Quadrupole Design for the 2 GeV Upgrade of the CERN PS-Booster

Jonathan Speed— CERN, Geneva, Switzerland

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LHC Injectors Upgrade

Abstract

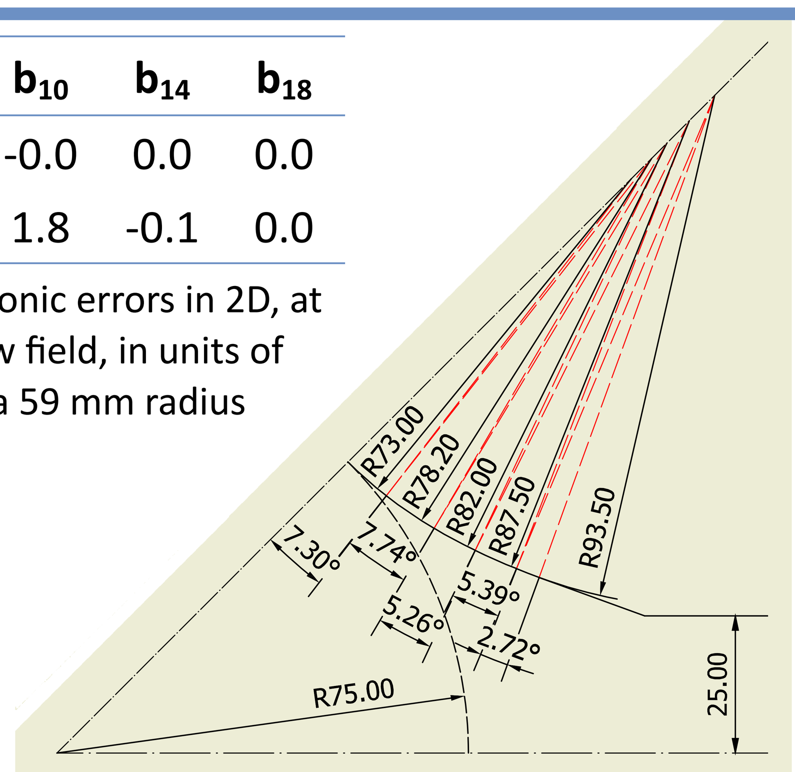
The CERN LHC Injectors Upgrade (LIU) seeks to reliably deliver the beams required for the High- Luminosity LHC (HL-LHC). As part of this, the Proton Synchrotron Booster (PSB) will be upgraded from 1.4 GeV to 2 GeV and will accelerate higher intensity beams. Along the transfer lines between the PSB and the Proton Synchrotron (PS) there are several D.C. operated quadrupoles which are unable to produce the gradients for the 2 GeV HL-LHC beams. To minimise future power consumption, these will be replaced by laminated quadrupoles, operated in pulse to pulse modulation mode. Despite being installed along a transfer line, the field homogeneity requirements imposed on these magnets is very tight, requiring a homogeneity of $5\text{x}10^{-4}$ on the integrated gradient. Such strict requirements presented several issues for the design, especially when considering the space constraints which naturally apply when upgrading a pre-existing accelerator. The design process of these quadrupoles is summarised here.

Pole Profile

* Complex pole profile
* 5 circular arcs + tangent
* Large taper angle to limit saturation
* Since the homogeneity requirement lies on the gradient, higher order harmonics are of great importance.
* To limit the $\int b_{10}$ and $\int b_{14}$ harmonic errors that appeared in 3D, small, opposite, b_{10} and b_{14} errors were introduced in the 2D profile.

