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THE NEW AGS SLOW EXTERNAL BEAM SWITCHYARD*

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Introduction

The original switchyard for the Slow External Proton Beam at the AGS of Brookhaven National Laboratory incorporated two current carrying, copper septa to split the beam into three parts. These septa were each .05 mm thick and intercepted a substantial amount of beam when, as often occurs, it was necessary to split the beam across its densest region. To adjust splitting ratios and optimize losses, a complex time consuming pattern of steering adjustments using various magnets was necessary. When the question of providing a fourth beam to a new target station arose, it was clear that adding a third copper septum in the very constrained space available would lead to unacceptable increases in the radiation and control problems. In order to circumvent these difficulties, it was decided to rebuild the switchyard using much thinner electrostatic septa as splitters and to provide a greater degree of independence of the various beam segments.[1]

The Basic Beam Division Triplet

The basic split in the beam is produced by inserting a thin, electrostatic septum into the beam with oppositely directed electric fields on either side producing deflections of ± 0.375 mrad. Downstream of this splitter (11.5 m or more) is an associated thin Lambertson type (Fe) septum magnet with a horizontal field on one side of the septum and a field free hole on the other, imparting a vertical kick of 8.0 mrad to one beam. To change the splitting ratio, the incident beam is held fixed while the splitter septum is translated mechanically to the desired position in the beam cross-section. The associated thin Lambertson septum is also moved by a known, corresponding amount, to lie in the shadow of the splitter septum. (Both of these septa can also be rotated about vertical axes to minimize losses.) Since the succeeding apertures in all four beam line branches are designed to transmit the full beam, no other adjustments or compensations are required. The shadow produced by the thin septum magnet then spans the thick Lambertson septa of one or two succeeding magnets with vertical fields for the final horizontal separation.

The Electrostatic Splitters

These three units, patterned after those in use at FNAL,[2] are each of identical construction, employing thin, wire grids as the anodes (.005mm, 75% tungsten, 25% rhenium alloy wire). The operating field used for design is a conservative 34 kV/cm across the 20 mm gaps. The electrode lengths are 3.05 m.

Figure 1 shows the first splitter and its typical placement in the beam. The cathode is made of thin-walled titanium tubing which is drawn to the desired shape. The cathode is supported in three places by titanium spacers which are attached to machined ceramic standoff insulators. There are interruptions in the wire grid at each of these supports. The frame that carries the wires is made from an aluminum forging. The wires rest against machined flats that are straight and parallel to within ± 0.001 in. Should a wire break, its tension causes it to withdraw behind a baffle plate. Each splitter has a remote-controlled motion system capable of ± 19 mm transverse motion and ± 2.5 mrad rotation.

The Thin Lambertson Septum Magnets

Bending vertically by a maximum of 8.0 mrad, these magnets must support fields of 2.5 kG over their 120 inch lengths with negligible fields in the shielded passages. Allowing 15 kG in the iron, the minimum septum wedge angle to be usable is estimated by:

$$\sin\theta = \frac{2.5\ \text{kG}}{15\ \text{kG}} \rightarrow \theta = 10^\circ .$$

This leads to a septum thickness of about 1.5 mm at the top and bottom of the beam. Rather than being tapered to zero at the mid-plane, the septum is cut on a circular arc which gives a thickness of about 0.75 mm at the mid-plane.

The basic design of the thin Lambertson magnets is given in Figure 2 which illustrates the magnet which is paired with the first splitter. (Note that all three splits are visible here since all three splitters are positioned sequentially upstream of the first Lambertson magnet.) The bore hole extends beyond the ends of the magnet coil far enough to maintain good magnetic shielding. The coils are simple race-track designs and are external to the vacuum so that no electrical and water feedthroughs are required. These magnets are also mounted on traversing and rotating mechanisms.

The Thick Lambertson Septum Magnets

These magnets have their horizontal septa fixed in position, in the shadows of the vertical separations caused by their upstream thin Lambertsons. They bend by a large enough horizontal angle (up to 2°) that, within a short distance, the affected beam segments become effectively independent. They support up to 13.25 kG over their 2.4 m effective lengths. The septum wedge angle implied is 60°. As with the thin Lambertsons, this wedge shape is replaced by a cylindrical hole bored in one pole piece. The septum thickness is 22 mm or greater depending on the specific unit. They were constructed using spare AGS ring magnet coils. Figure 3 illustrates the one associated with the first splitter and thin Lambertson.

