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MECHANICAL DESIGN CHALLENGES BUILDING A PROTOTYPE 8-POLE CORRECTOR MAGNET

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Abstract

An innovative design was developed for an 8-pole corrector magnet for the APS upgrade program. This is a combined function magnet consisting of horizontal and vertical correctors as well as a skew quadrupole. This paper describes technical challenges presented by both the magnetic design and the interface constraints for the magnet. A prototype magnet was built, and extensive testing on the magnet confirmed that all magnetic and mechanical requirements were achieved. The final design of the magnet has incorporated improvements that were identified during the manufacturing and testing of the prototype magnet.

INTRODUCTION

Multi-purpose 12-pole corrector magnets have been used in the past at several laboratories [1] but these tend to be quite large and there is not much space between the poles for mounting the coils. An 8-pole structure was developed which is more compact than a 12-pole design, yet offers a way to zero out the sextupole and decapole terms in the dipole mode and the skew octupole term in the skew quadrupole mode [2]. The magnet was designed to meet the requirements shown in Table 1.

Table 1: Design Parameters

Parameter	Value	Units
DC steering (at 6 GeV)	≥ 300	microradian
Dipole H-V field integral	≥ 0.006	T-m
Skew Quad filed integral	≥ 0.25	T
Maximum Current	15	A
Maximum required power	minimized	W
Steering at 1 kHz	> 1% or 3 microradian	
Cooling method	Air cooled	
Maximum insertion length	160	mm
Maximum insertion length with feet	90-U/S, 106-D/S	mm
Minimum Aperture	26	mm
Minimum Pole tip-to-pole tip gap	10	mm
Minimum coil-to-coil gap	16	mm
Magnet center height	279.5 ± 0.25	mm
Maximum Half-width from the vertical mid-plane	270	mm

Extensive testing was performed on the prototype 8-pole corrector magnet, photo shown in (Figure 1). This testing confirmed that the magnet is capable of providing the horizontal and vertical steering and skew quadrupole strength with good field quality and meets the specifications within the given space constraints.

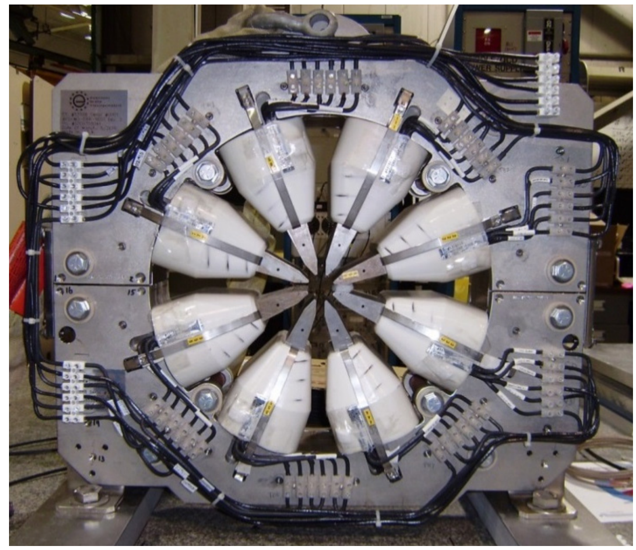

Figure 1: Prototype 8-Pole Corrector Magnet.

The magnet aperture was chosen to achieve a minimum pole-tip to pole-tip gap of 10 mm. Pole length and thickness are optimized to fit all the coils with a minimum coil-to-coil gap of 16 mm which is required at the horizontal mid-plane for the vacuum chamber extraction ports. The backleg thickness is optimized for low peak field, mechanical strength, and overall size.

COIL ASSEMBLIES

The coil pack for the 8-pole corrector magnet features three different coils on each pole, which are combined in series in a specific sequence to produce normal and skew dipole steering as well as a skew quadrupole corrector (see Figure 2).

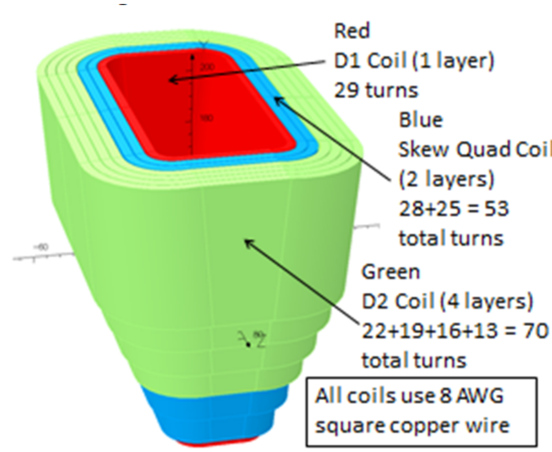

Figure 2: Coil Configuration.

