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Calculation and Optimization of Eddy-Current Type Thin Septum Magnet for Beam Injection of Diffraction Limited Storage Ring

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Abstract

Fast kickers such as strip-lines along with lambertson magnet or thin septum magnet could support on-axis injection for Diffraction Limited Storage Ring (DLSR), in which traditional off-axis injection becomes inadequate. This paper focuses on the designing, manufacturing and process optimization of thin septum magnet. The scheme of eddy-current type thin septum magnet (the thinnest portion is with the thickness of 0.9mm) was adopted with laminated silicon steel sheets as magnet core. Firstly, theoretical analysis and calculating about magnet parameters was conducted. Then the simulation of main field and leakage field along the beam trajectory, the stray field decayed over 1millisecond time had been carried out within Opera 2D/3D. Besides, special attention was paid to compare and analyze of various shielding and insulating materials, leakage field suppression methods and optimize structure of septum to satisfy the physical requirement that the integral leakage field is less than 0.1% with respect to the main one. The work laid a foundation for injection technology of advanced light source.

Key Parameters

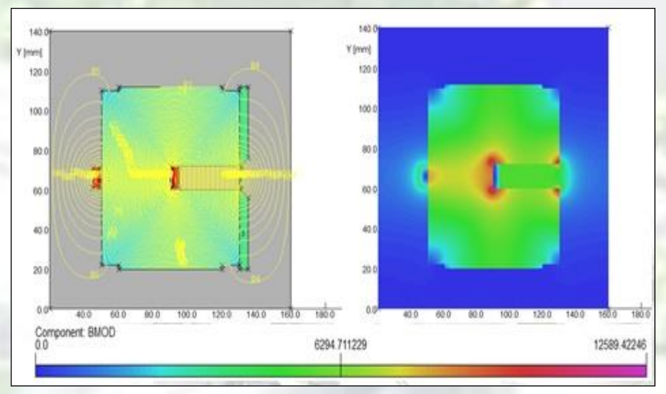
Ultra-low emittance causes the problem of inadequately injection with the traditional off-axis injection method. Small dynamic aperture means that the injection beam and storing beam should be close enough, which determines the thickness of the septum at injection point should be thin enough. Key parameters of the thin septum are selected or calculated in table 1 to achieve a balance between physical requirements and engineering practices. Considering the complexity and power consumption, eddy-current type of septum is adopted as the prototype for the project.

Table 1. Key Parameters of the thin eddy-current Septum Magnet

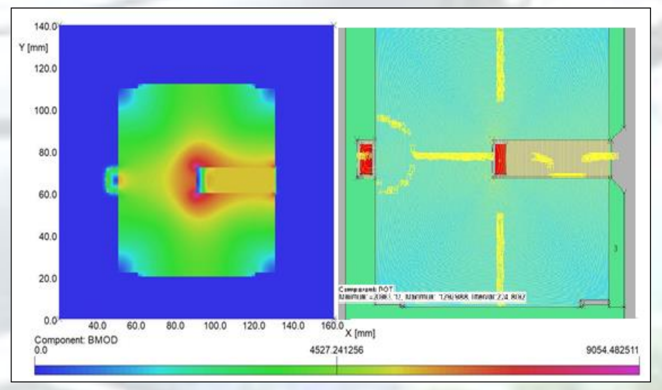
Parameters	Value	Unit
Beam Energy	2	GeV
Deflection Angle	50	mrad
Core Length	600	mm
Integral Field	0.32	T*m
Bend Radius	12.01	m
Peak Field	5560	Gauss
Gap Height	12	mm
Gap Width	40	mm
Good Field Region	28 × 10	mm*mm
Transverse Homogeneity	1.5%	--
Mini. Septum Thickness*	0.9	mm
Peak Current	5322	A
Magnet Inductance	2.5	μH
Number of turns on magnet	1	--
Leakage Field#	0.1%	--

* at injection point;
\# 2mm away from the septa.

