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Direct Drive and Eddy Current Septa Magnet Designs for CERN's PSB Extraction at 2 GeV

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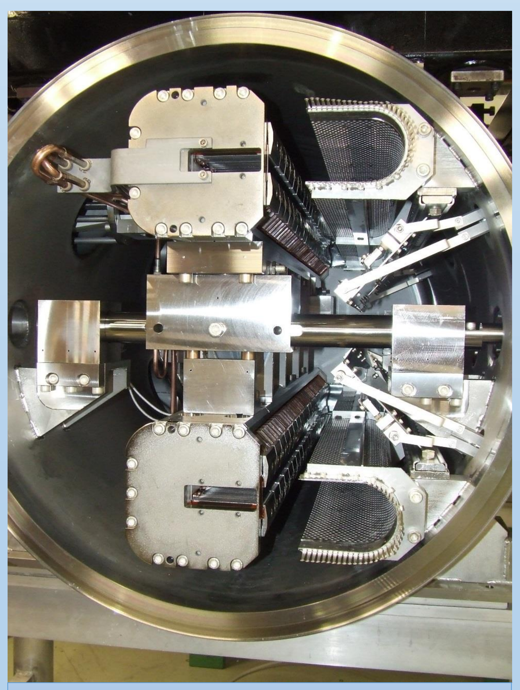
Introduction

In the framework of the LIU project, new septa magnets have been designed for CERN's PS Booster (PSB) extraction, recombination and PS injection. The upgraded devices are to deal with the increased beam energy from 1.4 GeV to 2 GeV. For the extraction (BESMH) of the PSB beams, the increased beam rigidity is taken into account, the new magnet current creates a corresponding increase in the thermal loading. The direct drive recombination septa (BT-SMV10) in the PSB transfer line to the PS, the eddy current PS injection septum (SMH42) together with a bumper (BSW42) at injection, have been investigated using Opera® finite element software.

PSB Extraction

The required integrated field increased by 30% and an extra 2 mrad is needed for trajectory corrections. These factors together with a possible decrease of repetition period from 1.2 s to 0.9 s lead to an increase of the RMS current from 253 A to 396 A. To cope with this, the cross section of the copper busbars has been increased from 200 mm^2 to 400 mm^2, and the cooling scheme of the magnets inside each tank is changed from series to parallel.



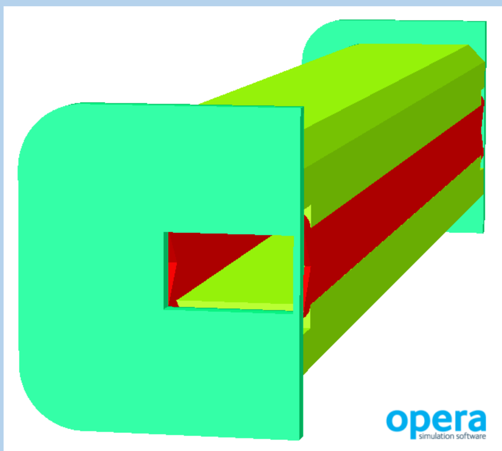
Lower tank of the BESMH, showing the extraction septa magnets of ring 1 and 2 of the PS Booster.

Parameters of the present and the upgraded PSB extraction septum BESMH		
Parameter	Present version	LIU version
Particle energy [GeV]	1.4	2.0
Physical length [m]	1.008	1.008
Magnetic length [m]	0.950	0.950
B_0 [T]	0.354	0.479
∫Bdl [T·m]	0.336	0.455
I [kA]	7.0	9.6
Deflection angle [mrad]	47	49
Gap height [mm]	25	25
Gap width [mm]	89	89
Septum thickness [mm]	3.8	3.8
½ sine pulse width [ms]	3.1	~3.1
Repetition rate [Hz]	0.8	0.8

The upgraded 400 mm^2 busbars for BESMH.

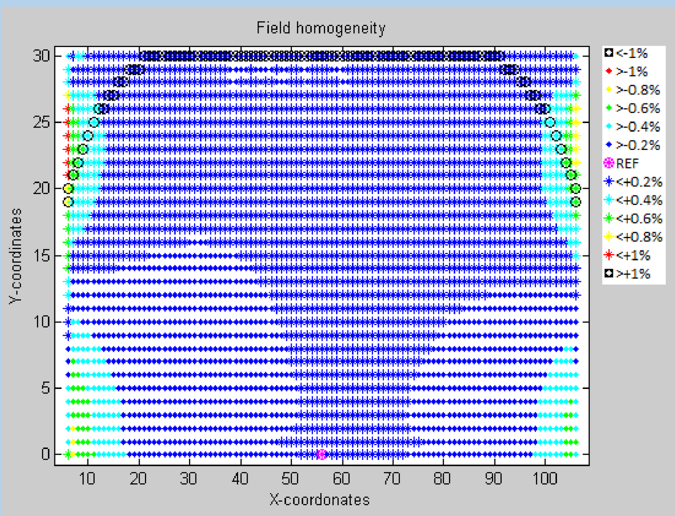
PSB Recombination

In order to deflect the beam with the same angle, the integrated field must be increased by 30% here as well, whilst preserving the present geometry of the recombination transfer line. Since the beam observation system used in the present layout can be relocated further downstream, the length of the magnet can be increased without having to make modifications to the magnet's vacuum vessel.