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Figure 3: Prototype Wound Coil.

This compact design presents demanding challenges for the coil manufacturer. Tooling similar to the tooling described in [3] is necessary to maintain the tight mechanical tolerance requirements and for producing coil assemblies with the most consistent shape and size. Building the prototype magnet verified that producing this compact coil design is possible by winding all 3 coil circuits directly on top of each other using a single winding fixture (see Figures 3 and 4).

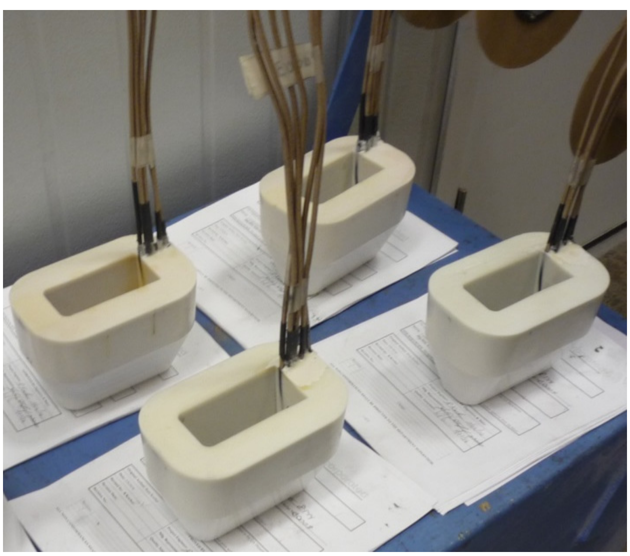

Figure 4: Prototype Potted Coil Assemblies.

Coil to coil connections between the eight coil assemblies that would typically be brazed or soldered together will instead be wired to terminal blocks. Terminal blocks are required in order to accommodate a possible future reconfiguration of the skew quadrupole circuit. The APSU accelerator physics group requested to have an option that would allow the reconfiguration of the skew quadrupole circuit into two circuits, a skew quadrupole circuit plus an octupole circuit. To accommodate this reconfiguration of the skew quadrupole circuit, the power input terminal block will have an extra pair of connections for future wiring of the octupole circuit.

POLE SEGMENTS

The 8 pole structure consists of 8 identical laminated pole segments. Each pole segment is made from 26 gauge (0.47 mm thick) M19 non-oriented steel that has a C-5 surface insulation coating on both sides. The laminations are bonded together to a length of 84.6 mm in the axial direction (see Figure 5).

Figure 5: Prototype Bonded Pole Segments.

Tooling will be required for stamping the laminations as well as stacking and bonding the pole segments. An assembly fixture will be used to precisely locate the 8 bonded pole segments that will form the magnet yoke. The assembled overall yoke cross section is 510 mm wide x 510 mm high (see Figure 6).

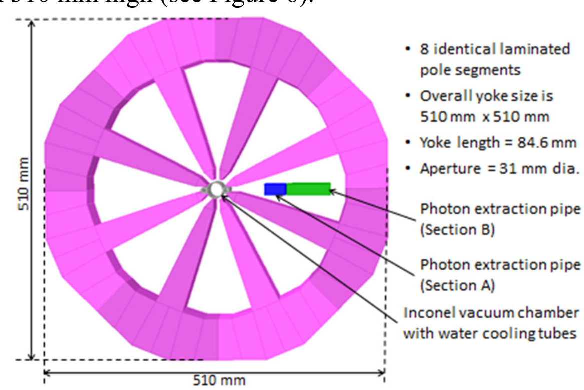

Figure 6: Magnet Yoke Cross Section.

Delamination on one of the pole tips was observed on the prototype magnet. Because there is such a small surface area at the pole tip, special attention will be required on the production magnets to ensure that there is an even distribution of pressure being applied across the entire stack of laminations during the bonding process. Each pole segment will be visually inspected for delamination after bonding, and if necessary a repair procedure will be used to apply room temperature curing epoxy to the unbonded area. In addition, a pole tip clamp has been designed that can be installed onto the magnet and used to mechanically secure the pole tips if needed.

