Extraction Septum Magnet for the SSRL SPEAR Injector*

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Abstract

The Stanford Synchrotron Radiation Laboratory (SSRL) successfully commissioned a 3-3.5 GeV electron injector for the SPEAR Storage Ring during 1990. The Injector operates at a 10 Hz repetition rate and accelerates $\approx 10^{10}$ electrons per second for extraction and transport to SPEAR. The extraction septum magnet is a pulsed Lambertson type which, for reasons of economy, was constructed from the same laminations which form 1/2 of an Injector booster synchrotron dipole magnet core block. The excitation coil also utilizes a design in common with the pulse chokes of the booster magnet circuit. The septum magnet is pulsed by an SCR controlled resonant LC circuit with a resonant frequency of 30 Hz.

I. INTRODUCTION

The high energy physics program on the SPEAR Storage Ring at SLAC has been terminated and the ring is now fully dedicated to production of synchrotron radiation beams. In order to reduce dependence of the SSRL schedule on the on-going high energy physics schedule of SLAC, a new injector has been built for SPEAR to supplant the SLAC 2 mile Linear Accelerator as its beam source.

The SSRL SPEAR Injector consists of a 3 GeV electron synchrotron fed from a 120 MeV LINAC. The Injector has a 10 Hz cycling rate and is designed to deliver $\approx 10^{10}$ electrons per second.[1]

II. GENERAL

The SSRL SPEAR Injector has been sited to utilize a portion of the transport line and injection components which were used for injection from the SLAC Linear Accelerator. A single turn extraction system has been designed and built, and a transport system which places beam at the injection point of SPEAR.

At approximately the peak of the injector synchrotron acceleration cycle, when the synchrotron beam energy matches the SPEAR injection energy, a fast extraction kicker magnet is triggered which kicks the electron beam horizontally into the gap of the extraction septum magnet. The kicker magnet is located in the nearest upstream straight section, approximately 125° in betatron phase ahead of the septum magnet.[2]

Due to current limitations of some of the injection components of SPEAR, injection energy is limited to 2.35 GeV. However, the Injector components are designed to operate at 3 GeV and, in the case of the septum magnet, up to 3.5 GeV.

The extraction septum magnet is a Lambertson type horizontal field device which produces a 3.61° deflection upwards. Its effective length is 1.03 meter and must produce 0.713 Tesla in its gap to extract 3.5 GeV electrons from the booster synchrotron.

Figure 1 shows elevation views of the magnet. During acceleration in the booster, the electron beam passes through a V shaped notch in the core of the septum magnet. If the core is adequate, there should be no magnetic field in the notch. When the extraction kicker is pulsed, the beam is kicked horizontally by 0.1623° into the septum magnet gap. Figure 2 shows cross section details of the gap area of the magnet. Beam position, size and the outline of the adjacent booster vacuum chamber profile are included.

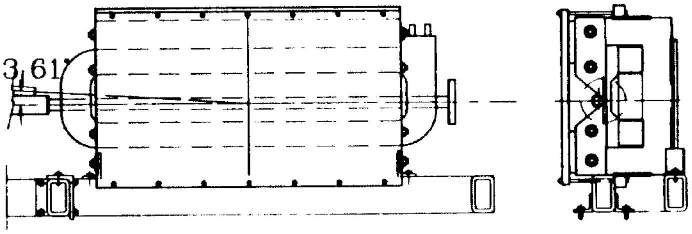

Figure 1
Septum Magnet Elevation Views

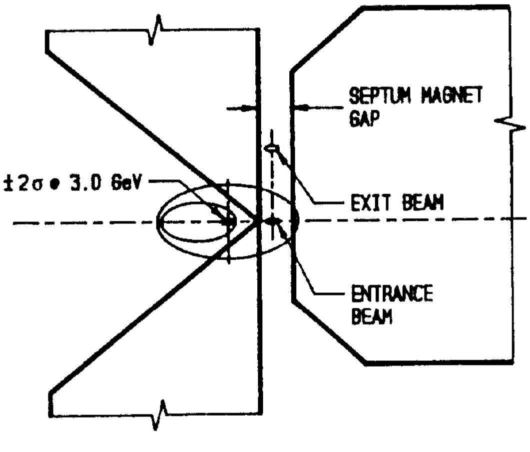

Figure 2
Septum Magnet Gap Area

The magnetic characteristics were modelled using the POISSON code. The analysis indicated that, for practical core materials and geometries, there would be a small, but significant and non-uniform magnetic field in the notch region. At 3.5 GeV excitation, the average field integral in the booster beam region is approximately 20 Gauss-meter,

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while the gradient is approximately 0.6 Gauss/mm. Later measurements of the magnetic field leakage into the notch confirmed the predictions.