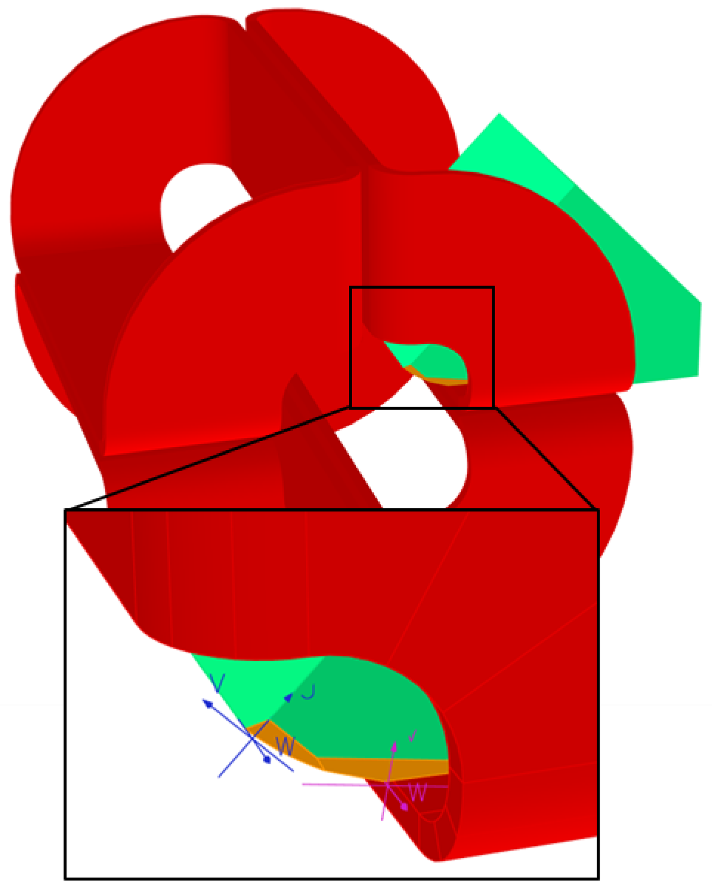
	b_6	b_{10}	b_{14}	b_{18}
Min	0.2	-0.0	0.0	0.0
Max	5.8	1.8	-0.1	0.0

Relative harmonic errors in 2D, at high and low field, in units of $\text{x}10^{-4}$, at a 59 mm radius



Pole profile measurement

Consistent Homogeneity

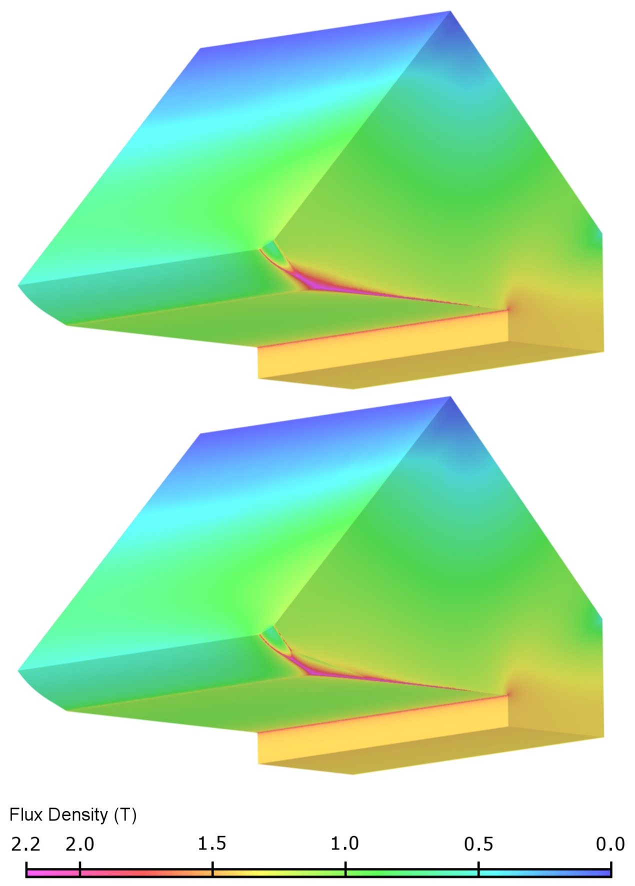


Opera 3D model showing 45° and 20° pole end chamfers

In order to remain within the tight $<5\text{x}10^{-4}$ homogeneity requirement across the full operating range, end chamfers were required to limit the saturation. The single 45° chamfer, used primarily to correct the $\int b_6$ harmonic error, was found to be insufficient for this task, so two additional 20° chamfers were added to each pole end.