MAGNET ASSEMBLY

Requirements for the assembled magnet include being able to split the magnet at the horizontal mid-plane to allow vacuum chamber installation, also removal and

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installation of a magnet has to be accomplished in-situ without venting of the vacuum system. In order to meet these requirements, the upper and lower yoke assemblies were designed to be separated and then reassembled (using fasteners and pull out dowel pins) to within a repeatable tolerance of ±0.1 mm and still maintain the field quality requirements for the magnet.

The magnet must also provide adequate clearance for the vacuum system components such as the vacuum chamber which passes through the central aperture of the magnet formed by the pole tips, and the photon extraction pipes which pass between the coils at the horizontal mid-plane of the magnet. This requires that the coils also be accurately located using an alignment fixture during assembly of the magnet (see Figure 7).

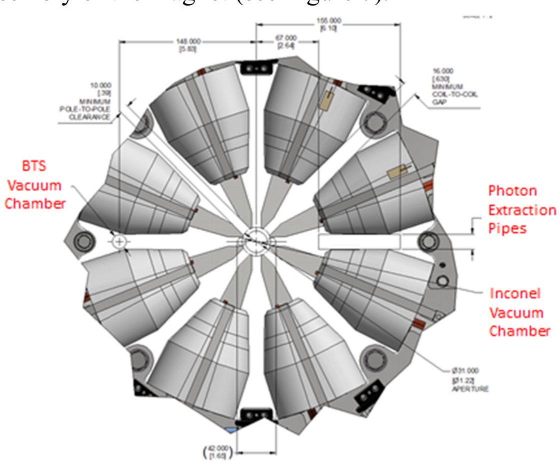

Figure 7: Vacuum System Component Clearance.

During assembly of the prototype magnet it was found difficult to clamp all 8 pole segments between the end plates in preparation for dowel pinning. Further investigation showed that the overall thickness of the pole segments varied by 0.5 mm, allowing the thinner pole segments to shift creating an asymmetric condition in the alignment of the pole tips. Instead of adding a tighter tolerance to the overall thickness of the pole segments, it was decided that it would be more economical to add set screws to the end plates so that each pole segment could be tightly secured regardless of its thickness.

Having a tight positional tolerance for the pole tip alignment while requiring the pole segments to make contact with each other created an over constrained condition in the assembly. An Opera 2D study was undertaken to investigate this problem [4]. A 2D model with all 3 correctors powered was analysed first with no gaps between the mating surfaces of the pole segments and then finally with a 125 µm gap between each of the 8 pole segments. The gap was added between the light blue regions as shown in (Figure 8). Because the gap study showed negligible effects on both the strength and the harmonics, the 8-pole corrector can be assembled with priority given to the symmetrical positioning of the pole tips about the central axis in their ideal location. A tolerance has been added to the drawings allowing a pole-segment to pole-segment gap of no more than 100 µm.

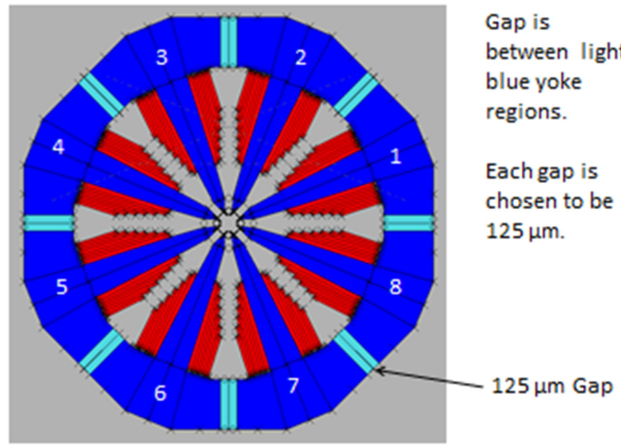

Figure 8: 2-D Model for the Pole Segment Gap Study.

SUMMARY

Manufacturing and assembly tolerances were established to meet the magnet field quality requirements and to ensure adequate clearance is provided between the magnet and mating vacuum system components. Tooling will be used to ensure that a manufacturing tolerance of ±0.05 mm is held on the component parts and fixtures will be used to align the component parts to a tolerance of ±0.1 mm on the assembled magnet.

The pole segment gap study verified that a 125 µm gap between each of the pole segments had negligible effect on the magnetic requirements for the magnet. This also helped to minimize the production cost by not having to perform a secondary machining operation in order to maintain precise pole tip alignment while ensuring contact between pole segments.

The prototype magnet demonstrated that the magnetic and mechanical designs are achievable. Improvements identified from manufacturing and testing the prototype magnet have been incorporated into the final design.

Production of the 8-pole corrector magnet is scheduled to start in the second half of 2018.

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