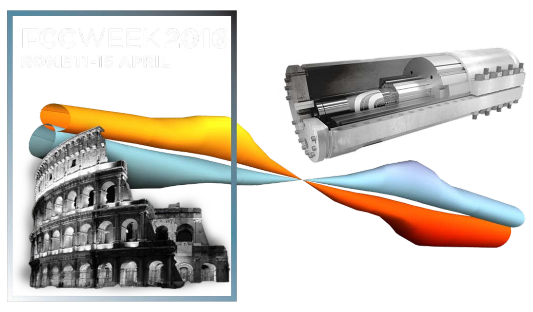
HIGH FIELD NORMAL CONDUCTING SEPTUM MAGNETS



M. G. Atanasov, W. Bartmann, J. Borburgh, A. Sanz Ull (CERN, Switzerland)

alejandro.sanz.ull@cern.ch

Abstract

For the FCC challenging requirements are set for the extraction septa magnets. A scaled up LHC-like beam dump system architecture poses many difficulties in terms of space reservation, power consumption and dissipation. To address these challenges whilst maintaining the reliability and availability of the insertion, the study will first explore steel dominated Lambertson type septum magnets with a minimum target field of 2 T. The study focuses on field quality, maximum obtainable field, the leak field limits and the effective shielding of the circulating beams. The use of high-saturation magnetic materials and the space reserved for the coil will also be taken into account in the context of the possible implementation of a cryostat for a superferric solution.

LHC-Like Lambertson septum

Current magnet system and 2 T upgrade

The current extraction system in the LHC is composed of three different models of Lambertson septa, MSDA, MSDB and MSDC [1]. The differences among them are the number of turns in the coils and the septum thicknesses. The main parameters and the scaling to 2 T are presented below. There is a MuMetal shield around the circulating beam hole.

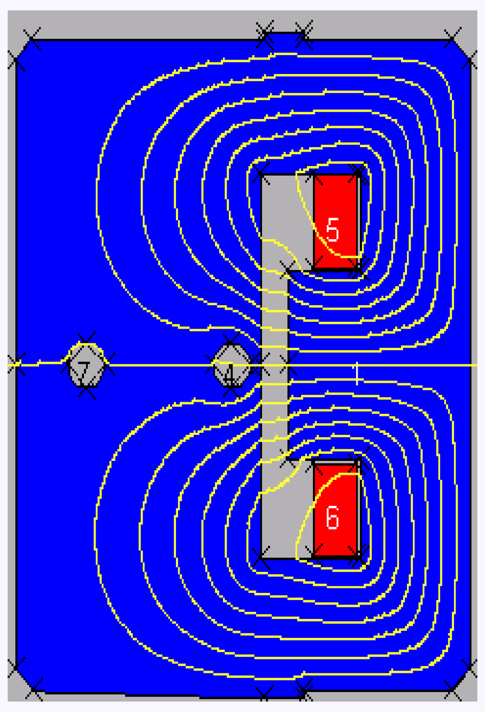
	MSDA	MSDB	MSDC
Length (m)	4.46	4.46	4.46
Number of turns	32	40	48
Diameter of hole (mm)	64	64	64
Diameter of shielding (mm)	50	50	50
Septum thickness (mm)	6	12	18

Summary of LHC Lambertson septa characteristics

2D		NO shield	WITH shield (14mm thick)
880A (LHC)	B_{leak} (T)	2.0E-04	2.0E-04
	Bgap (T)	1.16	1.16
5280A	B_{leak} (T)	1.7E-01	1.6E-01
	Bgap (T)	1.92	1.95
6160A	B_{leak} (T)	2.1E-01	2.1E-01
	Bgap (T)	1.99	2.02
7040A	B_{leak} (T)	2.4E-01	2.3E-01
	Bgap (T)	2.05	1.79
8800A	B_{leak} (T)	3.0E-01	2.9E-01
	Bgap (T)	2.17	1.88

Scaling of LHC Lambertson to 2T

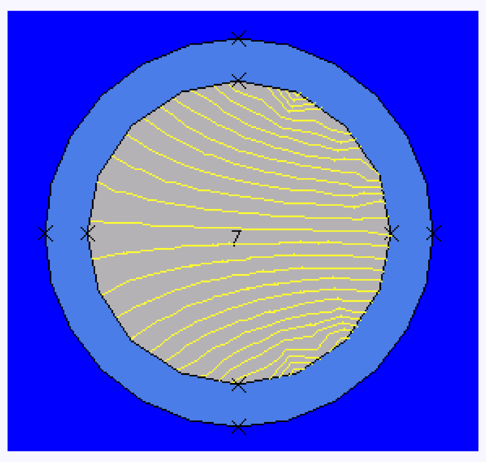
From the table it is obvious that it is necessary to add more iron to reduce the saturation. In that case it will be necessary to add also a hole for the second orbiting beam.



