MT 26 International Conference on Magnet Technology
Vancouver, Canada | 2019

Optimization of a Solenoid for an Electron Lens in SIS18

Carsten MUEHLE[(1)], Alexander KALIMOV[(2)], David ONDREKA[(1)], Kathrin SCHULTE-ULRICHS[(1)] , Peter SPILLER[(1)]

(1) GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, GERMANY; (2) Peter the Great St. Petersburg Polytechnic University, St. Petersburg, RUSSIA.

Abstract

An electron lens for space charge compensation – a novel instrument in accelerator physics to manipulate hadron beams with a magnetically confined electron beam - is under development at GSI, Darmstadt. It will be used to compensate the ion beam's space charge by an overlapping electron beam and therefore may help to increase the intensity of primary beams in the synchrotron SIS18 for FAIR. The main element of the lens is a solenoid with the longitudinal magnetic field of Bz=600 mT and the requirements to the field homogeneity of ΔB/B less than $\pm 5\cdot 10^{-4}$ relative units. The magnetic field in the solenoid will be ramped with the rate of up to 20 T/s. Acceptable geometry of the solenoid has been found by optimization of the coil parameters and the iron shield geometry. For this purpose we have combined the 2D finite element technology for the magnetic field modeling and the Nelder-Mead optimization strategy. Thorough investigation of the solenoid 3D model confirmed a quality and feasibility of the developed magnetic system.

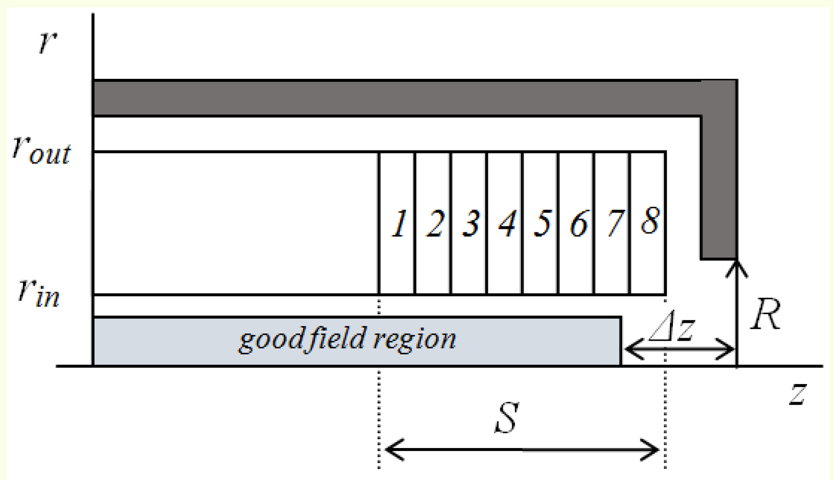
Main parameters of the magnet

Parameter	Unit	Value
Aperture diameter	mm	150
Diameter of the good field area	mm	80
Length of the good field area	mm	3000
Maximum longitudinal flux density	mT	600
Field quality	%	±0.05
The magnet overall length	mm	<3360
Minimum flux density ramp rate	T/s	2
Maximum flux density ramp rate	T/s	20

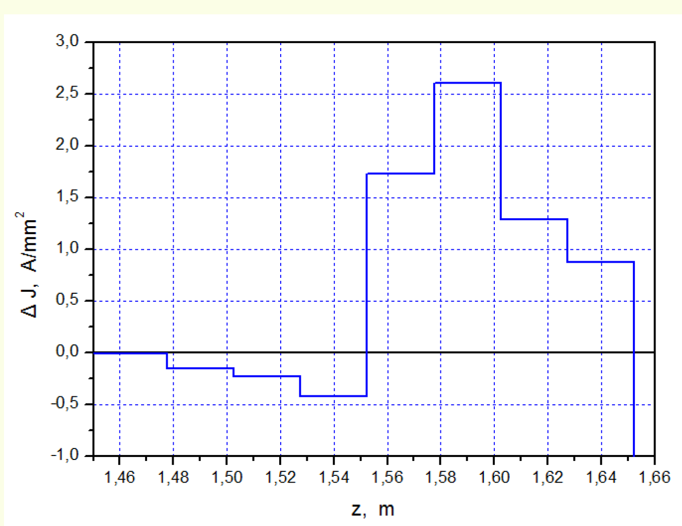
Current density distribution in the end part of the coil

