a novel structure design of 3rd ECR magnet which is a combination of graded layers of solenoids and Discrete-Cosine-Theta coils that embedded in sets of cylinder skeleton with machined grooves. The design is meticulously crafted to enhance the magnet's robustness, streamline the manufacturing process, and reduce production costs, offering a more resilient, efficient, and cost-effective solution for ECR technology advancements.

The performance of three existing 3rd ECR magnets structure

	VENUS	***SECRAL***	***MARS-D***
Served	LBNL	IMPCAS	LBNL in future
stucture	*Conventional(Sex-in-Sol)*	*reversed(Sol-in-Sex)*	*CLC*
Magnet design			
Advantages	*High utilization of the radial field(~50%)*	*Lower and simpler interaction forces, smaller magnet, simpler fabrication, lower cost*	*Lower and simpler interaction forces, less conductor, smaller magnet, Best utilization of the radial field(~67%)*
Disadvantages	*Huge magnet and cryostat structure, higher and complex interaction forces*	*Inefficient utilization of the radial field (~34%)*	*Complex fabrication of the closed-loop coil, complex cryostat.*

Advantages of DCT Coils

Suitable for the large aperture and high-quality magnetic fields application

The process is highly efficient and reliable, easy to combine with multifunctional field

The DCT sextupole coil has the characteristics of low end-shoe magnetic field and weakened the structure force with the discrete ribs

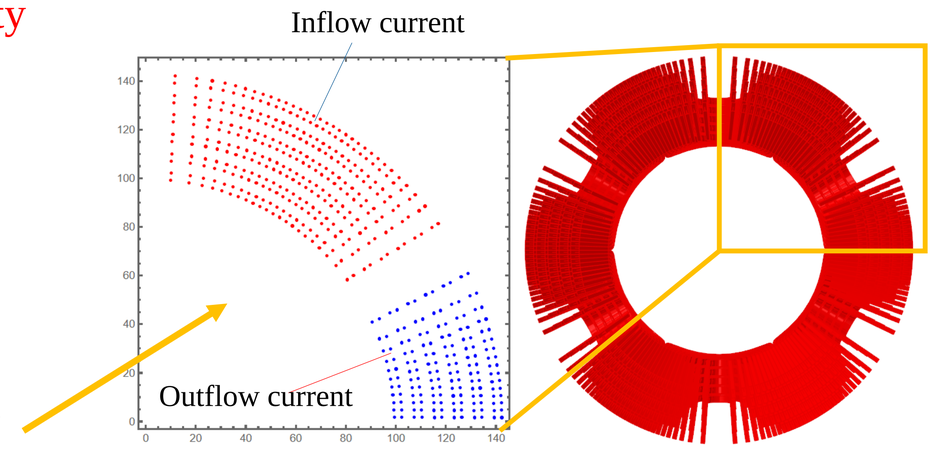
This makes the DCT-type ECR magnet have higher structural stability in complex magnetic field environments.

a cosine(mθ) current density distribution

$$J_z = J_0 \cos(3\theta)$$

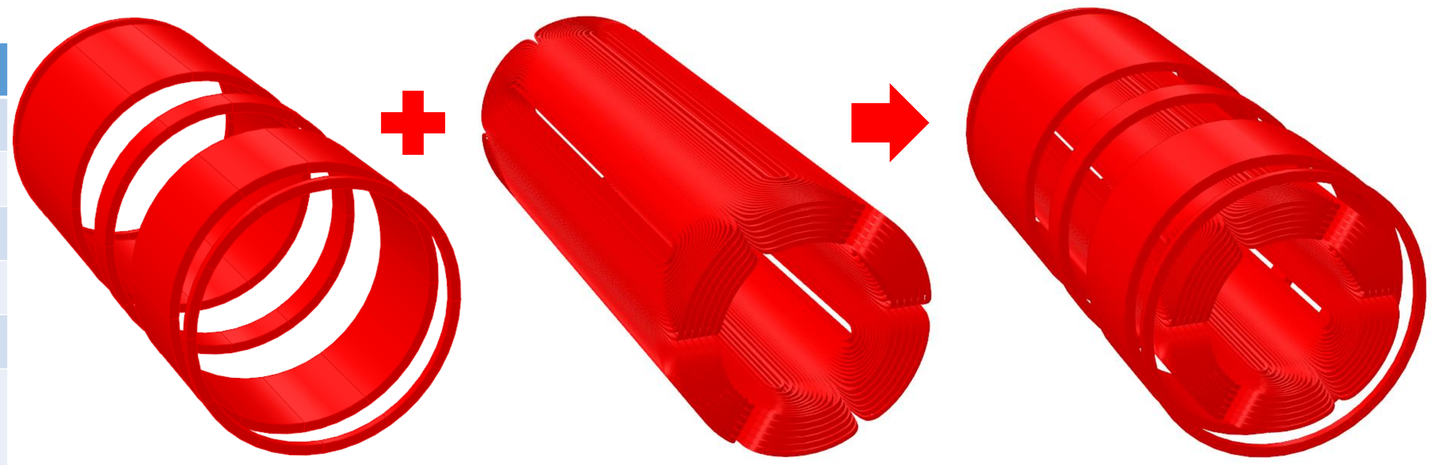
a discrete set of wires' angular positions