Proposal of a cross section with a hole for the second orbiting beam

As seen in the table, the septum produces a 1.16 T dipolar field in the deflected beam gap and the MuMetal shield successfully reduces the field in the circulating beam gap.

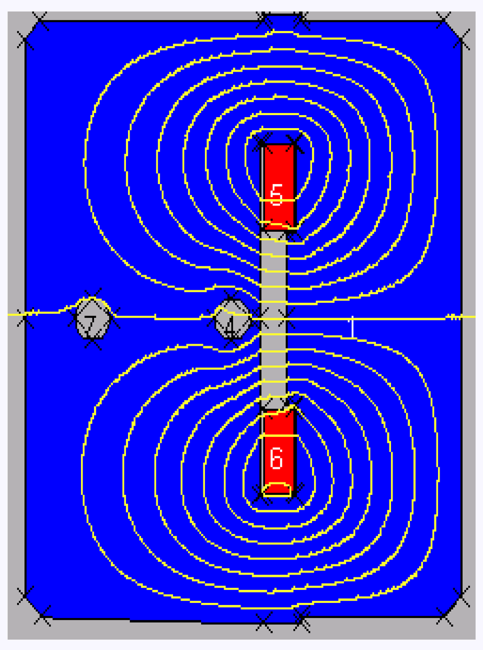
If the field in the gap is increased, the shield starts to saturate. The shielding effect is present until the MuMetal is fully saturated. When the field in the deflected beam gap is set to 2 T or above, the field in the circulating beam gap reaches 0.48 T, which is unacceptable.



Field lines in the circulating beam gap

Regardless of the leak field obtained in the simulations, the magnetic field homogeneity in the deflected beam gap at 2 T is similar to the homogeneity obtained at 1.16 T. The field homogeneity is within specification in all cases.

Adding more iron to the magnet decreases the saturation, and displacing the coils towards the gap helps reducing the flux density in the pole. However this implies that the yoke will be much bigger and it will be necessary to allow space for the second beam to circulate. It will also be necessary to change from a racetrack coil to a beadstead coil to allow the passage of the beam. At this stage the effects of the coil ends are not considered.



Proposal of a cross section with a hole for the second orbiting beam and coils closer to the gap

In this case, since the saturation in the pole tip is reduced, the current needed to produce the field is also lower, which will reduce the power consumption significantly.

However, it can be seen in the table that the leak field in the first hole is still unacceptable, even with a MuMetal shield around the hole like in the LHC design. On the second circulating beam hole the leak field is negligible and shielding is not necessary due to the low saturation of the iron in that area.

2D		NO shield	WITH shield (14mm thick)
880A (LHC)	B_{leak} (T)	7.0E-05	7.0E-05
	Bgap (T)	0.64	0.64
	$B2^{nd}$gap	1.2E-05	1.2E-05
1595A	B_{leak} (T)	2.8E-04	2.7E-04
	Bgap (T)	1.16	1.16
	$B2^{nd}$gap	1.8E-05	1.9E-05
1760A	B_{leak} (T)	1.0E-03	5.2E-04
	Bgap (T)	1.28	1.28
	$B2^{nd}$gap	2.0E-05	2.0E-05
2640A	B_{leak} (T)	1.0E-01	9.2E-02
	Bgap (T)	1.76	1.79
	$B2^{nd}$gap	3.1E-05	3.2E-05
3520A	B_{leak} (T)	2.9E-01	3.0E-01
	Bgap (T)	1.99	2.03
	$B2^{nd}$gap	4.4E-05	4.4E-05