The Switchyard Layout

Figure 4 presents a schematic layout of the various beam axes in the switchyard. Only the beam division components are shown, lenses and standard dipoles being omitted for clarity. Following extraction from the AGS, four quadrupole lenses are disposed in the line to match the AGS emittance to the requirements for efficient splitting; viz., an angular spread small compared to the splitter kick, but with a horizontal width not so large as to cause beam loss on the cathodes. The quads are followed immediately by the three splitters. Because of the pre-existing

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space limitations, the A Line must break away from the B Line far upstream. An early split in the D Line is also necessary due to downstream geometry. Therefore, the thin Lambertson septa associated with these two splits follow the splitters immediately, leading to a minimum splitter shadow width of 4.8 mm, still better than three times the Lambertson septum width of 1.5 mm. For the same reason, the thick Lambertson magnets associated with these two splits are encountered next. After this, the D, A, and (B,C) beams are effectively separated horizontally. Since the B and C targets are far downstream, these two beams are conducted for some distance in a common vacuum pipe before the associated thin and thick Lambertson septa are encountered. The 3-dimensional beam layout is tightly constrained, and it was essential to pay close attention to the surveying and installation of components.

Beam Steering

A number of vertical, and one horizontal, vernier magnets were included to ensure enough differential steering capability to place each beam axis correctly in the various apertures. Other vernier adjustments in the horizontal plane are made by increments in the main dipole fields. Where two or more dipoles are powered in series, trimming power supplies are often connected across one or more of the magnets.

Time dependent corrections are also required. During the slow external beam spill period (~1 sec), the momentum decreases by typically 0.5-0.6%. The effect of this on the entire switchyard to target system was analyzed, and programmed current ramp generators were provided where needed to remove the bulk of the momentum dispersion. Finally, servo controlled corrections are made at each target to keep the beam spots centered.

Instrumentation

Tuning the switchyard for efficient beam splitting and transport depends critically upon having sufficiently informative instrumentation. In addition, beam emittance characteristics must be established to set CQ1 → CQ4 correctly.[3,4] To this end, retractable, fluorescent, aluminum oxide flags with fiducial marks are accurately positioned at strategic locations. At three of these locations, Segmented Wire Ionization Chambers (SWICs) are included. These SWICs provide cross-sectional beam profiles which, in conjunction with CQ1 → CQ4, yield emittance measurements of sufficient accuracy. These retractable SWICS are contained in thin-walled reentrant cans, eliminating the need for vacuum penetrations and simplifying their maintenance. The total extracted beam intensity is monitored by a Secondary Emission Chamber (SEC) just after extraction from the AGS, and the intensity reaching the targets by similar chambers just upstream of them. Lost beam is detected by a loss monitor system which utilizes gas insulated coaxial cables as ionization chambers.

The flags are the prime detectors which are employed in aligning the beam axes in various apertures and in making the initial placements of the splitters and thin Lambertsons in the beam. Then the loss monitors are utilized to optimize the transmission efficiency. For example, the difference between signals from short loss monitors just upstream and downstream from a splitter is sensitive to losses which indicate that the wire grid septum does not lie in the local mean direction of the beam, while a similar monitor at the associated thin Lambertson can signal misplacements of the ends of its septum in the shadow of the splitter. Long detectors (~ 30 feet) are also installed to monitor general area losses. In all, 38 short and 20 long loss monitors are included in the switchyard instrumentation.

Operational Experience

The switchyard and transport to the targets is typically 90% efficient, as determined by foil activations. When splitting to the A, B, and C targets, the loss monitors indicate that about half of the loss occurs in the wire and thin Lambertson septa while the rest is due to scraping in the smaller downstream apertures. The D-line has not yet been completed, but beam has been split off and sent through the thick Lambertsons toward the future D target station with little change in losses. Minimization of these losses is accomplished quickly as the various steering magnets are coupled through the PDP-10 computer. These control algorithms are complicated by the fact that some of the bending magnets are rolled by up to 27° in order to combine horizontal and vertical bends. It is observed that a horizontal-vertical coupling is introduced in the thick Lambertsons of the A-line because the protons pass through these units above the symmetry plane of the sextupole field components of the magnets. A small skew quadrupole has been introduced to compensate this coupling.

