Mechanical Design and Vacuum Pressure Impregnation of Combined Function Electromagnets

FERMILAB-POSTER-25-0059-TD

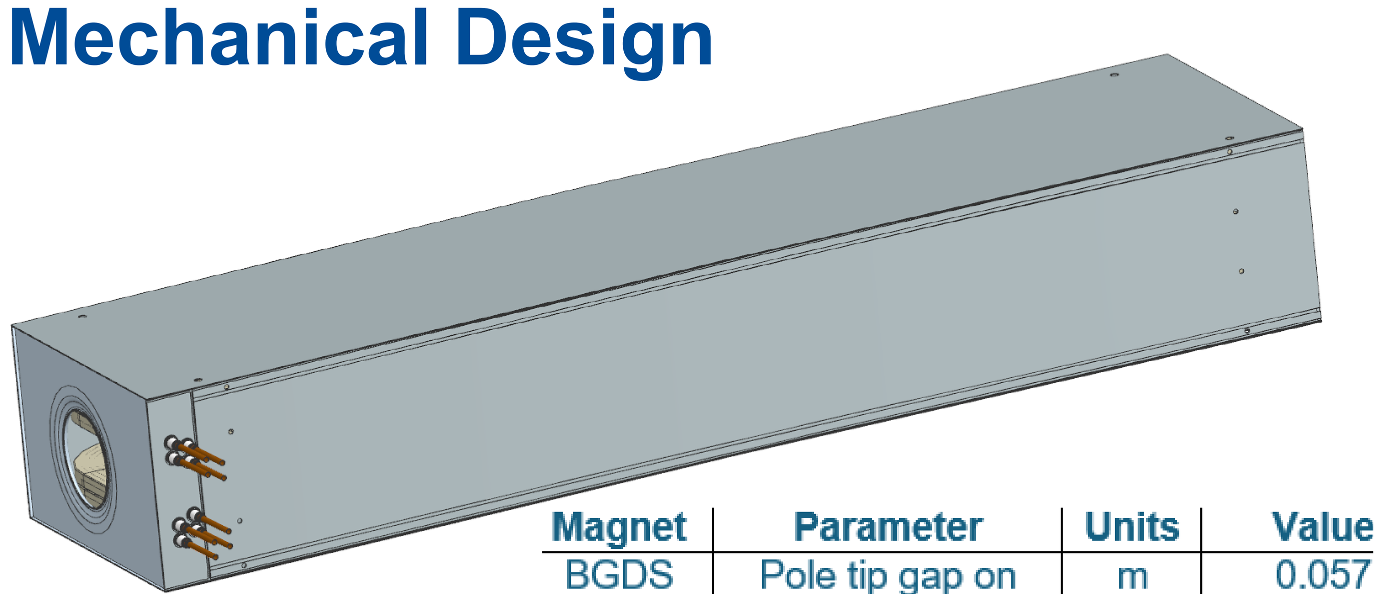
B. Szabo, S. Krave, D. Johnson, V. Kashikhin, B. Trevino, S. Chaurize, J. Williams, Z. Chen, C. Jensen, W. Robotham, K. Badgley, D. Harding, T. Strauss