2D Static & Transient Simulation

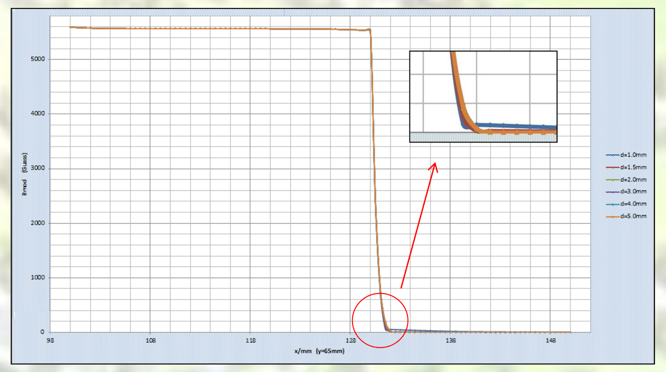


2D Static Simulation

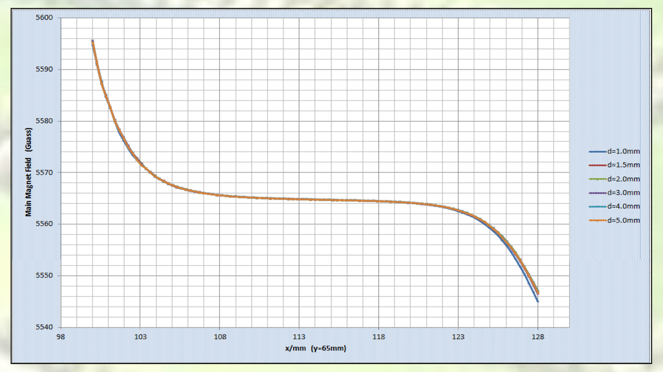


2D Transient Simulation

Generally, the thin eddy-current septum magnet is with of the C shape structure and the materials of support frame as well as septa itself are oxygen-free high thermal conductivity copper. Laminated steel sheets, which are 0.1mm thick and double coated with insulating layers, combine as the magnetic core with gap height of 12mm and width of 40mm. The silicon sheet material with high permeability and high resistivity could provide strong magnetic path and inhibit the eddy current to reduce the loss of the core at the same time.

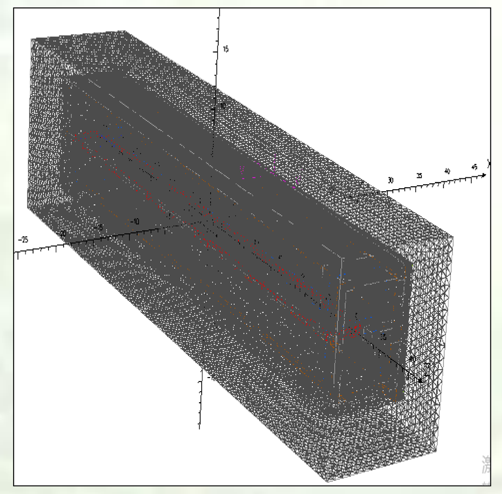


Leakage field varies with thickness of septa

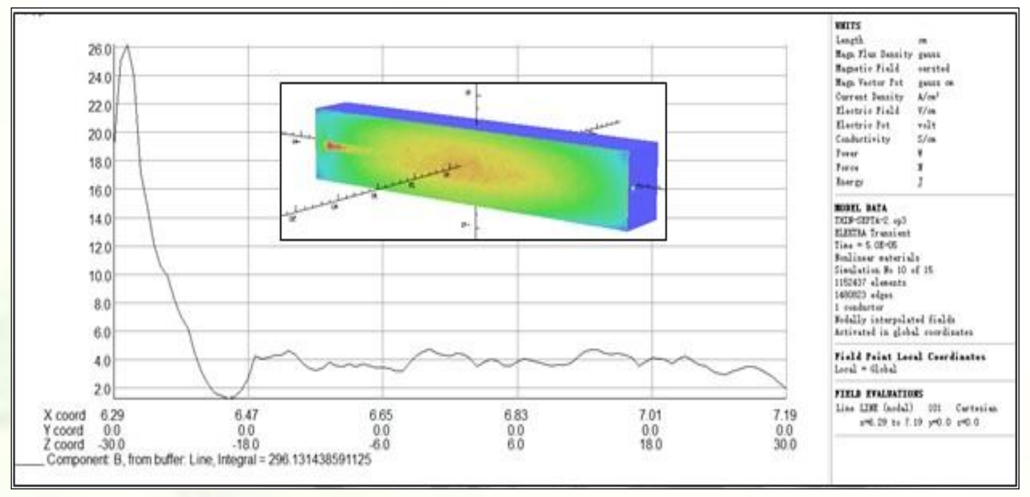


Transverse Homogeneity of Main Field (±0.45%)

