ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-THP093

UPDATE ON SEPTUM MAGNET REDESIGN AT LANSCE PROTON STORAGE RING*

H. Xu†, C. Buechler, A. Garcia, E.-H., Huang, G. Johnson, J. W. Lewellen, C. Taylor
Los Alamos National Laboratory, Los Alamos, NM, USA

Abstract

We report the progress of redesigning the septum magnet at the LANSCE Proton Storage Ring (PSR). The septum magnet at the PSR is used for extracting the accumulated 800-MeV proton beams for transport to the target stations. The existing septum magnet uses parallel, planar coils creating a uniform deflecting magnetic field. However, one coil plate co-locates with the septum; the placement results in the coil, witnessing intense radiation dose rates, receiving accumulated damage to the epoxy potting during the PSR operation. The redesigned septum magnet uses a low carbon steel septum, and the coils are positioned farther away from the beam pipes. This placement is expected to reduce the radiation dose rate on the coil pack, and, combined with adoption of a more radiation-resistant potting epoxy, increases the operating lifetimes. The magnet pole tips are refined with shim features to provide a sufficiently wide flat-field region. The mechanical engineering of the yoke components and the supporting structures is underway. Particle tracking simulations of the proton beam deflection in the septum magnet were performed, and the comparison of performance between the existing and the redesigned septum magnets is reported.

INTRODUCTION

At Los Alamos National Laboratory (LANL), the Los Alamos Neutron Science Center (LANSCE) Proton Storage Ring (PSR) accumulates 800-MeV proton bunches to increase the peak current delivered to the experimental target stations. To extract the accumulated proton beam, a set of electrostatic kickers generate a horizontal offset, and then the septum magnet deflects the beam into the extraction beamline.

The septum magnet is also referred to as the RODM01 septum magnet, where RODM represents "Ring Outlet Dipole Magnet." A photo of the RODM01 magnet is shown in Fig. 1 [1]. The beam pipes of the circulating proton beam and of the deflected beam are separated by a 7-mm septum. In Fig. 1, the rectangular beam pipe is for the deflected beam, sandwiched between two planar coils that provide a 0.6-T uniform vertical magnetic field; the beam pipe with a greater vertical dimension is for the circulating beam.

The PSR beam extraction process imposes two major requirements on the septum magnet. First, the deflected beam must witness a uniform magnetic field. Second, the circulating beam, when traveling through the RODM01 magnet, must witness minimal magnetic field. Therefore, the coil geometry shown in Fig. 2 was adopted. The advantages of this coil geometry are that the deflecting magnetic field is very uniform, and that the magnetic field division is very sharp, leading to minimal field leakage into the region of the circulating beam. Meanwhile, there are two major disadvantages. First, the coils are directly adjacent to the beam pipes, where the beam loss, and thus radiation dose rates are at local maxima; second, the coil on one side has to co-locate within the septum, causing the current density to be very high (over 90 A/mm^2). A photo of the coil pair of the RODM01 magnet is provided in Fig. 3.

At LANSCE PSR, the RODM01 coils must be replaced every five to seven years. The damages have been observed on the epoxy potting of the coils, in the form of cracking

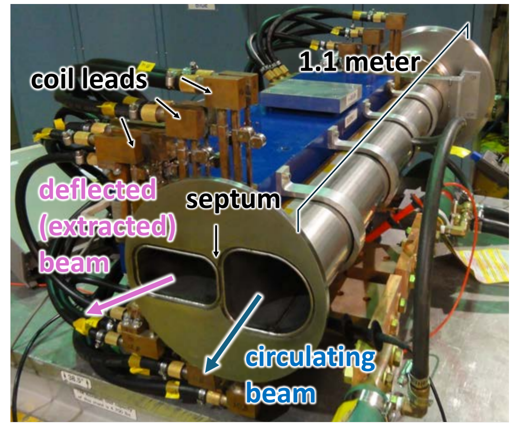

Figure 1: The RODM01 septum magnet used at LANSCE PSR, under magnetic field mapping.