The end part of the solenoid with the length of *S = 160* mm was split into 8 thin round layers The current density in each layer was a subject of optimization. Search for the optimal solution was performed for different values of the radius *R* of the hole in the end part of the iron shield.

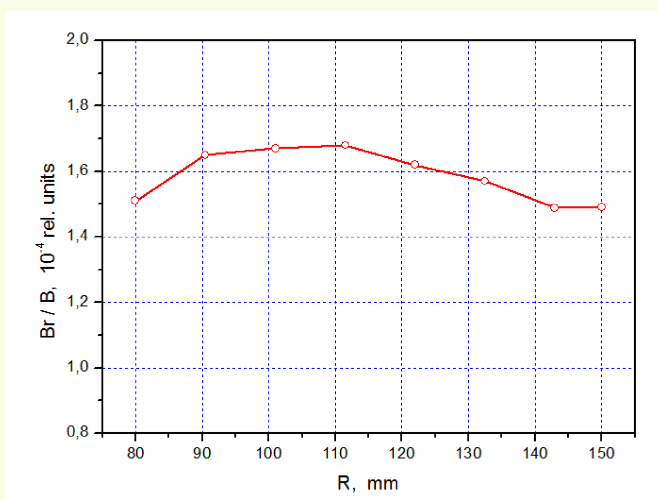
The optimization of the solenoid geometrical parameters has been done by applying the Nelder-Mead downhill simplex algorithm. The maximum value of the magnetic flux density radial component in the good field domain was used as the goal function to be minimized.



The model of the solenoid end part.



Distribution of the current density in the end blocks of the solenoid magnet corresponding to the optimal solution. The radius of the hole in the top plate is R = 120 mm. Zero level corresponds to the current density in the main coil J = 5 A/mm². The top pate occupies space from z =1.66 m to z = 1.68 m.