Thu-Af-Po.01-04

Introduction

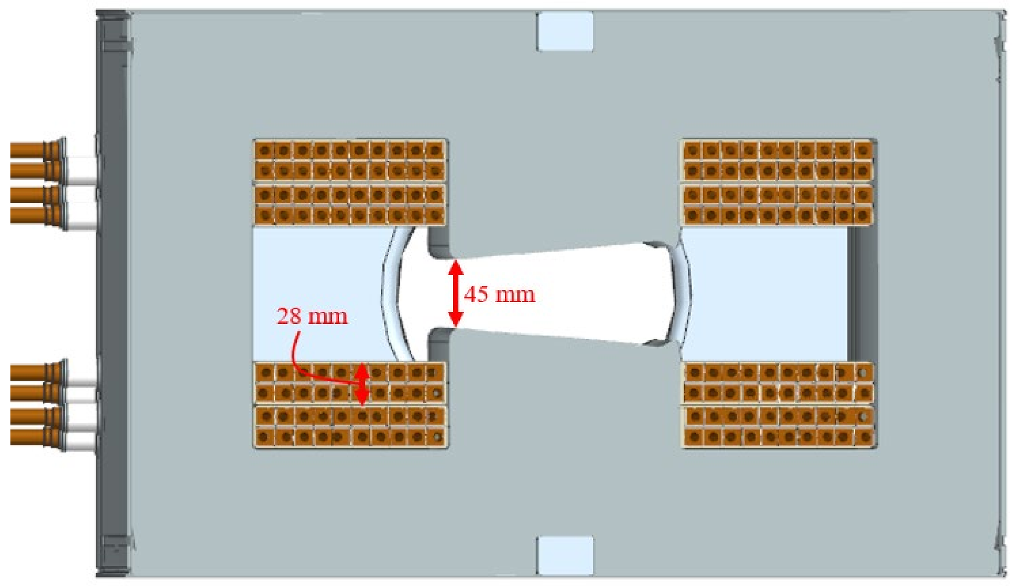
There are 96 combined function magnets, 48 focusing and 48 defocusing, that have been in operation in the Fermi NAL Booster without a critical failure requiring replacement for over 50 years. The Proton Improvement Plan-II (PIP-II) poses risk to these magnets and Fermilab does not currently have the tooling or knowledge of process to fabricate spares. Two new variants of these magnets are needed to reduce beam loss by having a larger aperture (Booster Gradient Defocusing Wide, or BGDS) and create space for a new injection system (Booster Gradient Defocusing Short, or BGDS). Risk of failure and need for spares will increase substantially with the implementation of PIP-II in consequence of a frequency increase from 15 Hz to 20 Hz and a 30 percent increase in peak to ground voltage. The BGDS and BGDW magnets will be fabricated in the same way as the current booster magnets so that future combined function magnet spares can be produced using learned processes.

Mechanical Design



Combined Function Magnet 3D Model

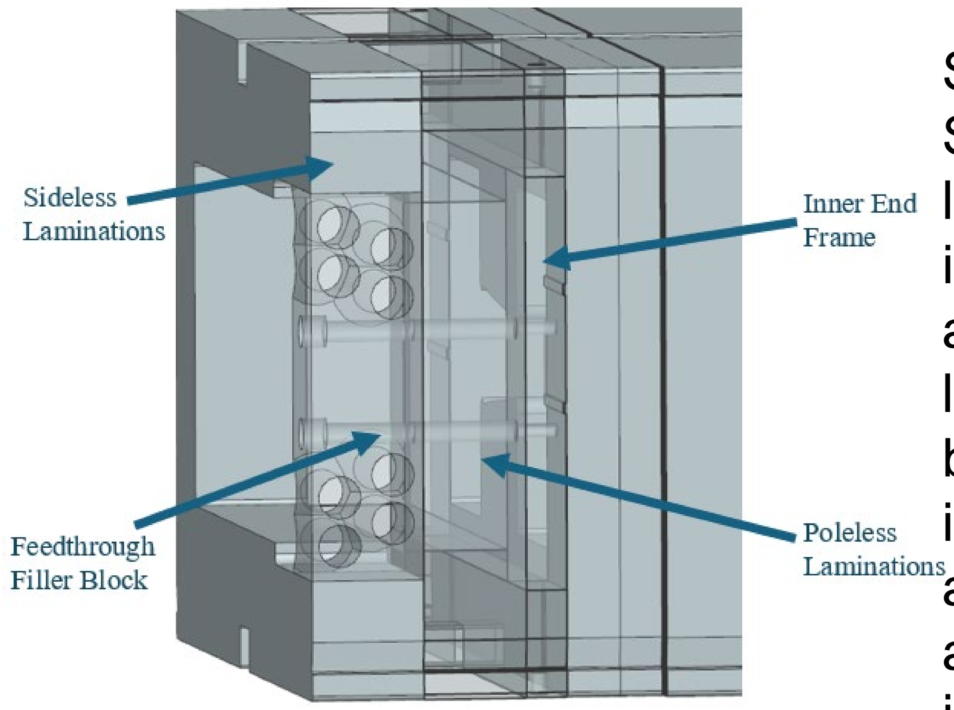
Magnet	Parameter	Units	Value
BGDS	Pole tip gap on the magnetic centerline	m	0.057
BGDS	Maximum Flange to Flange Length	m	2.42
BGDW	Pole tip gap on the magnetic centerline	m	0.067
BGDW	Maximum Flange to Flange Length	m	3.21
BGDS & BGDW	Maximum Width	m	0.635
BGDS & BGDW	Maximum Height	m	0.381
BGDS & BGDW	Bending Radius	m	33.69



Cross Section of Combined Function Magnet

0.46” square conductor coils are split into two-layer pancakes to fit through the aperture, but magnetic modeling is ongoing to have ½” x 1” coils. This would reduce exterior manifolding complexity and number of feedthroughs. Current would double through the conductor while number of turns being halved, keeping the power consistent

The laminations are full H-shaped and not split to improve field quality and reduce size. Keys at top and bottom of the core ground the laminations. There is a stainless-steel skin all around the magnet that serves as a vacuum impregnation container and adds structural rigidity to the magnet. Since these magnets do not have vacuum tubes, the skin also acts as a reliable vacuum seal which can provide protection in the case that there is a crack in the insulation.