$$\sin(3\theta) = (i - 1/2)/N$$



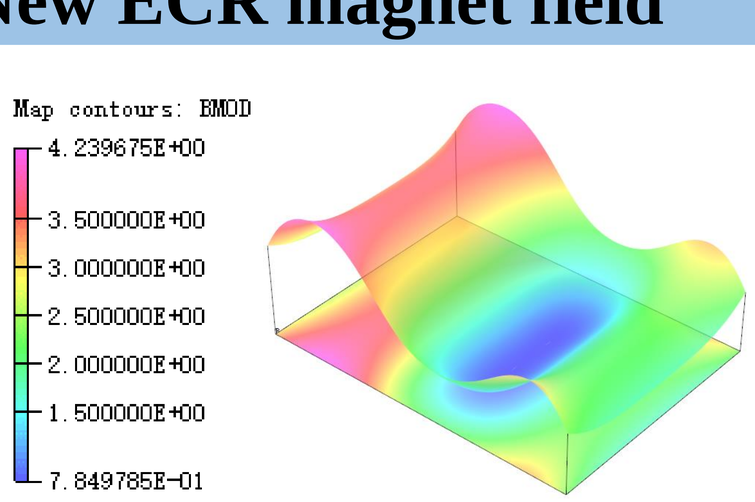
New ECR magnet design

Item	SECRAL	DCT-ECR
Sextu-field@R63mm	2T	2T
Sole-field(Inj/Mid/Out)	3.6T/0.8T/2.2T	3.6T/0.8T/2.2T
Max field@Conductor	8.6T	7.7T
Storage Energy	0.8MJ	0.6MJ
Volume	Φ800mm × 850mm	Φ500mm × 850mm
Advantage	high excitation efficiency	linear excitation, compact structure, robust performance

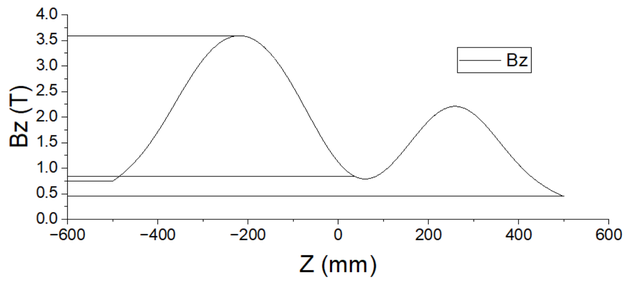


Solenoids DCT-Sextupole DCT-ECR magnet

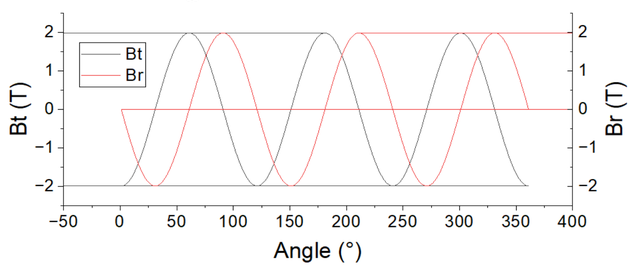
New ECR magnet field



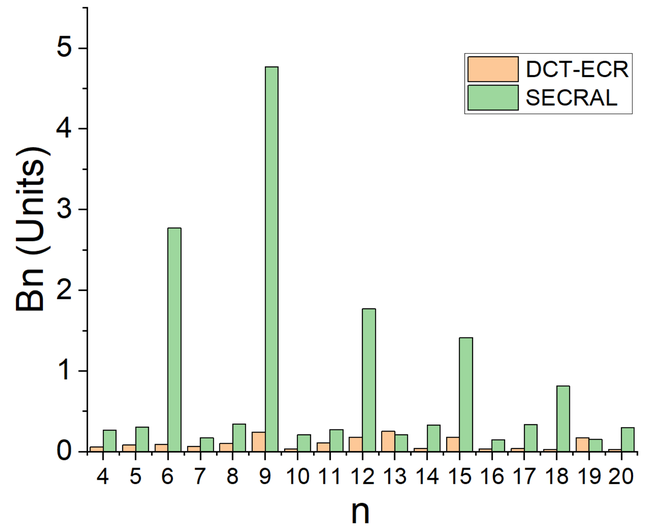
3D field distribution at x-z plane in the plasma chamber (y=0,x=-63~63mm,z=-340~340mm)



Axial mirror magnetic field distribution at the axis



Radial field distribution at the min-B position along azimuthal direction@R=63mm



Comparison of the harmonic quality of Bt field @R=63mm between SECRAL and DCT-ECR

Conclusion

The new ECR magnet, featuring an innovative DCT coil design, boasts an exceptional sextupole magnetic field quality and a compact form factor. This design also mitigates the buildup of Lorentz forces in the end adjacent conductor turns. The structure's standout features include an efficient manufacturing process, as well as a robust and compact construction. The superior sextupole magnetic field is anticipated to improve the performance of the ion source significantly.