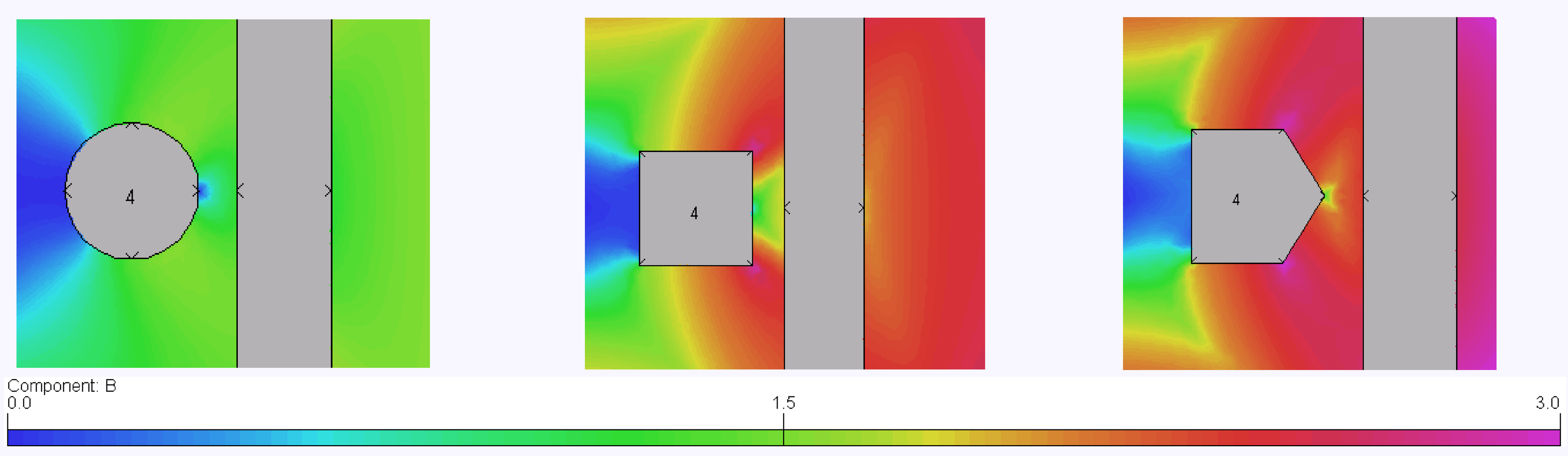
Scaling of the double aperture with closer coil design to 2T

Reducing the leak field by changing the shape of the orbiting beam aperture

An alternative to improve the design is to change the cross section of the circulating beam gap. The circular cross section is better for alignment and pole saturation, but it is worse for the leak field.

A number of alternatives to reduce the leak field while trying not to saturate the pole are explored. The square cross section is not optimal but is very helpful to observe the effects of adding and displacing compensation coils. However, the saturation in the tip increases with respect to the circular hole.

The wedge shape is much better for the leak field and the field quality since it naturally guides the field lines towards the pole. However, this cross section is much worse for alignment and saturation than the circular one.



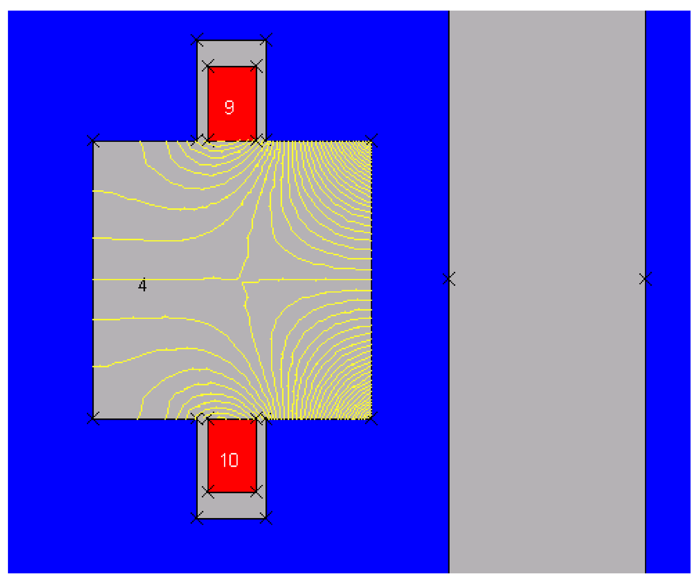
Different cross sections of the circulating beam gap and their influence in the pole saturation