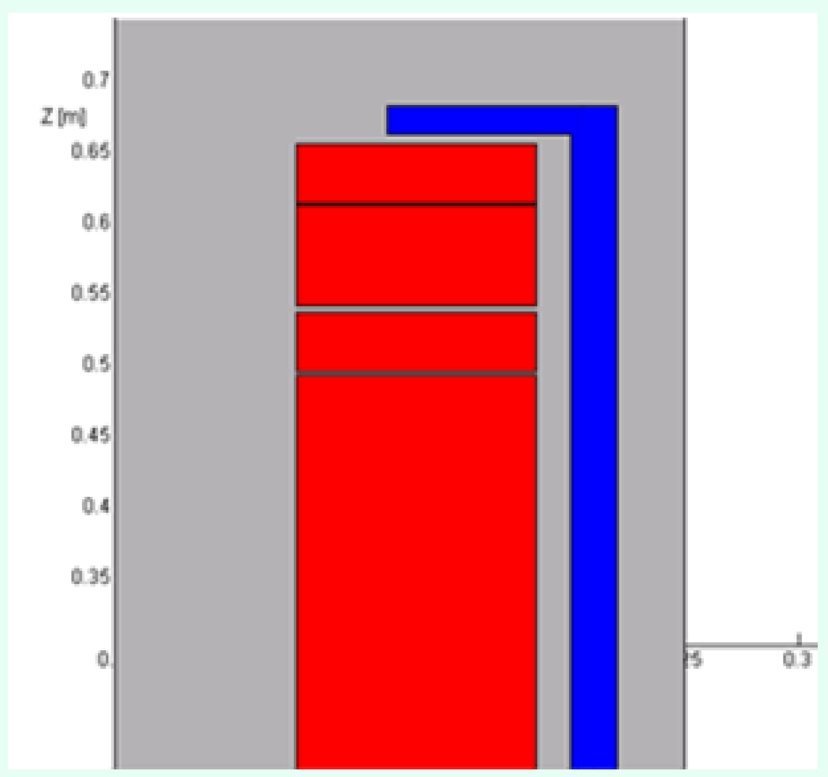


Dependence of the maximum radial flux density on the radius of the hole in the top plates. The current density in the end part of the solenoid has been optimized.

The coil structure

For the main coil of the solenoid a conductor with the cross section of 10 × 10 mm² and with a channel inside for the water cooling has been chosen. Each end part of the solenoid coil is split into 3 sections The reduced current density inside two sections is imitated by introducing appropriate gaps between sections. For the middle section the conductor with a reduced cross section of 8.25 × 8.25 mm² has been chosen. So the required distribution of the current density was reproduced approximately.

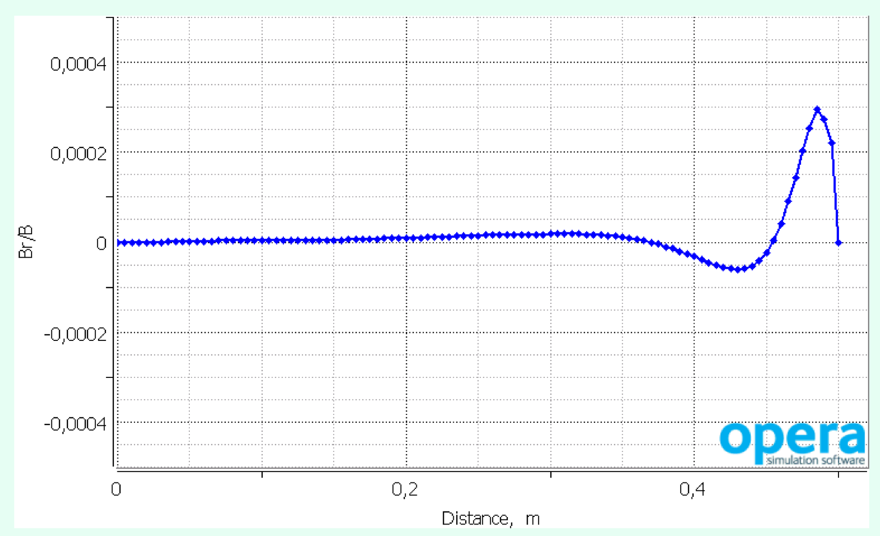
A number of columns and their positions in the coil sections were optimized to achieve the best possible field distribution in the solenoid aperture. Optimal results for the model with the radius of the window in the iron shield of *R = 120 mm* ensures the required field quality.



A model of the solenoid end part with 3 separate sections.

PARAMETERS OF THE COIL SECTIONS

Section	R_{in}, mm	R_{out}, mm	Z_1, mm	Z_2, mm	J, A/mm²
main	80	185	-1491	1491	4.5
1	80	185	1493	1535	4.5
2	80	185	1540	1610	6.48
3	80	185	1612	1654	4.5



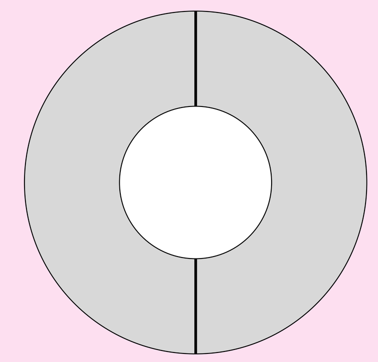
Radial component of the flux density along a line of *r= 40 mm* in the magnet end part.

