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AGS SLOW EXTRACTION IMPROVEMENTS*

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Abstract

Improvement of the straightness of the F5 copper septum increased the AGS slow extraction efficiency from ~ 80 percent to ~ 90 percent. Installation of an electrostatic septum at H20, 24 betatron wavelengths upstream of F5, further improved the extraction efficiency to ~ 97 percent.

Introduction

The slow extracted beam at the Brookhaven AGS was put into operation in 1968.[1] There have been minor improvements in the extraction equipment since then, but no substantial changes. Extraction efficiency is an important parameter, particularly because of component radiation damage and eventual personnel radiation exposure resulting from protons which are not extracted. The extraction efficiency is determined by the effective thickness of the first septum, which until recently has been the 0.075 cm thick copper septum in the F5 straight section.

Schemes to improve the extraction efficiency are constrained by three major factors:

(1) The considerable investment in beam transport and experimental areas, which militates against changing the extraction point;

(2) the AGS lattice, with its relatively short straight sections; and

(3) the requirement that the extraction septa not intercept the particles of -120 and -240 degrees relative betatron oscillation phase that pass by during third-integer resonant extraction.

A way to improve the extraction efficiency despite these constraints was suggested ten years ago.[2] The improvement is based on an electrostatic septum in the long straight section at H20. After deflection by this septum, the beam makes approximately 2-3/4 orbits around the accelerator before arriving at the existing F5 copper septum in the proper phase for further deflection and extraction. Since the distance traversed corresponds almost exactly to 24 full betatron oscillations, the angular deflection at H20 would in linear approximation produce no net spatial separation at F5 and the process would not work. However the non-linear effect of the sextupole moment of the extraction sextupole magnets and of the main magnet is significant, and for various assumed sextupole moments the calculated separation is large.[2]

Extraction Efficiency Measurements and Copper Septum Straightness

The extraction efficiency is measured directly by taking the ratio of the external intensity measured on a Secondary Emission Chamber (SEC) to the internal intensity measured by a current transformer (CBM). Such measurements have in the past been plagued by SEC aging effects depending on accumulated proton dose. A significant improvement was made with the recent installation of a new SEC using glow-discharge-cleaned, silver-coated aluminum foils,[3] for which no aging has been observed.

The extraction efficiency is also measured indirectly by means of calibrated loss monitors consisting of lengths of gas-filled coaxial cables at various positions in the ring. In particular there are loss monitors placed near each extraction septum, and there is a long monitor (RLM) that encircles the entire ring. These monitors are calibrated against the SEC by inducing losses at various points in the ring, for example by changing septum skews, and observing the loss monitor response for various reductions in SEC reading.[4] Based on these calibrations it is estimated that the extraction inefficiency is measured to an accuracy of ± 30% of itself. For example with an extraction efficiency of 97% and hence an inefficiency of 3%, the uncertainty in inefficiency is ± 1% with the loss monitor method.

Measurements made[4] in 1977 gave an extraction efficiency of 78% without an electrostatic septum. When a 150 cm long, 0.0076 cm thick Molybdenum foil septum which was installed in the H20 straight section was energized to 80 kV/cm, the extraction efficiency rose to 85%.

The copper septum was removed and found to have a large deformation in its upstream end. A procedure was established to measure septum straightness using an alignment telescope to measure the position of a probe which was moved along the length of the copper. By careful adjustment it was found possible to obtain septa with an effective thickness, measured mechanically, of 0.10 cm, about 33% more than the copper thickness. These septa, when installed in the accelerator, gave extraction efficiencies of ~ 90%. The expected extraction efficiency is

$$E = 1 - \frac{ft}{s} \tag{1}$$

where t is the effective septum thickness, s is the spiral pitch and f is a factor, typically 1.5, to account for the horizontal density variation due to nonlinear growth of betatron amplitude. Since the spiral pitch at F5 is typically 1.5 cm, the extraction efficiency with straightened septa agrees with expectations.