BT-SMV10 Opera-3D® finite element model.

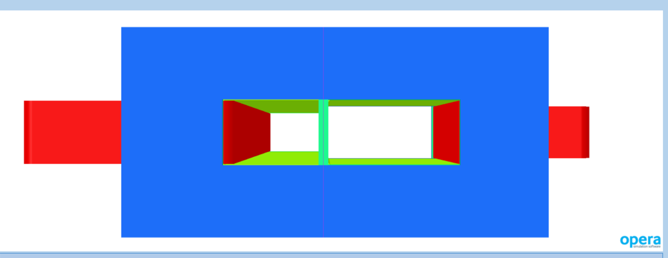
Parameters of the present and the upgraded PSB recombination septum BT-SMV10		
Parameter	Present version	LIU version
Particle energy [GeV]	1.4	2.0
Physical length [m]	1.060	1.300
Magnetic length [m]	0.996	1.225
B_0 [T]	0.569	0.546
∫Bdl [T·m]	0.566	0.670
I [kA]	27.5	26.3
Deflection angle [mrad]	79.3	80
Gap height [mm]	60.4	60.4
Gap width [mm]	102	102
Septum thickness [mm]	5	5
½ sine pulse width [ms]	3.1	~3.0
Repetition rate [Hz]	0.8	0.8



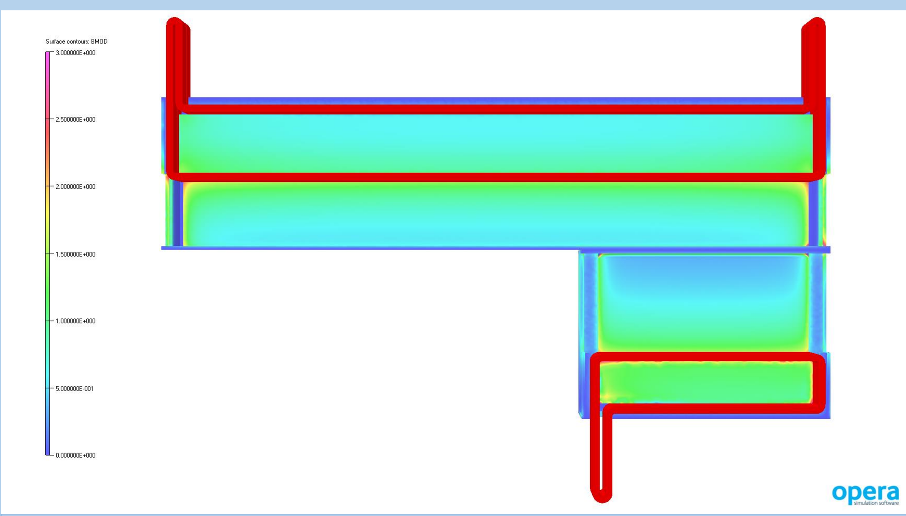
BT-SMV10 ∫Bydl homogeneity plot, septum blade on the left. Resulting homogeneity in the GFR: ±0.59%.

PS Injection

The beam will be injected also with an increased energy into Straight Section 42 of PS. The present injection septum SMH42 is at its very limit and cannot deflect a higher energy beam with the correct angle. To obtain the required integrated field for the 2 GeV beam, the new septum magnet requires the full length of SS42 to be available. The injection bump is achieved with five bumper magnets. Since one of them, BSW42 is located in SS42, it has to be installed next to the septum in the same vacuum vessel.



SS42 Opera-3D® model: the septum is on the left, the bumper is on the right of the figure.



SS42 Opera-3D® model: the septum is on the top, the bumper is on the bottom of the figure, cut into two at their symmetry plane.