In order to avoid the effect of the leakage field upon the newly injected 120 MeV or lower electron beam in the booster synchrotron, the possibility of pulsing the septum magnet was considered. This led to consideration of using the core laminations from the booster dipole magnets[3] to form the main septum magnet core. The final design is pulsed with a 30 Hz sine wave so that the beam in the booster has reached high energy before any leakage field occurs.

III. EXCITATION COIL AND CORE CONSTRUCTION

The septum magnet layout is illustrated in Figure 1, and the design specifications are in Table 1. To optimize the fabrication costs every effort was made to use existing materials and tooling; the core fabrication and complete assembly were done at SSRL taking advantage of magnet lamination stacking methods which were developed for the ring magnet construction.[3] Also the pulsing choke required for the ring magnet white circuit[4] was designed concurrently with this magnet to share the same coil, core backleg, and tooling.The total fabrication cost for the septum, including a spare coil, was $21K and the construction took roughly twelve weeks.

Table 1
Septum Magnet Specifications

Beam Energy	3.5 GeV
Field Strength	0.713 Tesla
Excitation Waveform	30 Hz Sinewave
Gap Height	15 mm
Bending Radius	16.36 m
Bending Angle	3.61°
Excitation	8511 Amp-turns
Peak Current	531.94 Amperes
Peak Magnet Voltage at 30 Hz	351.2 Volts
Magnet DC Efficiency	98.8%
Coil Average Power	97.6 Watts
Conductor Material	Pierced Aluminum
Coil Cooling	0.875 GPM LCW
Main Core Lamination Material	1005 Low Carbon Steel
Septum Lamination Material	M-36 Silicon Steel
Core Length	1.00 m
Total Magnet Weight	1300 kG

The magnet core consists of the "E" shape back leg and the septum "V" shaped pole. To reduce AC power losses booster dipole laminations were stamped from 16 gauge 1005 low carbon sheet and stacked together in the same fixtures that were used for the ring dipole construction. The lamination stack was then welded together with steel straps. This design relies on the natural oxide coating of the steel surface for interlaminar resistance. To minimize local eddy current heating and to reduce the lamination separation forces the pole ends were tapered and were also epoxied together.

The septum poles are of similar construction, yet use 0.025" thick silicon strip steel. Because the field is significantly higher in the septum pole, 0.025" thick silicon strip steel with C-5 organic insulating coating was used and the fabrication process was modified. The pole laminations were hand glued, stacked in a fixture, compressed with long tension rods, oven cured, and finally machined to achieve the tight tolerances required to minimize the leakage field in the septum notch. The septum pole side is one magnet gap distance longer on each end than the backleg to avoid forming a compound taper on the pole ends.

The excitation coil was vacuum cast in an aluminum mold by a local vendor, and again the tooling from the ring magnet dipole coil fabrication was modified and used. Hollow aluminum conductor of the same cross-section as the ring dipole coil was used. To allow removal of the coil in the booster tunnel the split between the two core halves sits directly on a support strut allowing removal of the septum side without disturbing the back leg or other components.

IV. VACUUM CHAMBER

The thickness of the septum across which the beam must be kicked is largely determined by the walls of the vacuum chamber in which the beam travels during acceleration in the booster. It is important to minimize this distance so that the extraction kicker parameters will not become too stringent. Also, since the maximum of the kicked beam displacement occurs in the upstream focussing quadrupole magnet, the booster vacuum chamber limits the maximum beam displacement in the Septum Magnet itself.

Figure 3 shows the cross section of the septum vacuum chamber, the 3 GeV beam profile and the beam stay clear (BSC) for the newly injected beam. It is constructed of Type 304 Stainless Steel. The main "U" shaped chamber forms the structural support for the 0.040" wall thickness nose section which is TIG welded to it. The ends are welded into flanges which connect it to the Injector vacuum system. The flange at the entrance end of the septum magnet also has mounted a 0.001" thick Type T-347 half-hard Stainless Steel window of 0.5" diameter, through which the kicked beam leaves the booster vacuum and enters the septum magnet gap. The thin window was brazed to its mount in a reduction atmosphere and the assembly welded into the flange.

