# DESIGN AND CONSTRUCTION OF SEPTUM MAGNETS AT THE 7-GeV APS*

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*Abstract*

The mechanical design, construction, and assembly procedure of six different septum magnet designs used in the Advanced Photon Source (APS) facility will be described. This will include a positron accumulator ring (PAR) AC septum magnet, a synchrotron thin injection septum, AC thin and thick extraction septa, and storage ring AC thick and thin injection septum magnets.

Design parameters, material selection, assembly procedures, and operational results will be presented.

## 1 INTRODUCTION

The development of septum magnet fabrication at the APS facility has been a challenging endeavor. Pulsed septum magnet design and construction offers the magnet engineer several challenges in material selection, magnet assembly, and construction tolerances. Nonsteady-state forces can lead to material flexture and resultant metal fatigue. High radiation environments limit material selection for coil electrical insulating materials. In some situations, designs require that the laminated core of the magnet be in the vacuum environment. Outgassing of trapped interlamination air can be a major concern when one is required to maintain an ultrahigh vacuum. With core-in-vacuum designs special care must be taken with water connections. No water to vacuum joints are allowed in the septum magnet design. The electrical constraints are no less trivial. Pulsed septum magnets naturally imply high currents of the order of 500 to 12000 amps.

The most important feature of septum magnets is to have a homogeneous field in the magnet gap and a low to zero leakage field outside the gap such that the circulating beam is not affected. A single septum conductor is used to separate the gap field from the zero field external region. To facilitate merging of the injected and stored beams, the septum conductor is designed to be as thin as possible without compromising its mechanical, thermal, electrical, or magnetic shielding performance. In some designs, septum conductors can be 2.5 mm thick or less.

## 2 MECHANICAL AND OPERATIONAL PARAMETERS

The APS facility uses six different septum magnets that are described below.

### 2.1 PAR AC Injection and Extraction Septum

The PAR AC septum magnet is mechanically the most complex of all the APS septa. Designed to operate with a peak current of 12.057 kA and a repetition rate of 60 Hz, its thermal design required considerable development. The complete magnet is contained in a vacuum enclosure 61 cm long by 25.4 cm wide by 17.8 cm high. The core, septum plate, and backleg conductor are all water cooled. The septum plate thickness is 2 mm. The core is stacked laminations of M22 silicon steel with C5 coating on both sides; each lamination thickness is 0.36 mm. The core end-pack is fabricated from laminations that are modified with tapered bevels designed to reduce heating at the ends. Additional cooling plates are provided on the end packs for water cooling. All power and cooling water feedthroughs are electrically insulated from the vacuum enclosure. The magnet is shown schematically in Fig. 1 with operational parameters listed in Table 1.

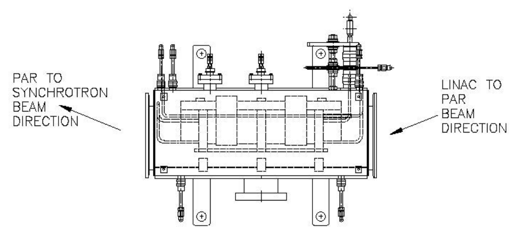


Figure 1. PAR AC septum magnet

Table 1: PAR AC septum magnet parameters

| | |
|---|---|
| Number | 1 |
| Physical Length | 0.48 m |
| Effective Length | 0.4 m |
| Field Strength | 0.75 T |
| Maximum Septum Thickness | 2 mm (+) |
| Magnetic Field Aperture | 7.0 × 2.0 cm |
| Bending Angle | 199.6 mrad |
| Peak Current | 12.057 kA |
| Peak Power | 29 kW |
| Rep Rate | 60 pps |
| Pulse Length (half sine wave) | 275 µs |
| Average Power | 0.574 kW |

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### *2.2 Synchrotron Injection Thin Septum*

The synchrotron injection thin septum magnet is of the core-in-vacuum design. The core is stacked to a radius of curvature of 3.18 m. The laminations are 0.36-mm-thick M22 silicon steel coated with a C5 type insulation on both sides. The laminations are oven baked before use to insure cleanliness. As is usual in the stacking process, the laminations are stacked in approximately 25.4 mm packs, alternating the witness notches from one side to another. The ends of the stack have solid end packs 1.19 cm thick, composed of CRS-1018 steel. As can be seen in Fig. 2, all the magnet components are put into a vacuum-tight box-like structure. The septum plate itself is 2 mm thick and machined from explosion-bonded copper and steel material. It is not direct-driven but rather acts as an eddy-current shield preventing field from leaking into the field free region. The single-turn primary coil is fabricated from OFHC copper of dimensions 1.59 cm by 0.635 cm. The synchrotron injection thin septum is shown schematically in Fig. 2 with operational parameters given in Table 2.

