VERTICAL SEPTUM MAGNET DESIGN FOR THE APS UPGRADE*

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Abstract

The vertical injection scheme proposed for the APS Upgrade (APS-U) Project requires a challenging septum magnet which must meet stringent beam physics, magnetic field leakage, and vacuum requirements.

The current iteration of this magnet design includes an enlarged stored-beam chamber aperture of 9 mm x 12 mm and a reduction of the septum thickness to 1.5 mm. The enlarged aperture accommodates a non-evaporable getter (NEG)-coated stored beam chamber to better achieve the required vacuum.

A prototype septum magnet has been built and measurements confirm the cancellation of a peak leakage field even though the value is six times larger than the design. The leakage field measured at the upstream (US) end cancels the downstream (DS) end as was expected by design.

The measured and simulated leakage field and the stored beam trajectories are reported.

INTRODUCTION

The APS-U Project included the investigation of two on-axis injection schemes, one of which uses a vertical septum magnet [1, 2]. Requirements include a minimum super-ellipsoidal aperture of 8 mm x 6 mm (H x V) for the stored-beam chamber to maintain sufficient acceptance, and a main field of 1.01 T to deflect the injected beam by an angle of 84.55 mrad in the horizontal plane. To minimize the integrated leakage field to meet the required <100 µrad deflection of 6-GeV stored electron beam, we have developed a design for the septum magnet which cancels the excessive leakage field at the DS end [3-5].

The required vacuum level inside the stored beam chamber over a length of 1.78 m is 10^{-8} torr, which is impossible to achieve without a NEG coating and cooling of the beam tube. For these reasons, we have enlarged the aperture to 9 mm x 12 mm by further reducing the septum thickness to 1.5 mm.

The dimensions of the Vanadium Permendur (VP) shield around the stored beam chamber at the upstream (US) end were optimized to cancel the integrated B_y leakage field to a level of 5 G-cm. The integrated B_x after the cancelation was 742 G-cm, which deflects the stored 6 GeV electron beam at an angle of 37 µrad, less than half of the specification of <100 µrad.

Based on these parameters, a prototype septum was fabricated. For the leakage field measurement inside the stored beam chamber, the main field was increased to 1.15 T, which enlarges the peak leakage field at the DS by a factor of 6 compared to the design. Remarkably, even with that excessive main field, the measured integrated leakage field inside the stored beam chamber cancelled out successfully. The beam exit position and the integrated leakage field mapped inside the stored-beam chamber matched well between measurement and simulation and met our specification [6].

MEASUREMENT & SIMULATION

Figure 1 shows an image at the DS end of the APS-U vertical septum magnet built at Fermilab. The stored beam chamber is located in the bottom pole. The gap is 10 mm, and the seven pancaked coils are stacked around the top pole. Each pancaked coil has four layers in the horizontal and two layers in the vertical direction. The conductor is an oxygen-free high thermal conductivity copper with a 6 mm x 6 mm cross-section and a cooling channel of 4-mm inner diameter (ID). The thicknesses of the yoke and bottom pole are 40 mm and 60 mm, respectively.

Figure 1: An enlarged DS image of the vertical septum magnet. The septum thicknesses of a and b, which are at the aperture center and the corner, are 1.5 mm and 1.0 mm, respectively.

The minimum DS septum thickness (Fig. 1) was about 1 mm due to the aperture's roll angle, which is 93 mrad. The stored beam chamber US end (Fig. 2) is located under the side leg to create an opposite sign leakage field to the DS leakage field. Figure 3 shows the aperture that will al-

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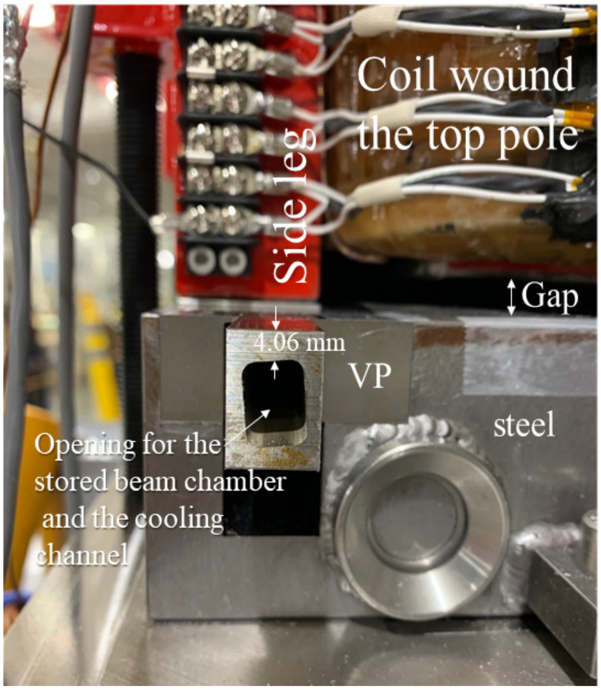

Figure 2: An enlarged US image of the vertical septum magnet. The septum thickness at the US end is 4.06 mm due to the magnet tilt angle of 1.54 mrad.

low insertion of a 9 mm x 7 mm beam tube (wall thickness is 500 µm) with a 9 mm x 5 mm cooling channel under it. Both tubes are nonmagnetic materials. The as-built magnet images (Figs. 1 and 2) do not include the stored-beam chamber and the cooling channel.