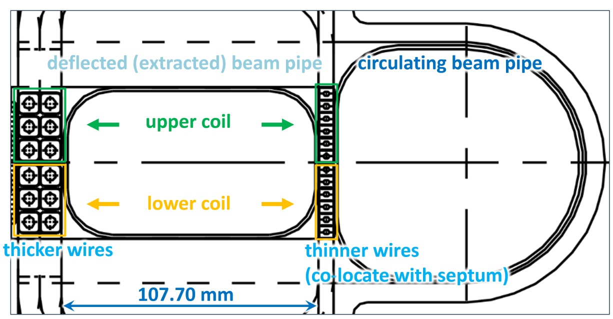

Figure 2: RODM01 coil geometry. Two parallel, planar coils build up a uniform, vertical magnetic field in the beam pipe region for the deflected beam. The upper and the lower sections of the coils on both sides are assembled separately, forming a coil pair.

* This work benefited from the use of the LANSCE accelerator facility. Work was performed under the auspices of the US Department of Energy by Triad National Security under contract 89233218CNA000001.
† haoranxu@lanl.gov

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-THP093

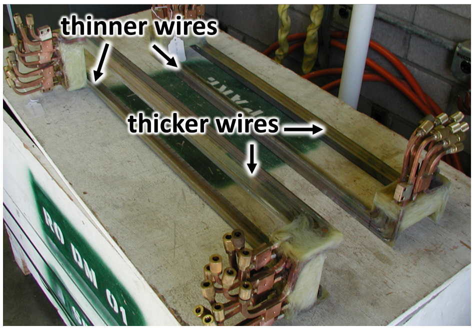

Figure 3: RODM01 magnet coil pair, where conductors are assembled using epoxy potting. When assembled to form two parallel sets of conductors, a uniform deflecting magnetic field can be established.

and progressive pulverization as well as marks of shorting arcs. The direct cause of shorting arcs is under investigation. However, when the epoxy potting is damaged, the shielding it provides against the contaminants and moisture in the environment is compromised, as well as allowing relative motion between coil turns. Over months and years of operation, electrically conductive paths can be established, ultimately leading to short circuits. The RODM01 magnet redesign preliminary study was initiated within the LANSCE Accelerator Modernization Project (LAMP) [2], now under evaluation for inclusion in future LANSCE upgrade projects.

PRELIMINARY REDESIGN

The preliminary redesign of RODM01 aimed at two major improvements. First, the coils must be moved away from the beam pipe locations, where the radiation dose rate is high. Second, the coil transverse cross section area must be significantly increased to reduce the current density in order to enhance the longevity of the coils. One RODM01 upgrade geometry studied is shown in Fig. 4, where we referred to the septum magnet design by Yamaguchi *et al*. [3]

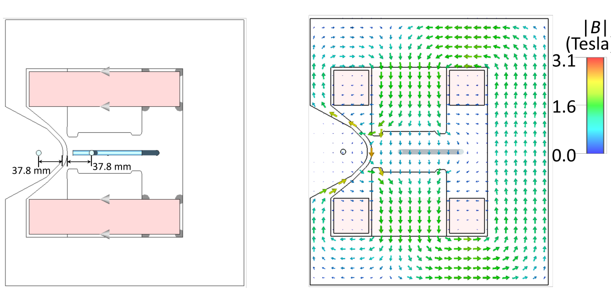

Figure 4: Preliminary redesign geometry of the RODM01 magnet. The septum is made of low carbon steel, conducting the magnetic field lines through it, allowing minimized magnetic field leakage into the region of the beam pipe for the circulating proton beam. The blue models are the specially defined vacuum volumes for mesh refinement.