	$\int b_6$	$\int b_{10}$	$\int b_{14}$	$\int b_{18}$
Min	0.2	-0.0	0.0	0.0
Max	-0.2	0.0	0.1	0.0

Variation in relative integrated harmonics at high and low field, in units of $\text{x}10^{-4}$, at a radius of 59 mm



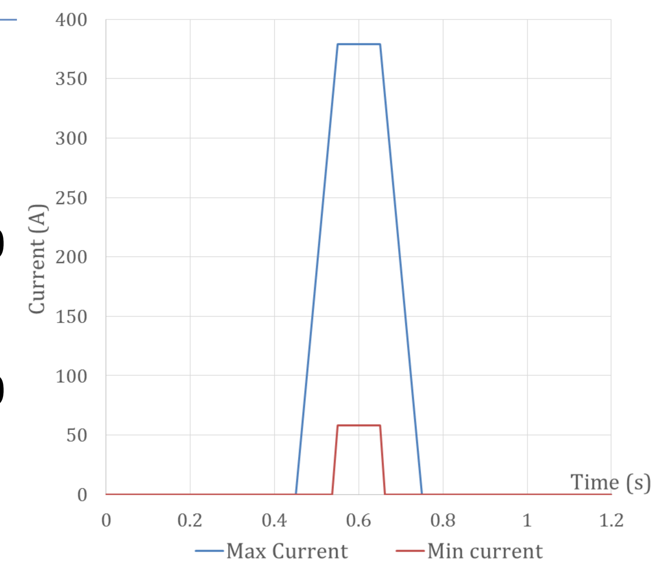
Variation in saturation at high field with one (top) or two (bottom) end chamfers

Design Overview

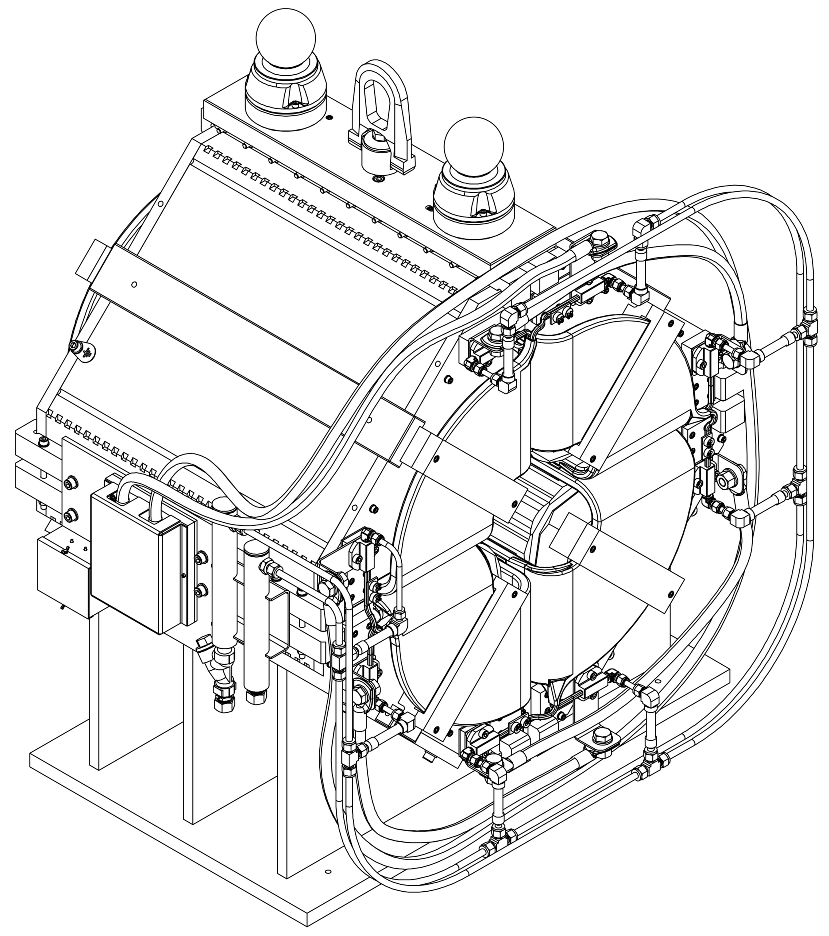
* 610 mm long, laminated yoke
* Non-magnetic steel end plates and tie bars
* Two layered, water cooled, tapered racetrack coils
* Cycled-D.C. powering