Reducing the leak field by adding compensation coils

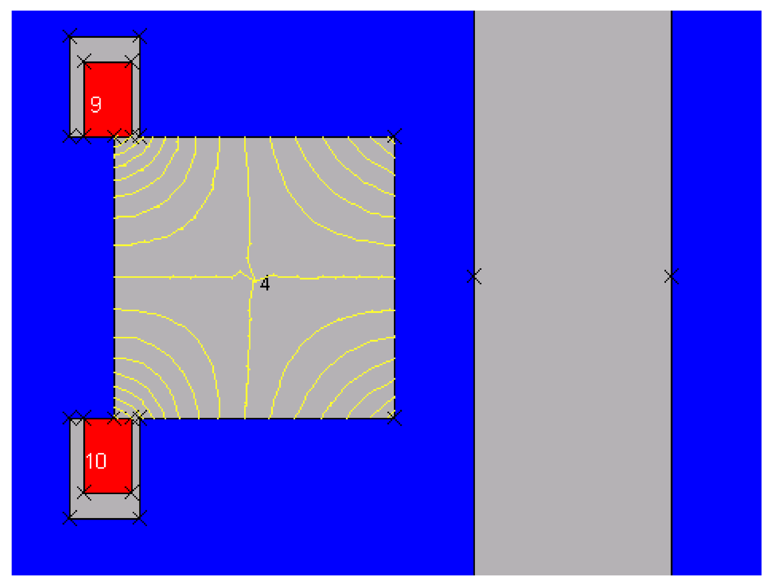
Adding one coil

Since shielding the leak field with MuMetal is not possible, another option is to try to cancel the leak field without disturbing the dipole field in the gap. For that purpose, a racetrack coil is installed close to the circulating beam gap with the aim to cancel the leak field. The reason for using a single bedstead coil is the simplicity of its design. At this stage is treated as a small coil with a high current density also for simplicity and the effects of the coil ends are not considered. The current in the compensation coil is chosen as 6% of the current in the main coil. This value will play an important role on the optimization of the design but is a good starting point.

If the compensation coil is not placed in the symmetry axis of the gap the compensation is more efficient. The cross section of the gap has been changed from a circle to a square to improve the compensation.



Leak field lines in the circulating beam gap with compensation coil in the centre



Leak field lines in the circulating beam gap with compensation coil shifted

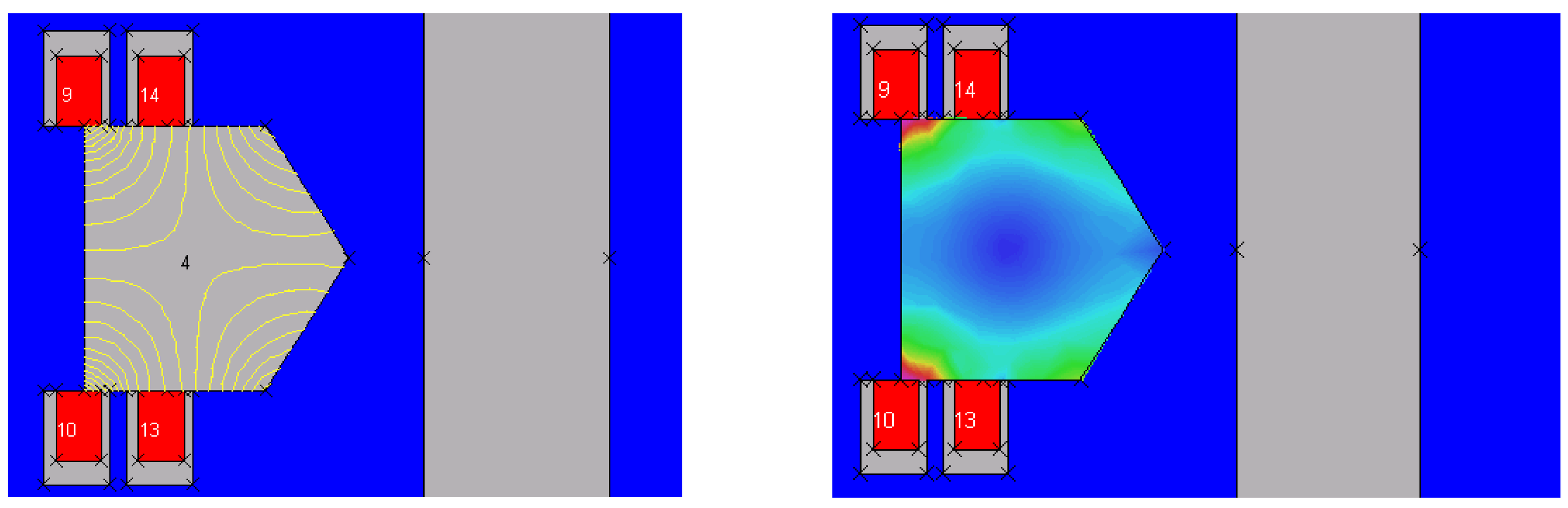
Surprisingly the resulting field in the shifted configuration is a quadrupole field produced by a single coil. While the leak field in the centre of the circulating beam hole is zero, the gradient of the field is 43T/m, and this field also reduces the main field in the deflected beam gap by 0.3 T.