Expected Efficiency of H20 Extraction

Analysis of the 1977 test results showed that the poor extraction efficiency of 85% with the electrostatic septum could be understood in terms of two effects. First is the non-straightness of the F5 copper septum, discussed above. The second effect is wrinkling due to beam heating in the foil septum at H20; one can easily calculate, and verify by experiment with a small heat source, that a foil stretched between two long supports with no longitudinal tension will wrinkle severely when heated along its median plane. It was concluded that, with a 225 cm long wire septum at H20 operating at 80 kV/cm, and a straightened copper septum at F5, high extraction efficiency would be obtained.

The predicted extraction efficiency is still given by Eq. (1), but now s is about half that at F5 and t is the effective thickness of the wire septum. The effective thickness t exceeds the wire thickness 0.0051 cm for two important reasons. The first is construction errors, which are estimated to contribute 0.0025 cm. The second is the effect of the finite beam divergence. The upstream end of a number 20 straight section in the AGS is nearly a point of minimum horizontal beta function, i.e., a point of maximum horizontal beam divergence. Thus H20 is unfavorable from the point of view

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of beam divergence. The effect of beam divergence is miminum for a curved septum, of curvature half that of the proton trajectories in the electric field, or a sagitta of approximately 0.0075 cm for the H20 septum. For such a septum, with a reasonable model of the SEB emittance, the predicted increase of effective thickness due to beam divergence is 0.0065 cm. Tolerance calculations indicate that the septum sagitta may vary by ± 0.0040 cm from the optimum value without degrading extraction efficiency. Taking all effects into account, one predicts an extraction efficiency of about 97 percent. (Details of these estimates will be given in a future report.)

Electrostatic Septum Design and Construction

Figure 1 shows the septum construction. The septum is similar in many aspects to the septa used at Fermilab.[5] One difference is that, because of the larger vertical beam size at the AGS, the cathode is mounted inside the mounting frame and the circulating beam is outside (to the right of the septum in the figure).

Another difference is in the mechanical mounting. The frame is supported in four places by support posts (G in Figure 1). One of these is fixed and the other three constrain the frame transversely but are free to move longitudinally, to allow for differential thermal contraction. The septum frame is machined into an approximation, by three straight line segments, of a circle with a sagitta of 0.0075 cm as required for optimum extraction efficiency. After winding and assembly, the actual septum shape is measured optically using an alignment fixture which indexes on the wires where they rest on the frame, and carries an optical target. With this technique a measurement accuracy of about ± 0.001 cm is obtained, and based on the measurements small transverse adjustments of the support posts are made.

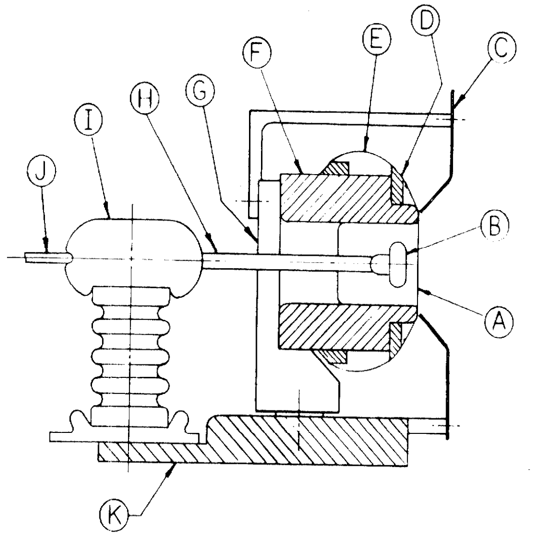

Fig. 1. Electrostatic septum construction. A: wire septum, 0.0051 cm diameter, 75% tungsten, 25% rhenium alloy wires, 0.127 cm spacing; B: titanium cathode (1 cm spacing from septum); C: baffle; D: soft aluminum strip to which wires are swaged; E: retractor spring, 0.041 cm diameter spring steel; F: mounting frame, aluminum forging; G: support post, anodized aluminum; H: cathode support, stainless steel; I: HV insulator; J: HV feedthru probe; K: base plate.