Power Supply Constraints	
Max Peak Current (A)	450
Max RMS Current (A)	200
Max Voltage (V)	450

Magnetic Field		Dimensions	
Min $\int$Grad (T)	0.9	Total Length (mm)	810
Max $\int$Grad (T)	5.8	Total Width (mm)	1050
$\int$Grad Homogeneity	$<5\text{x}10^{-4}$	Total Height (mm)	1070
Max Good Field Region Radius (mm)	59	Aperture Radius (mm)	75



Idealised current profile



Manufacture

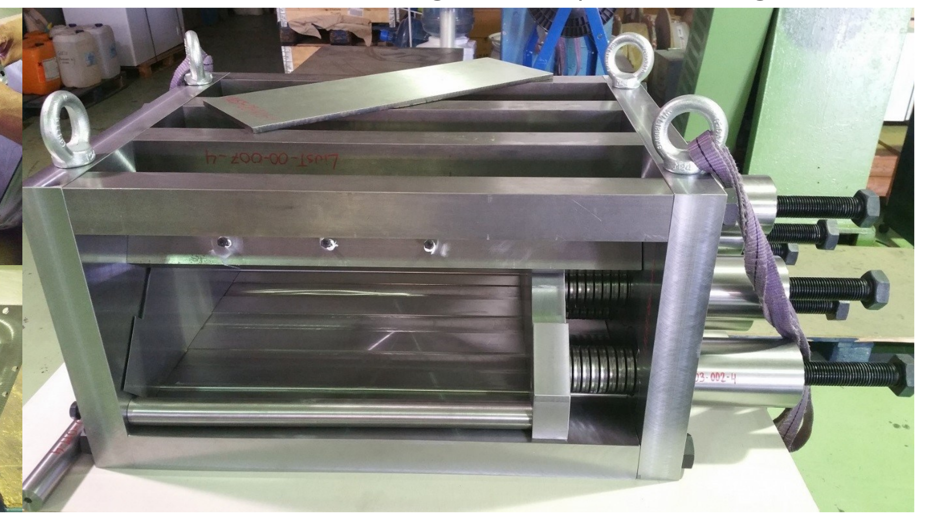
The manufacture of the magnets is currently being undertaken by Antec Magnets S.L.U. in Spain. Each coil is produced from a single piece of hollow copper conductor, insulated and impregnated in resin. The yoke is made from four quadrants of stacked laminations, glued, cured and welded together.

Images courtesy of Antec Magnets S.L.U.

Coil winding setup

Coil awaiting impregnation

Coil impregnation mould



Yoke quadrant stacking tool

Conclusion

The design process of a quadrupole magnet series for the upgrade of the CERN PSB has been presented. The size and variation of the harmonic errors has been limited through the use of a complex pole profile and additional pole end chamfers. Simulations show that such a design meets the strict field quality requirements across the full operating range, whilst allowing operation with the desired power converter. These magnets will also be capable of operation in cycled DC, PPM mode.

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