The beam transits the septum magnet in a helium atmosphere and then enters another vacuum transport system through another thin window. This avoids having additional vacuum chamber wall in the gap and, hence increasing the effective septum thickness.

The chamber became distorted during the welding of the nose to the "U", making it necessary to restraighten it by

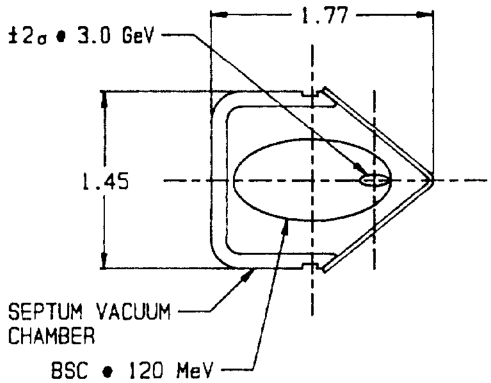

Figure 3
Septum Vacuum Chamber Cross Section

applying weld beads along the back. The final position was within 1 mm of straight and was deemed acceptable.

V. Power Supply

The ejection septum power supply is powered from a pulsing network that supplies a single 30 Hz damped sine wave current cycle to the magnet each time the network is triggered. Figure 4 shows the power supply and pulser circuit elements. Capacitor C1 is resonantly charged through choke L_{ch} from a DC voltage regulated power supply, and then resonantly discharged through the septum magnet when SCR1 is triggered. Figure 4 shows the current waveforms in the septum magnet coil and in the charging choke.

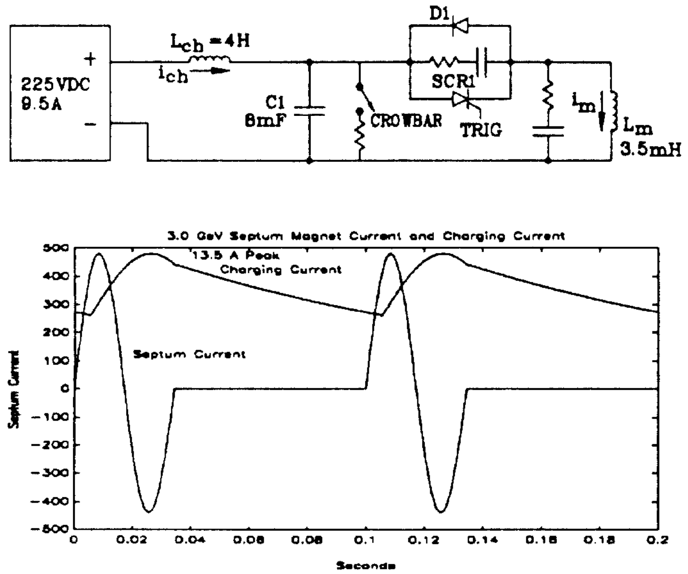

Figure 4
Ejection Magnet Power Supply

The design value of the charging choke inductance was chosen to be large enough to limit the charging current peak-to-peak amplitude modulation to ≈ 70% of its average value so that 1) the current would always be positive, and 2) the AC current load on the power supply would not be excessive. The choke core and much of the septum magnet core were fabricated using the relatively thick (0.06") core laminations that were used for the 10 Hz booster magnets.[3] The resulting core losses in both caused by the 30 Hz current components increased the required charging current from the dc power supply from 3 Amperes, assuming no core losses, to 9.5 Amperes for 3 GeV operation.

RC suppression networks across the SCR1-D1 pair and across the magnet load reduce voltage transients and currents that would otherwise propagate through the system and in the magnet. They also aid in absorbing residual energy stored in the magnet when SCR1 and D1 stop conducting.

VI. Operating Experience

The extraction septum magnet has been in operation for several months, and has performed largely as expected. When the magnet was first powered with beam being accelerated in the booster synchrotron, the newly injected beam from the LINAC was affected by it. This was unexpected since there is no current flowing in the septum at the time when beam is being injected.

A measurement determined that a remnant field exists in the top and bottom septum pole pieces. It is induced by the $\dot{B}$ term of the septum excitation pulse and leaves sufficient field in the beam notch to perturb the low energy injected beam. Trim windings were installed on the septum pole pieces to buck the remnant field and alleviate the problem.

The source of the field is believed to be the clamping rods of the septum core which form a shorted turn around a portion of the core. These rods will be electrically insulated from the core laminations and each other when the next opportunity occurs. We expect that this will eliminate the problem.

VII. References

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