The resulting septum conforms to the ideal curve to within ± 0.002 cm.

Results

The septum was conditioned up to gradients of 130 kV/cm in tests. At these gradients electron currents of the order of 100 µA are emitted by the cathode; about a fifth of this is collected by the wire septum and the rest passes thru to the walls of the vacuum vessel. Sparking is seen during conditioning but evidently it rarely happens that a significant part of the stored energy is deposited as heat on a wire since to date only one wire has broken. After conditioning the electron current and sparking rate at 80 kV/cm are both negligible.

In operation in the AGS at pressure 2 x 10^{-6} torr and with 0.9 x 10^{13} protons circulating, a positive ion current, proportional to beam intensity, of approximately 100 µA is collected by the cathode; the septum current is negligible. The device thus acts as a clearing electrode. Turning on the HV results in a small reduction in proton intensity; this effect can be compensated for by retuning injection parameters.

In operation a 3/2 λ orbit bump centered at H19 is produced by means of backleg windings, analogous to the existing F area orbit bump.[1] The excitation of the two orbit bumps, and of the extraction sextupoles, has to be stabilized to within ± 0.1% in order to stabilize the shadow of the H20 septum on the F5 septum. Since the momentum sweep during extraction is approximately 1%, the H20 orbit bump is ramped to compensate and hold the shadow steady.

Figure 2 is a plot of extraction efficiency and ring loss as the radial position of the septum is varied. At the optimum position an extraction efficiency of 97% is obtained. Figure 3 shows the same data replotted to verify that the calibration of the ring loss monitor, determined earlier,[4] is still valid.

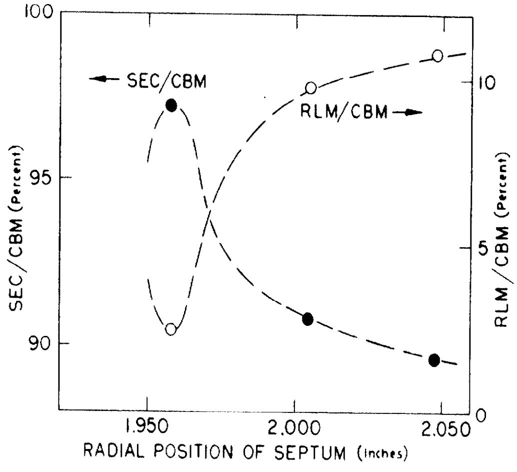

Fig. 2. Extraction efficiency (SEC/CBM) and ring loss (RLM/CBM) vs electrostatic septum upstream radial position.

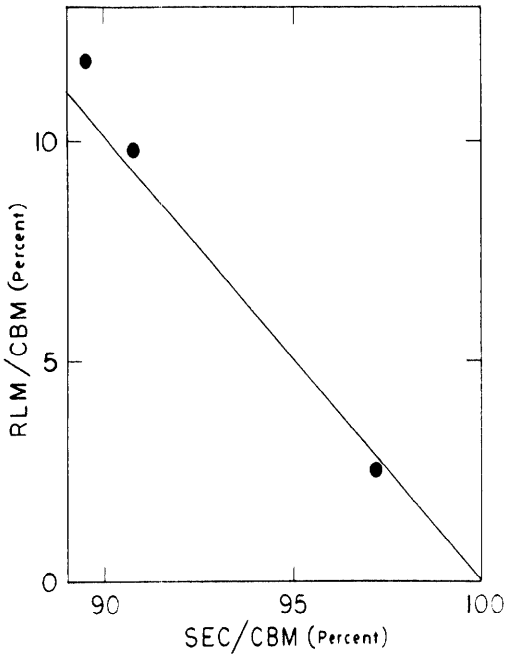

Fig. 3. Measured ring loss vs measured extraction efficiency for the data of Fig. 2. The straight line of slope -1 is what is expected for ideally calibrated instrumentation. The points lie on the line to within measurement accuracy.

Acknowledgments

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