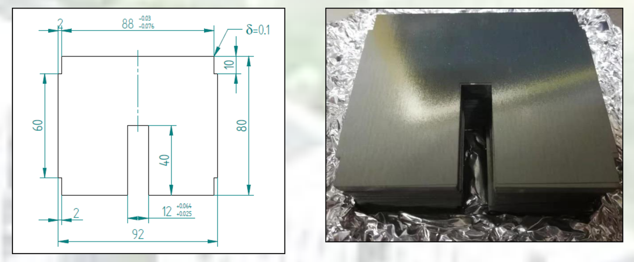
3D Transient Verification & Engineering Design



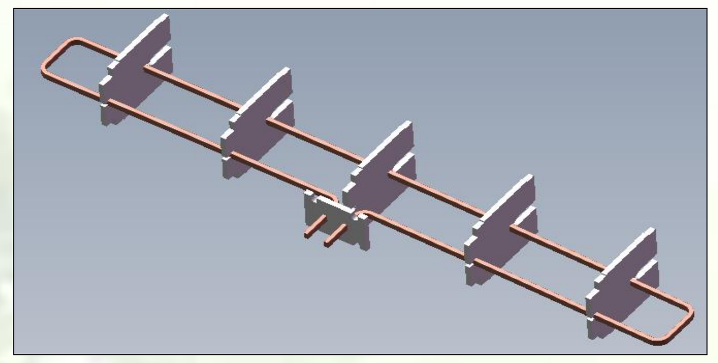
3D Meshing



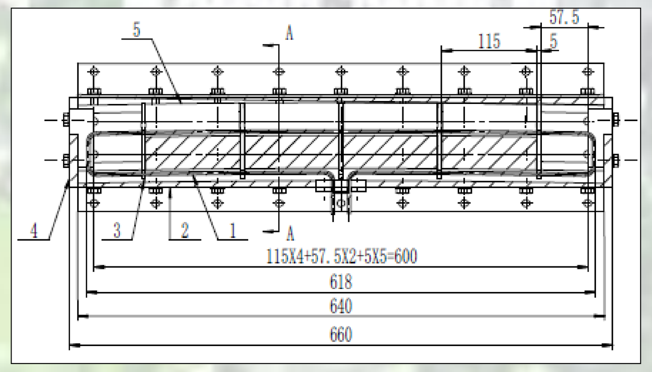
The line integral of the leakage filed along the beam direction (0.09%)