This redesign geometry involves a trade-off between magnetic field uniformity and improvements to the coil operation environment, including lower radiation dose rates and greater allowed transverse cross section area of the coils. The coils are moved away from the beam pipes, so radiation damage rates should be reduced. At this new location, there is more space for accommodating larger conductor cross sections. The septum takes the form of a low-carbon steel (1006 steel) layer, shielding the magnetic field for the beam pipe region of the circulating beam. The edges of the poles of the magnet are designed with shims, optimized in the CST [4] Magnetostatic solver. The shims effectively helped maintain a more uniform magnetic field distribution along the horizontal direction between the poles of the RODM01 redesign. As an example, a comparison of the vertical, deflecting magnetic field distributions along the horizontal direction is provided in Fig. 5, at the center of the magnet.

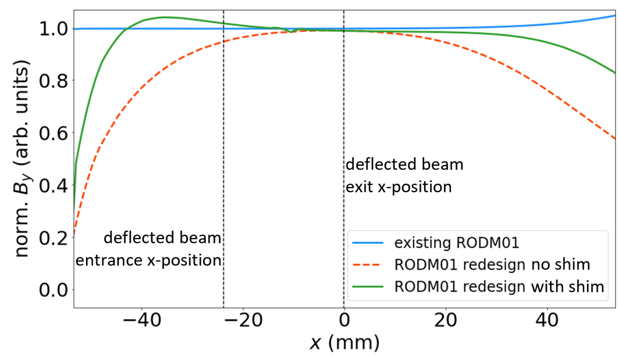

Figure 5: Deflecting magnetic field distributions plotted on the transverse plane at the center of the RODM01 septum magnet, versus the horizontal position. The shims of the RODM01 redesign model allowed the uniformity to match that of the existing RODM01 design for a central region with a width of about 60 mm.

Unlike the existing RODM01 septum magnet in operation at PSR, the preliminary redesign of the RODM01 magnet cannot entirely eliminate the residual magnetic field leak outside the septum, penetrating into the region of the circulating beam. Further work needs to be performed to mitigate the field leak and evaluate its impact on beam dynamics.

BEAM DEFLECTION SIMULATION

The CST Particle Tracking solver was used to simulate the deflection of the extracted beam after 1745 revolutions in the PSR. The beam deflection performance of the existing RODM01 in operation at PSR and the redesigned RODM01 magnet were simulated. The setup and an example of the result are presented in Fig. 6. The total deflection by both designs was 5.6 degrees. In the simulations, a 2D beam monitor was setup to be perpendicular to the weighted beam propagation direction for calculating beam emittances.

The horizontal phase spaces of the beam at the exit of the operating RODM01 at PSR and of the redesign are compared in Fig. 7, where x denotes the horizontal direction.

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-THP093

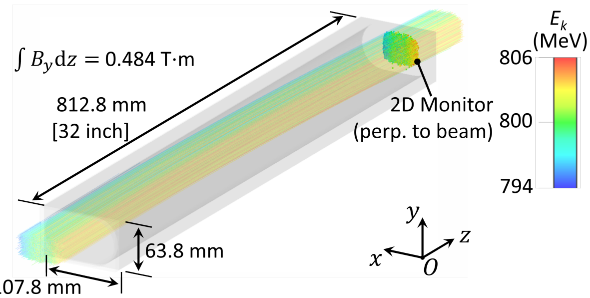

Figure 6: Beam deflection trajectory in the existing RODM01 magnet in operation at PSR. The septum is at the farther end in the $+x$-direction. The beam enters the simulation space from the lower-z side.