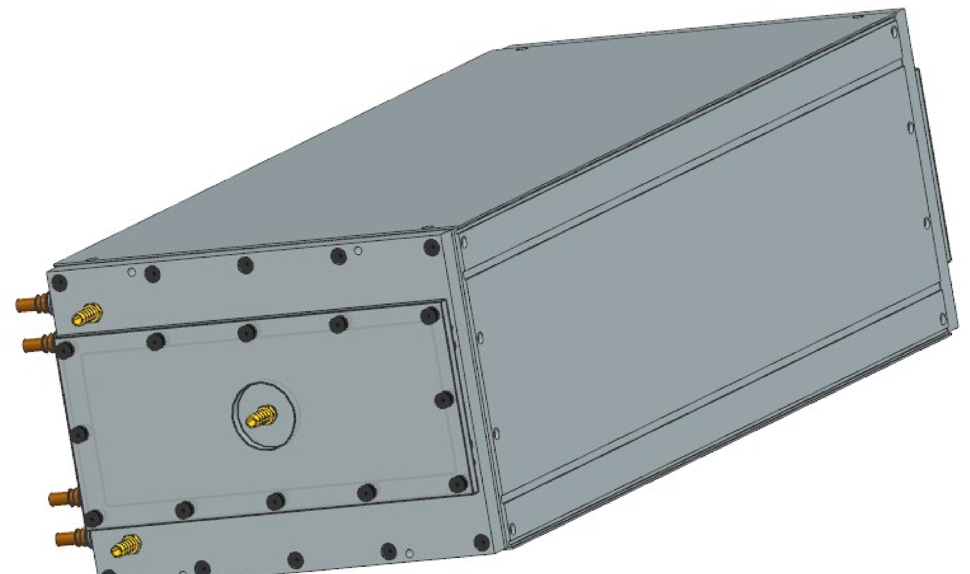
Coil Installation Design

Since the core is not splitable, Sideless laminations are stacked at lead end of the core and coils are installed before a filler block is added. Holes in poleless laminations allow filler block to be bolted to inner end frame after coil installation. Skins are then welded along with ceramic feedthroughs, and the magnet is ready for impregnation.

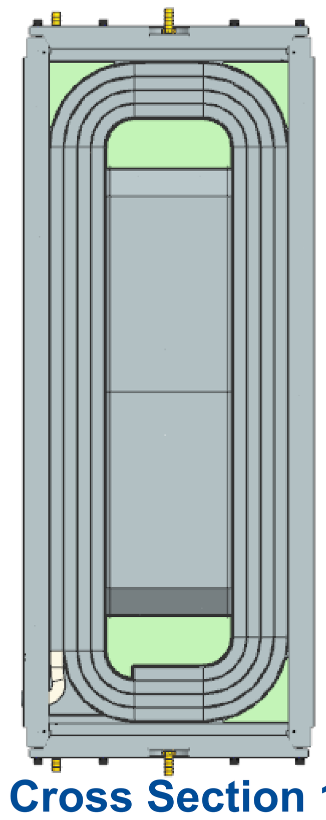
Vacuum Pressure Impregnation

The magnet core and coils are impregnated simultaneously with the outer skin acting as the impregnation vessel. This forms a monolithic void free structure that reduces tooling costs, increases rigidity and radiation resistance, and reduces epoxy surface area to increases vacuum quality.

A three-foot model is ongoing at Fermilab to test the impregnation technique using aluminum core and coils.