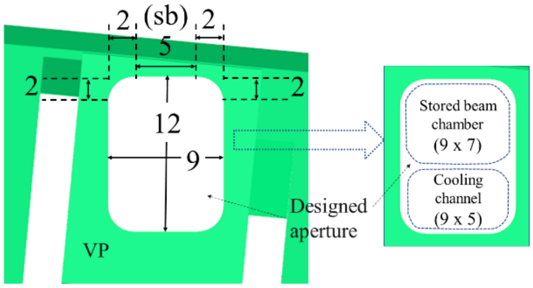

Figure 3: Designed aperture for the vertical septum magnet (DS view). The “sb” on top of the left images means the length of the septum blade. The units are in mm.

Figure 4 shows the designed B_x and B_y leakage field inside the stored-beam chamber at a main field of 1.01 T with a 1.5-mm thick septum. The 1.01-T field creates a 1.69-T-m integrated main field over the magnet length of 1.78 m to deflect an electron beam (6 GeV) at the specified angle of 84.55 mrad.

Due to the cancellation method incorporated into the design, the negative B_x and B_y leakage fields at the DS end are cancelled by the positive fields at the US end (Fig. 4.) As a result, the integrated B_x and B_y leakage fields are only 742 G-cm and 5 G-cm, respectively.

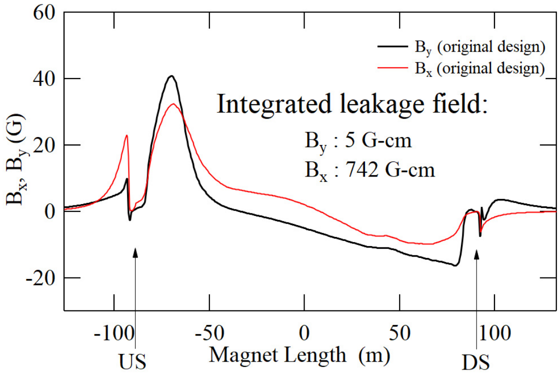

Figure 4: Simulated B_x and B_y leakage field inside the stored-beam chamber for a 1.01 T Injection Field.

Figure 5 shows the measured and simulated main field at the center of the gap. The offset between the simulated and measured values is due to the setup of the encoder in the measurement system. The measured peak field and integrated B_y field at a current of 210 A were 1.15 T and -1.88575 T-m, respectively, which would deflect a 6-GeV electron beam at an angle of 94.18 mrad. The difference is consistent with the change expected between the 1.01 T design field and the 1.15 T measured field.

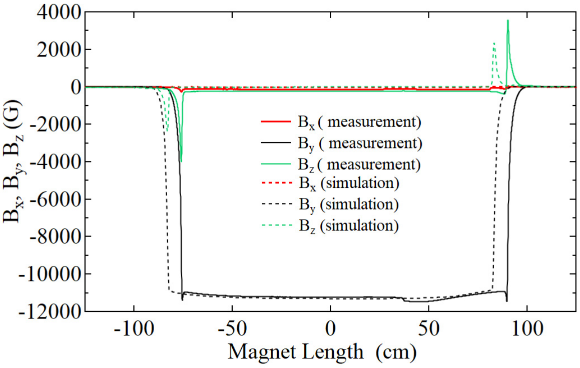

Figure 5: Measured and simulated injected field of B_x, B_y, and B_z at the center of the APS-U Project vertical septum magnet. The applied current to the measurement is 210 A.

Figure 6 shows the corresponding measured and simulated leakage field inside the stored-beam chamber along the length. The design DS peak leakage field increased from 15 G to 100 G, creating an integrated leakage field of about -4,000 G-cm at the magnet's DS end. However, the total measured leakage field integral of B_y is only 232 G due to the cancelation method incorporated into the design. Also, the integrated B_x leakage field measured only 1,385 G-cm.