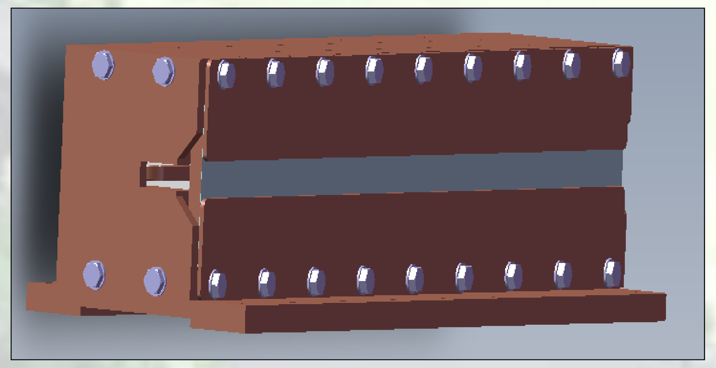
Stamped silicon steel



Coil insulation and support



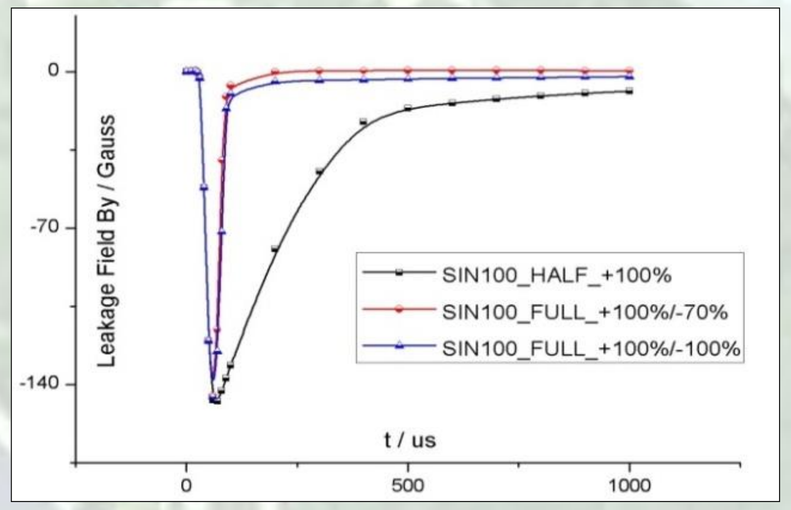
Mechanical drawing



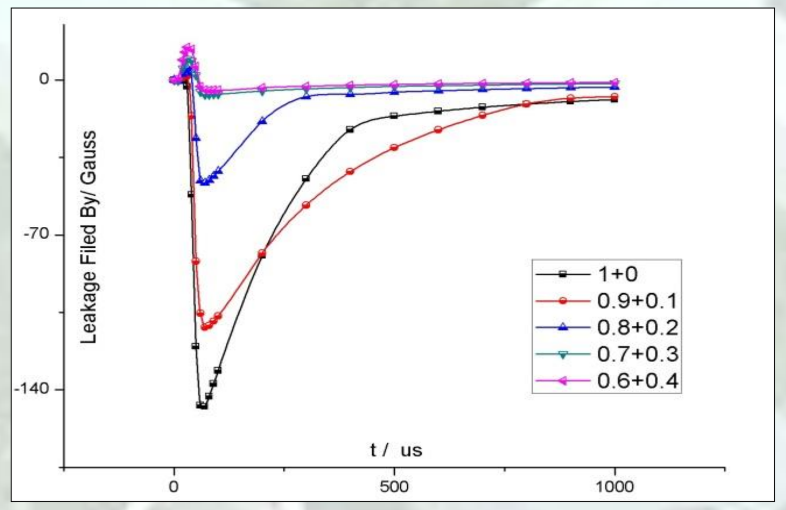
Overall framework

Optimization

Although the leakage field at the time of peak of main field almost can meet the requirement, the peak of leakage field which decays over 1ms is so large to tolerate and needs some ways to optimize.



Exciting with a half sine wave and a certain amplitude ratio of recoil



Deploying the thickness ratio between high permeability material and copper

On the foundation of deploying the thickness ratio, 0.3mm 10JNEX900 high permeability layer has been adopted for inhibiting the leakage field. The final simulation results could meet the 0.1% requirement obviously. Besides, reasonable using of double sine excitation could effectively reduce the integral leakage field at the same time.

Conclusion

Thin eddy-current septum aiming at the on-axis injection for DLSRs has been calculated, simulated, analyzed and optimized in SSRF. On the basis of arrangement about the beam trajectory, main field transverse homogeneity could meet the requirement well. Through a variety of optimization approach, integral leakage field could satisfy 0.1% eventually.

Besides, Challenges on process and structure design need to be taken seriously. Magnetic measurement, including effective magnetic length, transverse homogeneity, longitudinal profile and integral leakage field needs to be conducted timely. The stability and reliability of final septum within e- beam exists a lot of uncertainty, which needs further research and more engineering experience.

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SSRF 上海同步辐射光源 Shanghai Synchrotron Radiation Facility

SINAP 中国科学院上海应用物理研究所 Shanghai Institute of Applied Physics, Chinese Academy of Sciences