Acknowledgments

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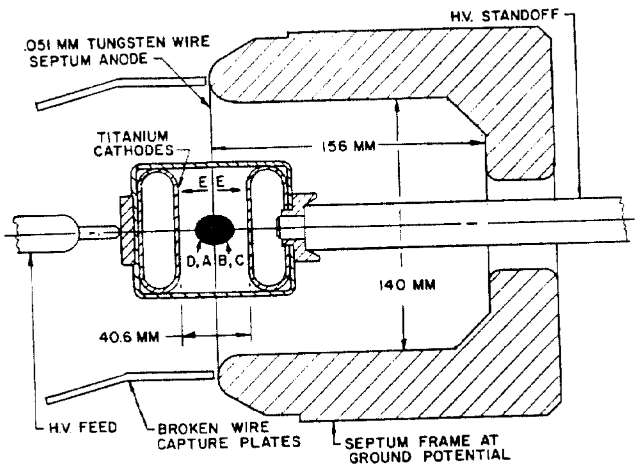

Fig. 1. Electrostatic Splitter Cross-Section. Typical placement for the D,A/B,C split. The D/A and B/C splits are made in succeeding splitters.

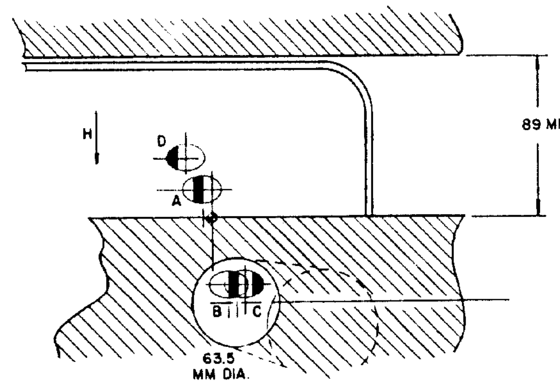

Fig. 3. Thick Lambertson Septum Magnet Cross-Section. This septum lies between the beam segments separated by the magnet of Fig. 2. The D,A beams are deflected to the left.

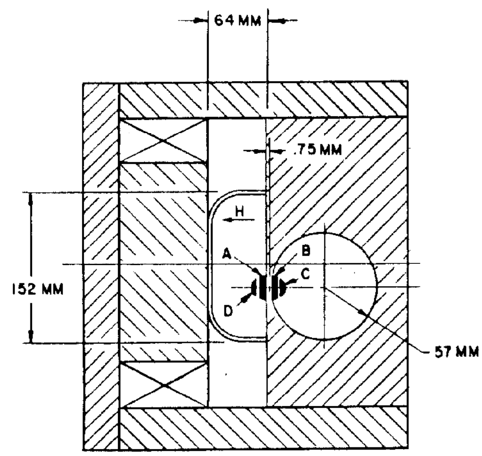

Fig. 2. Thin Lambertson Septum Magnet Cross-Section. This septum lies in the shadow of the splitter of Fig. 1. The D,A beams are deflected up.

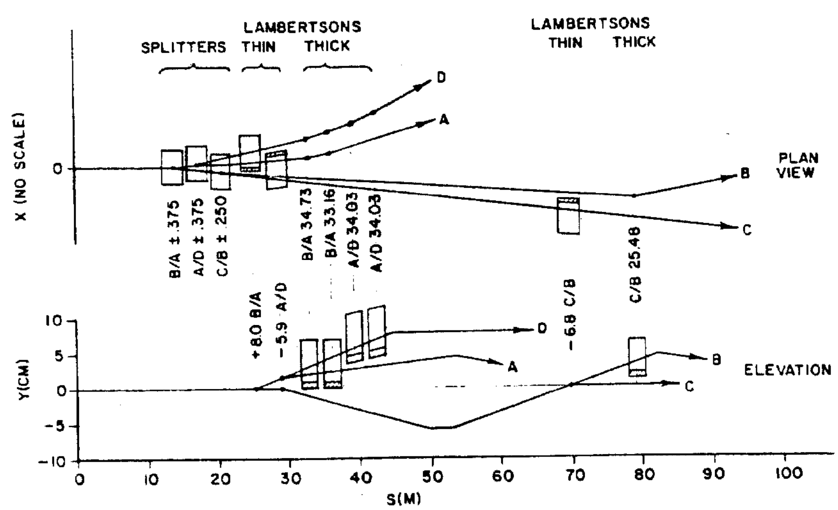

Fig. 4. Schematic Beam Splitting Layout. The Lambertson magnets are outlined to show their septum placements; they deflect in the opposite plane. Deflection angles are shown in milliradians.