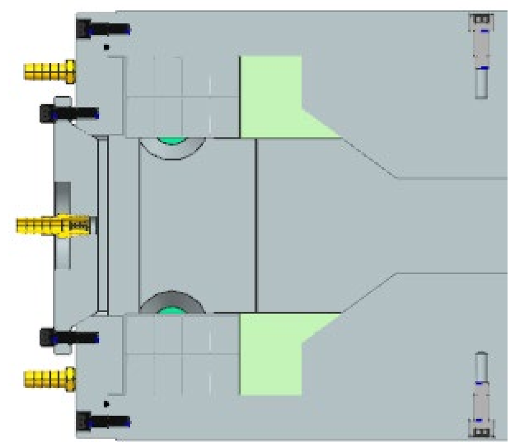


Impregnation Prototype



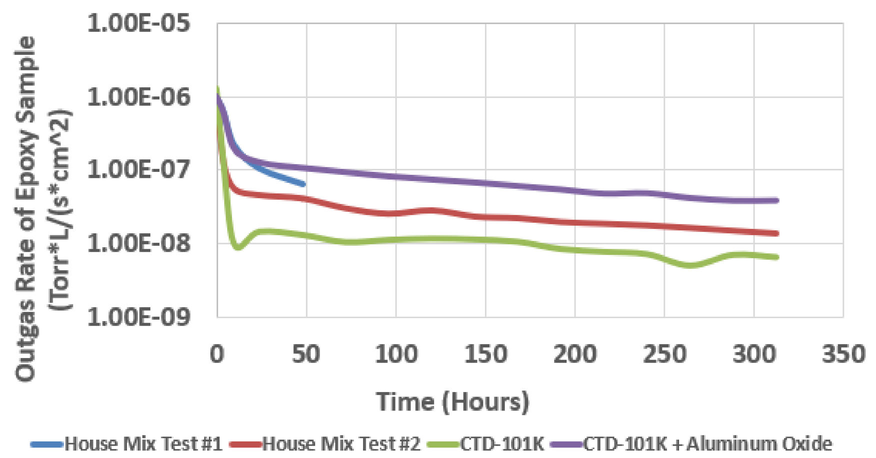
Cross Section 1

The three-foot prototype will test the insulation package and dielectric strength, vacuum properties, silicone bag aperture creation process, and epoxy resin impregnation



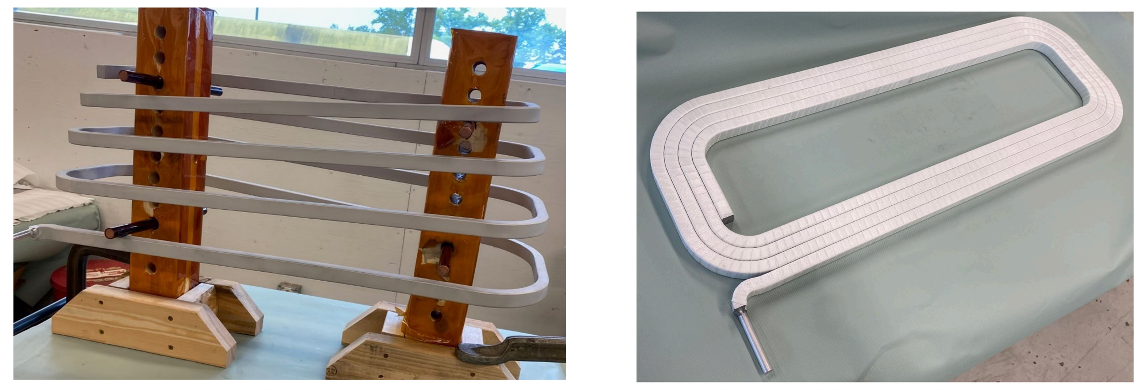
Cross Section 2

A bag sealing plate will compress the bag to a manifold plate to create an air-tight seal. Manifold plates will allow for epoxy to be introduced to the prototype through NPT threaded holes outside of the silicone bag



Epoxy Outgassing Results

Epoxy Resin samples were baked for two weeks to remove moisture. They were then tested against a baseline reading for 336 hours to obtain the outgassing rate. CTD-101K preformed the best at $6.49 * 10^{-9} \frac{Torr*l}{s*cm^2}$



Aluminum Coil Insulation Wrapping

Prototype coils were water jet to save cost on winding tooling while being able to test insulation package of fiberglass cloth

Silicone Bag and Sealing Plate

Silicone Bag can expand up to 500% its circumference during impregnation process. Bags will be filled with Nitrogen to 3 psi above atmosphere to ensure pressure is greater than that of epoxy and does not collapse

This manuscript has been authored by FermiForward Discovery Group, LLC under Contract No. 89243024CSC000002 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.