3D model of the Solenoid

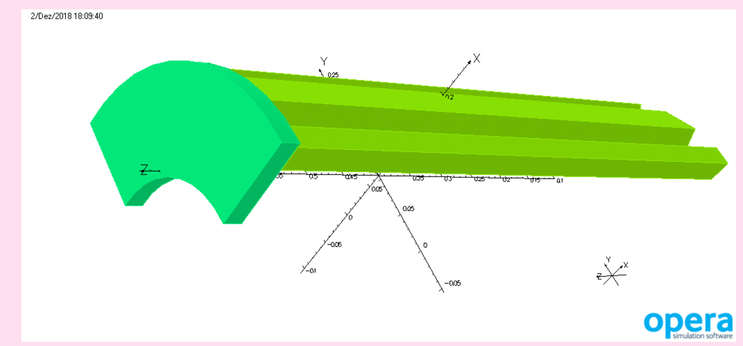
The top plates of the iron shield conduct the magnetic flux from the axial part of the magnet to the return yoke. To prevent the eddy currents in these plates they should be laminated. Nevertheless a part of the magnetic flux enters the plates along the axial direction and induces planar currents inside laminations. To restrict a magnitude of these currents to acceptable level we propose to compose the top plates of two half-rings.

A preferable lamination direction of the return yoke is a radial one. In such a case the eddy currents induced by the main flux and the magnetic field which enters the yoke in the central part of the solenoid are suppressed. The best possibility to provide such property of the return yoke is to compose it of several straight laminated steel bars.

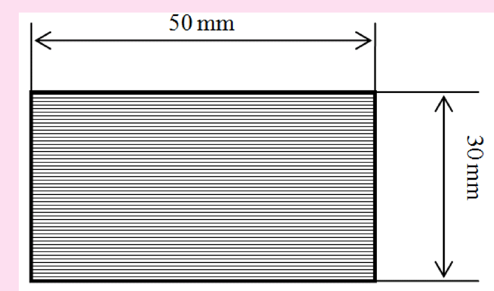
Influence of eddy currents on the field quality is acceptable.



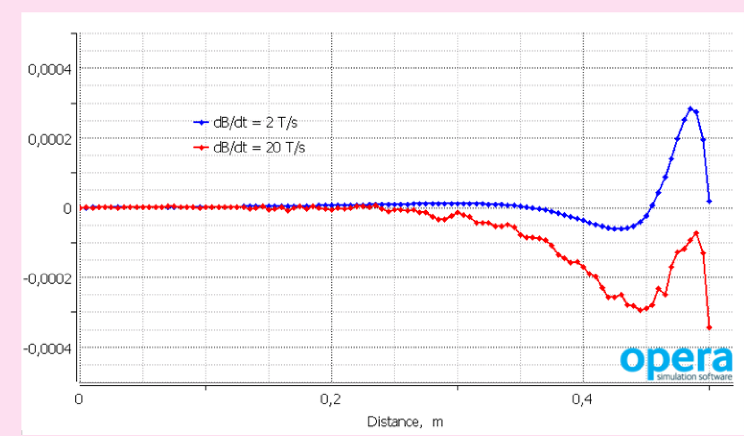
Top plate assembled of half-rings with an insulating gap in between.



One quarter of the magnet yoke (end part). Coils are not shown.



Cross section of a return yoke element.



Radial component of the flux density along a line of *r= 40 mm* in the magnet end part (3D model, dB/dt = 2 T/s and dB/dt = 20 T/s)

Main results

The model of the solenoid type magnet for the electron lens to be installed on the beam line of the accelerator SIS18 has been developed. The required field quality of $B_r/B < 5\cdot 10^{-4}$ was ensured in the good field region by optimizing the coil structure in the end part of the solenoid for different geometrical parameters of the external iron housing. Optimization of the magnet coil and iron shielding system was undertaken for both 2D and 3D solenoid models. Proposed design of the top plates and the return yoke ensures acceptable disturbance of the magnetic field radial component in the magnet aperture excited by the eddy currents in the iron shield.

50 YEARS GSI