Apart from the undesired quadrupole field, the septum magnet will need to operate at different beam energy levels, which would be difficult (if possible) with just one compensation coil. The logical step now is to add a second compensation coil.

Adding two coils

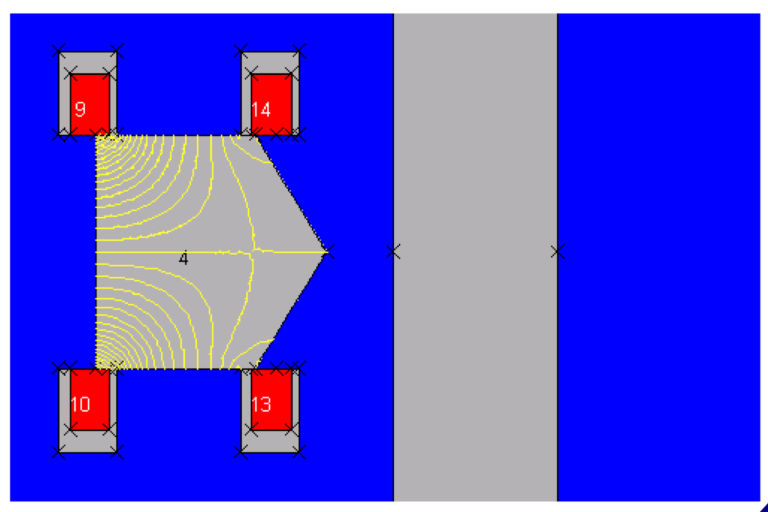
In order to compensate the quadrupole field in the circulating beam gap, a second compensation coil is added. Again, the most obvious choice is to add a racetrack coil with opposite current, following the same idea to cancel the resulting field. At this stage, the best option seems to be to place the second coil close to the first one, with a current of 75% of the first compensation coil, to take into account the different position of the second coil. Again, this value can be optimized but it's a good starting point.

Unfortunately, with the second coil is still not possible to cancel the quadrupole field completely, but it improves the one coil design. The field in the extracted beam gap is increased to 2.3 T but the field in the circulating beam gap is still far from zero. The maximum field gradient is 42 T/m approximately.



Field lines and field map in the circulating beam gap with two compensation coils.

Moving the second compensation coil to the right doesn't have much effect on the field in both gaps. The quadrupole field is still present in the circulating beam gap but since the point where the magnetic field is zero moves to the right, the maximum gradient now is 35 T/m. As seen in the figure, the main effect of moving the second compensation coil is moving the magnetic centre of the field.



Field lines in the circulating field gap when the coils are moved to the right.

Conclusions

A 2 T version of the current LHC Lambertson septa is produced. Achieving the required field in the gap is feasible but the main problem is the leak field in the circulating beam gaps. The use of a shield, different cross sections and the addition of compensation coils are studied. Another issue is the high power consumption of such a magnet. Future studies involve a superferric version of the magnet to save energy and the use of a superconducting magnetic shield [2]. Another line of work is to optimize the compensation coils, in number, position and current. The coils will have to be calibrated for every field level.

References:

[1] Expected magnetic field quality of the LHC septum magnets used for injection (MSI) and extraction to the beam dump (MSD). LHC project note 129

[2] Septum concepts, technologies and prototyping for FCC-hh injection and extraction. Daniel Barna. https://indico.cern.ch/event/438866/session/20/contribution/30