At the present time, another synchrotron injection thin septum magnet of an out-of-vacuum core design is being assembled. With core laminations outside the vacuum envelope, this design will allow quick pump down in case of a vacuum leak.

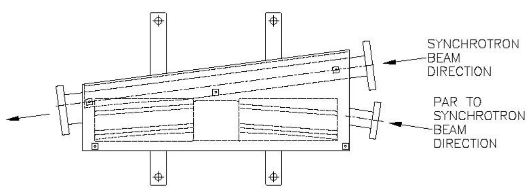


Figure 2: Synchrotron injection thin septum

Table 2: Synchrotron injection thin septum parameters

| | |
|---|---|
| Number | 1 |
| Maximum Allowable Septum Thickness | 4 mm |
| Physical Length | 0.9 m |
| Effective Length | 0.85 m |
| Bending Angle | 0.2771 rad |
| Peak Field at 450 MeV | 0.49 T |
| Gap Height | 30 mm |
| Gap Width | 40 mm |
| Peak Current | 11.8 kA |
| Peak Power | 30 kA |
| Pulse Width | 333 μs |
| Average Power | 0.02 kW |

### *2.3 Synchrotron AC Thin Extraction Septum*

This septum magnet is of the core-in-vacuum type with a total septum plate thickness of 4 mm. The core itself is composed of a stack of approximately 2680 laminations (0.36 mm thick) stacked to a core length of 1.03 m. The laminations are a low carbon silicon steel coated with C5 insulation on each side. The ends of the core have solid end packs of CRS-1018 steel, 1.19 cm thick. The core was stacked and welded in the same fixture alternating 2.54-cm packs of laminations along the length of the core.

The septum plate itself is fabricated from explosion-bonded copper and steel plate. The total septum plate thickness is 3.76 mm and again acts as an eddy-current shield. The septum magnet is shown schematically in Fig. 3. Some operational parameters are given in Table 3.

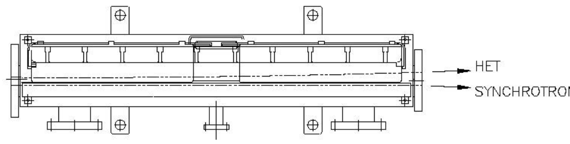


Figure 3: Top view synchrotron extraction AC thin septum

Table 3: Synchrotron AC thin extraction septum parameters

| | |
|---|---|
| Number | 1 |
| Maximum Effective Septum Thickness | 4 mm |
| Physical Length | 1.06 m |
| Effective Length | 1.05 m |
| Bending Angle | 33 mrad |
| Peak Field at 7 GeV | 0.73 T |
| Gap Height | 20 mm |
| Gap Width | 34 mm |
| Peak Current | 11.74 kA |
| Peak Power | 62 kW |
| Pulse Width (1.5 kHz 1/2 sine wave) | 333 μs |
| Average Power | 0.042 kW |

### *2.4 Synchrotron AC Thick Extraction Septum*

This septum magnet is of the core-out-of-vacuum design, stacked to a radius of curvature of 30.5 m, yielding a bending angle of 73.53 mrad. The core is composed of stacked laminations (4712) with laminated end packs that are chamfered at 45°. The core length is 1.7 m.

The coils used in this magnet are fabricated from 4.19-mm square conductor with a 2.41-mm diameter hole for water cooling. The material is oxygen-free copper with CDA alloy no. 102. The coil configuration itself is a $6 \times 6$ matrix with dimensions of 2.86 cm $\times$ 2.86 cm with a 4.19-cm gap. The coil is a saddle type, 1.76 m long, and weighs 15 kg. This magnet is shown schematically in Fig. 4 with operational parameters given in Table 4.