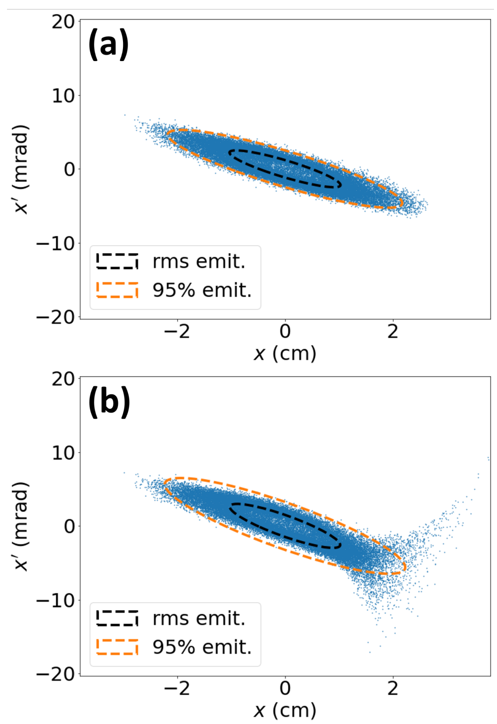

Figure 7: Comparison of the horizontal beam phase space at the exit of the RODM01 magnet, for the (a) operating design at PSR and (b) for the redesign. The ellipses denote the rms and the 95% emittances, respectively.

The beam enters the magnet at a horizontal position that is close to the septum. Therefore, for the preliminary redesign of the RODM01 magnet, the $+x$ side (see Fig. 6) of the beam witnesses the non-uniform region of the magnetic field distribution, resulting in the horizontal phase space shown in Fig. 7b. In comparison, due to the more uniform distribution of the deflecting magnetic field in the existing RODM01 in operation at PSR, the beam phase space at the exit of the magnet shows minimal perturbation. At the exit of the magnet, Fig. 7a shows a horizontal normalized rms beam emittance of 1.89 π cm mrad for the existing RODM01 at PSR, and Fig. 7b 2.21 π cm mrad for the RODM01 preliminary redesign.

INORGANIC COIL ASSEMBLY

An alternative redesign path is also under evaluation. This alternative approach uses the geometry of the existing RODM01 septum magnet at PSR, but the coil assemblies will be built using an entirely inorganic method. Inorganic insulation, such as mica-tapes and ceramics, can enhance the lifetime of the coils in a radiation-intense environment by at least one order of magnitude [5].

For designing an inorganic coil assembly, the greatest challenge is to design the shielding of the coils against the contaminants, dust, and moisture in the environment. Inorganic insulation itself cannot entirely encapsulate the conductors like the epoxy impregnation does. We are investigating solutions to establishing an effective shielding for an inorganic coil assembly design for the RODM01 septum magnet.

CONCLUSIONS

The RODM01 septum magnet redesign is under development at Los Alamos Neutron Science Center for the Proton Storage Ring. The purpose of the investigation is enhancing the longevity of the coils of the RODM01 magnet, delaying the progress of damage caused by radiation.

The preliminary work investigated a redesign geometry using a low carbon steel septum, which allowed the coils to be moved away from the vicinity of the beam pipes, so that the radiation dose rate and the current density in the coil can be reduced. In the meantime, magnetic field leakage into the circulating beam region was identified, and the non-uniformity of the deflecting magnetic field distribution caused the beam emittance to increase.

Inorganic methods of assembling the RODM01 coil conductors are under investigation for enhancing the longevity of the coils, with the focus on designing the shielding against the contaminants and moisture in the environment for the conductors.

REFERENCES

[1] Y. K. Batygin, "Tests and field mapping of RODM01 septum magnet," Los Alamos National Laboratory, Los Alamos, USA, Rep. LA-UR-20-21936, Feb. 2020. doi:10.2172/1602723

[2] K. Bishofberger *et al.*, "An overview of the LAMP front-end upgrade at LANSCE," in *Proc. IPAC'24*, Nashville, USA, May 2024, pp. 1677–1679. doi:10.18429/JACoW-IPAC2024-TUPS18

[3] H. Yamaguchi *et al.*, "Design and demonstration of low current density dc septum magnet," *Phys. Rev. Accel. Beams*, vol. 26, no. 9, pp. 092401, 2023. doi:10.1103/PhysRevAccelBeams.26.092401

[4] CST Simulation Suite, https://www.3ds.com/products/simulia/cst-studio-suite

[5] P. Beynel, H. Schönbacher, and P. Maier, "Compilation of radiation damage test data," CERN, Geneva, Switzerland, Rep. HS-RP-093, Nov. 1982. doi:10.5170/CERN-1998-001