Poster

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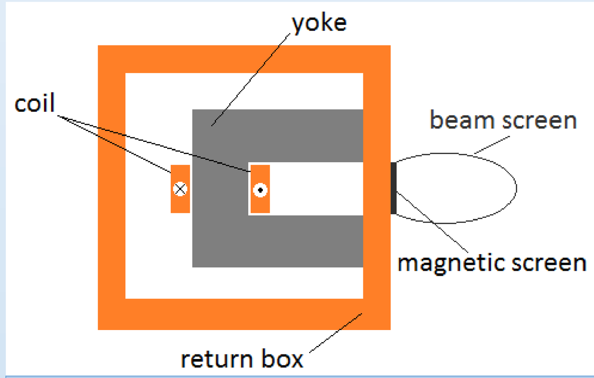
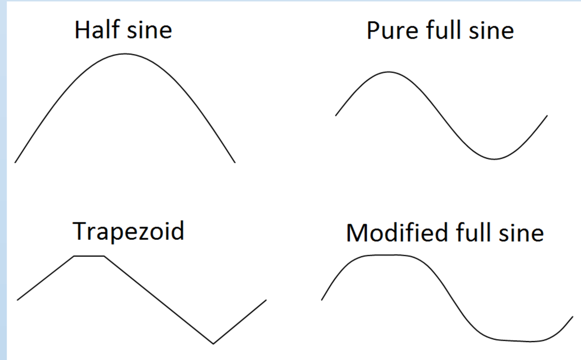
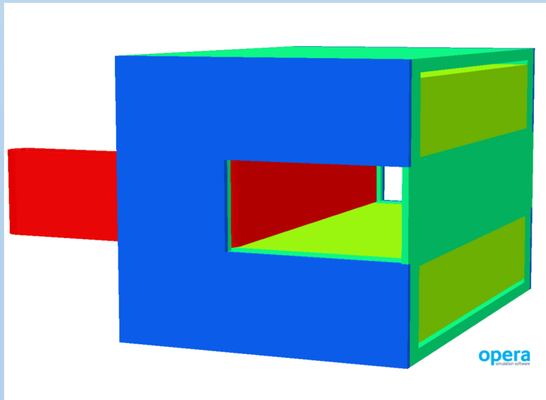
Eddy current technology was chosen for its robustness, with the aim to increase the mean time between failures above the 20 million pulses (2 years) of the present system. Using this technology the coil is located around the back leg of the yoke. When the magnet is pulsed, the septum part is not directly driven by the power supply, however the magnetic field induces eddy currents in the septum blade. Half sine current waveforms cause slowly decaying eddy currents in the box. Ideally for a 5 mm septum a 100 µs full sine current excitation would be used to minimise the fringe field and optimize field homogeneity. To avoid excessively high voltages, a 2 ms full sine excitation pulse was chosen for the new septum SMH42.



Cross section of an eddy current septum magnet.



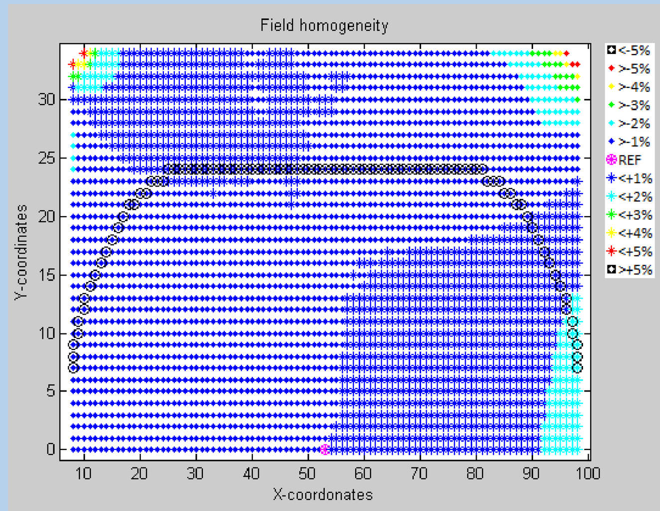
The investigated excitation waveform shapes for SMH42.



Opera-3D® model of the „direct drive-like" BSW42.

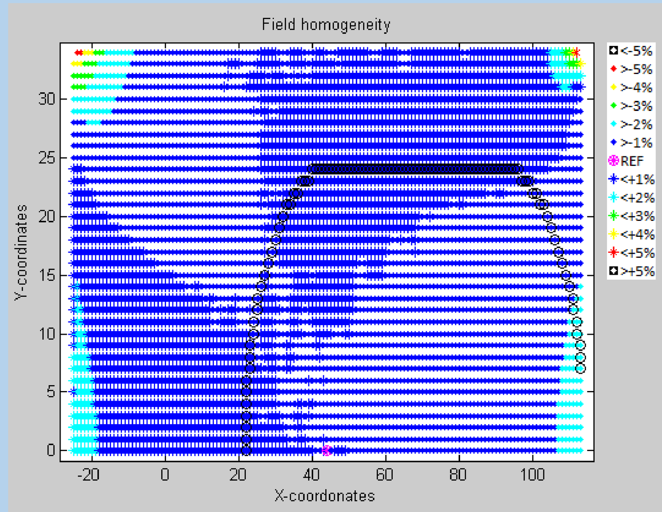
The homogeneity of the bumper BSW42 is critical. In order to reach values below ±1%, whilst keep using a 1 ms half sine excitation, a so-called „direct drive-like" magnet is proposed. The septum conductor is only present in the height of the magnet gap.