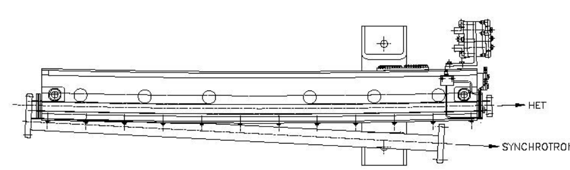


Figure 4: Top view synchrotron AC thick extraction septum

Table 4: Synchrotron AC thick extraction septum and storage ring thick injection septum parameters

| | |
|---|---|
| Number | 1 |
| Minimum Septum Thickness | 30 mm |
| Physical Length | 1.79 m |
| Effective Length | 1.75 m |
| Bending Angle | 73.53 mrad |
| Peak Field at 7 GeV | 0.98 T |
| Gap Height | 30 mm |
| Gap Width | 40 mm |
| Peak Current | 0.66 kA |
| Peak Power | 80 kW |
| Pulse Width | 10 ms |
| Average Power | 0.797 kW |

### *2.5 Storage Ring AC Thick Injection Septum*

The core and coils used for this magnet are identical to those used in the synchrotron AC thick extraction septum. The vacuum chamber used in this magnet is a curved rectangular chamber 1.535 inches high made from an Inconel® channel. The coils are the same as in the synchrotron AC thick extraction septum.

This magnet is shown schematically in Fig. 5 with operational parameters given in Table 4.

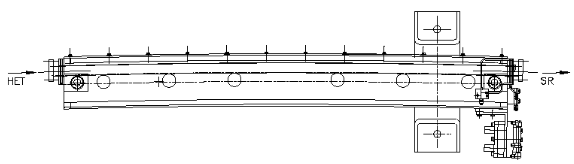


Figure 5: Storage ring AC thick injection septum

### *2.6 Storage Ring AC Thin Injection Septum*

The core of the storage ring AC thin injection septum is comprised of 0.356-mm thick laminations (M22 silicon steel with C5 coating) stacked to a length of 1.04 m. On each end of the core are 2.52-cm-thick laminated end packs. The core, which is stacked straight, is held together with side and bottom tie bars. Inside the gap is a formed beam vacuum tube. This tube is made from Inconcel 625 metal and is 127.8 cm long with a 0.347-mm wall thickness. It is positioned in the core by means of five tube supports fabricated from MYKROX/MYCALEX GRADE machinable ceramic. The copper septum conductor is 1.1 mm thick. Following assembly of the core, Inconel vacuum chamber, and ceramic stand-offs, the remaining open volume of the magnet gap is filled with a concrete type material thereby yielding a solid, one-piece unit suitable for high radiation environments. The magnet is then completed with the addition of the field-free tube vacuum chamber which doubles as a magnetic shield, tie bars, flanges, etc. The gap between the inside wall of the embedded vacuum chamber and the inside wall of the stored beam vacuum chamber is specified to be 2.4 mm; however, in actuality it is 3.5 mm. Special care is necessary in welding the vacuum chambers to prevent weld bead from enlarging this area. The septum magnet is shown in Fig. 6. Some operational parameters are given in Table 5.

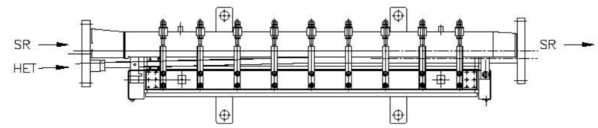


Figure 6: Top view of the storage ring AC thin injection septum

Table 5: Storage ring AC thin injection septum parameters

| | |
|---|---|
| Number | 1 |
| Maximum Effective Septum Thickness | 3.5 mm |
| Physical Length | 1.06 m |
| Effective Length | 1.05 m |
| Gap Height | 20 mm |
| Gap Width | 34 mm |
| Bending Angle | 33 mrad |
| Peak Field | 0.73 T |
| Peak Supply Current | 11.74 kA |
| Peak Power | 62 kW |
| Power | 0.042 kW |
| Pulse Width (1.5 kHz 1/2 sine) | 530 μs |
| Average Power | 0.042 kW |

## 3 CONCLUSION

The primary septum effort at the APS is complete, and spare magnets have been assembled and tested. Existing magnets in the facility are being monitored for their performance, and maintence and upgrades are made as rquired. A new out-of-vacuum core direct-drive design for the synchrotron injection septum will soon be complete.

## 4 ACKNOWLEDGMENTS

The septum magnet program at APS has occupied the talents of many physicists, engineers, designers, and technicians. The author (AG) is at the end of a long effort that was a collaboration of many very capable people, listed below.

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