The as-built septum blade width was 5.5 mm, larger than the 5 mm of the design (Fig. 3), meaning the VP material around the corner was cut 250-µm more than the design. Since the DS aperture corner has a 1-mm septum only, a 250-µm cut increased the peak leakage field more at the DS end. By design, the simulated DS peak leakage field was 70 G for the main field in Fig. 4 and the 5 mm septum blade. Also, the US gap of the stored beam chamber, which is the gap between the side leg and the bottom pole of the magnet, was reduced by 120 µm compared to the design. The as-built septum blade length and the reduced gap of

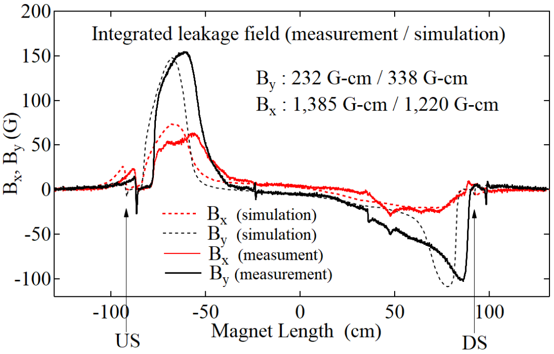

Figure 6: Measured and simulated B_x and B_y leakage field inside the stored beam chamber. The injected field is 1.15 T.

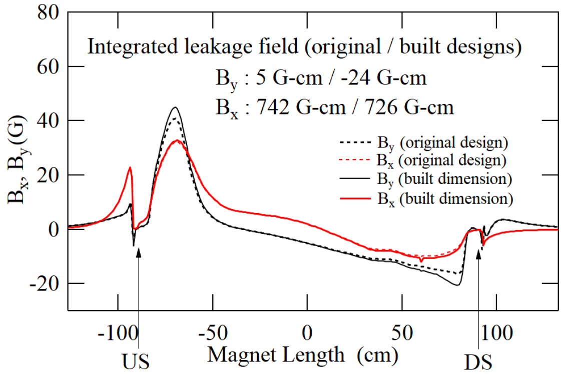

Figure 7: Simulated leakage field using the as-built and designed aperture vertical septum magnet. The injected field of the simulations is 1.01 T.

120 µm at the US of the stored-beam chamber are included in the simulation data in Fig. 7. The integrated B_x and leakage of the simulation were -24 G-cm and 726 G-cm, closing approaching the measurement. The Z position differences between measurement and simulation in Figs. 5 and 6 are due to the Hall-probe position offset.

Figure 8 shows the leakage field of the vertical septum magnet simulated with the as-built aperture and the design main field of 1.01 T. The magnet's enlarged septum blade width increases the peak leakage field from 15 G to 21 G at the DS end. However, the leakage field integral of B_y inside the stored-beam chamber canceled out even with the as-built differences from the design. Figure 8 shows the beam exit position using the measured and simulated leakage fields at an injected field of 1.01 T and 1.15 T.

CONCLUSIONS

We have succeeded in canceling about 4,000 G-cm of integrated B_y leakage field created by a main field of 1.15 T against a septum of thickness 1 mm in the APS-U Project vertical septum magnet. The measured peak leakage field at the DS end was 100 G, which is a factor of 6 more than the design, owing to operating at higher-than-intended main field and to differences between the design and the as-built magnet. The measurement proved that the vertical septum is a robust design, performing well even with 15% higher main field.

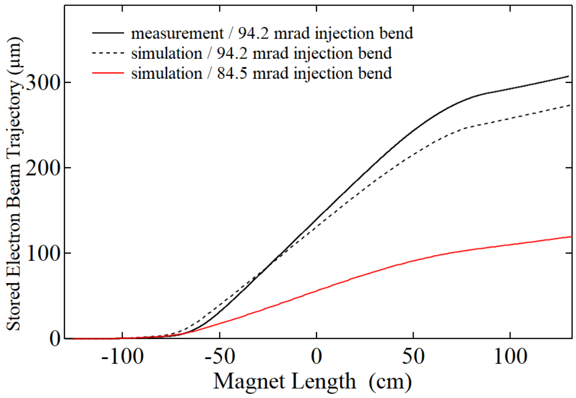

Figure 8: 6-GeV stored electron beam trajectories at the different injected fields of the APS-U Project vertical septum magnet. The beam goes in from the (-) side and out (+) of the magnet length.

With the super ellipsoidal aperture, the septum blade width strongly affects the leakage field. The wider the septum blade, the more significant the leakage field. The as-built septum blade width was 500 µm more than the design, which increased the peak leakage field by 30 G more on top of the 70 G induced by the higher injected field of 1.15 T. However, the integrated leakage field was canceled out even with this geometry.

Normally, a Lambertson septum creates a large B_y leakage at the DS end and a large B_x field at the US end. However, with the cancellation method of the B_y leakage field applied to the design, the integrated B_x field was also minimized. As a result, the total deflection angle of the stored beam would only be 70 microrad, in spite of several differences between the as-built magnet, measurement field level, and the design point.

ACKNOWLEDGEMENTS

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