Parameters of the present and the upgraded PS injection septum SMH42		
Parameter	Present version	LIU version
Particle energy [GeV]	1.4	2.0
Physical length [m]	0.62	0.94
Magnetic length [m]	0.567	0.913
B_0 [T]	0.69	0.56
∫Bdl [T·m]	0.39	0.51
I [kA]	33.5	31.2
Deflection angle [mrad]	54.7	55
Gap height [mm]	60.4	70
Gap width [mm]	102	95
Septum thickness at the downstream extremity [mm]	5	5.8
Septum thickness at the upstream extremity [mm]	n.a.	11
Pulse width [ms]	3.2 (half wave)	2 (full wave)
Repetition rate [Hz]	0.8	0.8



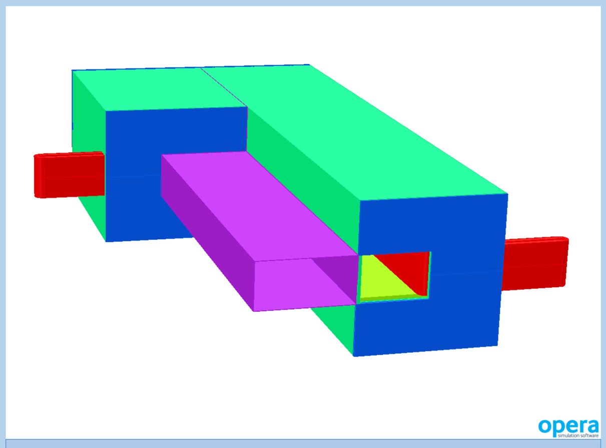
SMH42 ∫Bydl homogeneity plot, septum blade on the left. Resulting homogeneity in the GFR: ±1.18%.

Parameters of the present and the upgraded PS injection bumper BSW42		
Parameter	Present version	LIU version
Type of magnet	Outside vacuum	Under vacuum
Particle energy [GeV]	1.4	2.0
Physical length [m]	0.22	0.35
Magnetic length [m]	0.192	0.322
B_0 [T]	0.667	0.375
∫Bdl [T·m]	0.127	0.121
I [kA]	4.5	20.9
Deflection angle [mrad]	n.a.	13
Gap height [mm]	90	70
Gap width [mm]	n.a.	145
Septum thickness [mm]	>6	5
½ sine pulse width [ms]	1.6	1
Repetition rate [Hz]	0.8	0.8

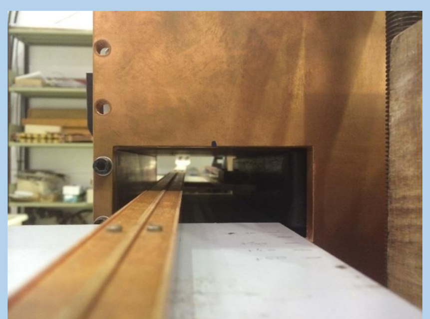


BSW42 ∫Bydl homogeneity plot, septum blade on the right. Resulting homogeneity in the GFR: ±0.78%.

The fringe field values are inherently high due to the technology used and the special construction of the bumper. According to preliminary Opera-2D® simulations, the best solution is to insert a Mumetal screen between the septum blades of the two devices and to install a shielding Mumetal box around the circulating beam, fitted downstream of BSW42, adjacent to SMH42.



Opera-3D® model about SMH42 (right) and BSW42 (left) with Mumetal box (purple).



Eddy current prototype during main field measurement.

Before building the full-sized eddy current septa magnets, a prototype was constructed. The goal was to demonstrate the working principle of the new technology and to measure different shielding options in practice. Improvements in precision on both simulation and measurement are being carried out.

Conclusion

As part of the LIU project, PSB extraction, recombination and PS injection upgrades are presented in this paper. The new design of SMH42 and BSW42 uses the novel eddy current technology in order to fit the existing vacuum chamber and to increase the magnet reliability. They will provide sufficient ∫Bdl for the required deflection at the increased beam energy, whilst remaining within the limits of acceptable homogeneity and fringe field values using the magnetic shielding and beam screen. The choice of eddy current magnets provides for a more robust system and should require less maintenance. The cross-talk between the eddy current devices and the post-pulse undershoot of the bumper is being investigated further.

References

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