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SLOW BEAM EXTRACTION EFFICIENCY MEASUREMENT USING CALIBRATED LOSS MONITORS

F. Hornstra

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Collider Accelerator Department
Brookhaven National Laboratory

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

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No. 112

F. Hornstra[†], L. Blumberg, J. Glenn, J. Keane,
Y.Y. Lee, L. Smith, A. Soukas
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CALIBRATED LOSS MONITORS

I. Introduction

The extraction efficiency of the AGS was determined by measuring the extraction losses with a calibrated loss measuring system similar to that described in Fermilab publication FN-252, April 26, 1973 by Hornstra and Bleser. The extraction efficiency is typically 90%.

When accelerator extraction efficiency approaches 100%, accurate measurement of that efficiency becomes difficult. Typically, the ratio of the extracted beam to the accelerated beam is used to measure extraction efficiency. Aside from the problems associated with measuring beam intensity in the presence of background radiation caused by beam losses, accurate measurements with the use of two intensity monitors requires precise intercalibration of the monitors as well as high resolution in the readings. The use of a calibrated loss monitor system allows one to determine extraction efficiency in terms of the internal intensity monitor alone (or the external intensity monitor) and to intercalibrate the internal and external beam intensity monitors.

The AGS is equipped with an internal torroid intensity monitor and an external secondary emission chamber intensity monitor. A loss monitor system described later was installed for this experiment.

II. Theory

For the moment, assume that extraction losses dominate other beam losses during extraction or that one can contrive this situation. The following

[†] Summer visitor, 1974, from Fermi National Accelerator Laboratory, Batavia, Illinois.

equation accounting for all protons can be written:

$$N_a = N_x + N_l \tag{1}$$

where N_a = the number of protons accelerated,

N_x = the number of protons extracted,

N_l = the number of protons lost.

Dividing both sides of the equation by N_a normalizes the expression to give:

$$1 = \frac{N_x}{N_a} + \frac{N_l}{N_a} \tag{2}$$

$$1 = \mathcal{E} + \frac{k\Sigma LM}{N_a} \tag{3}$$

$$1 = \mathcal{E} + \bar{\mathcal{E}} \tag{4}$$

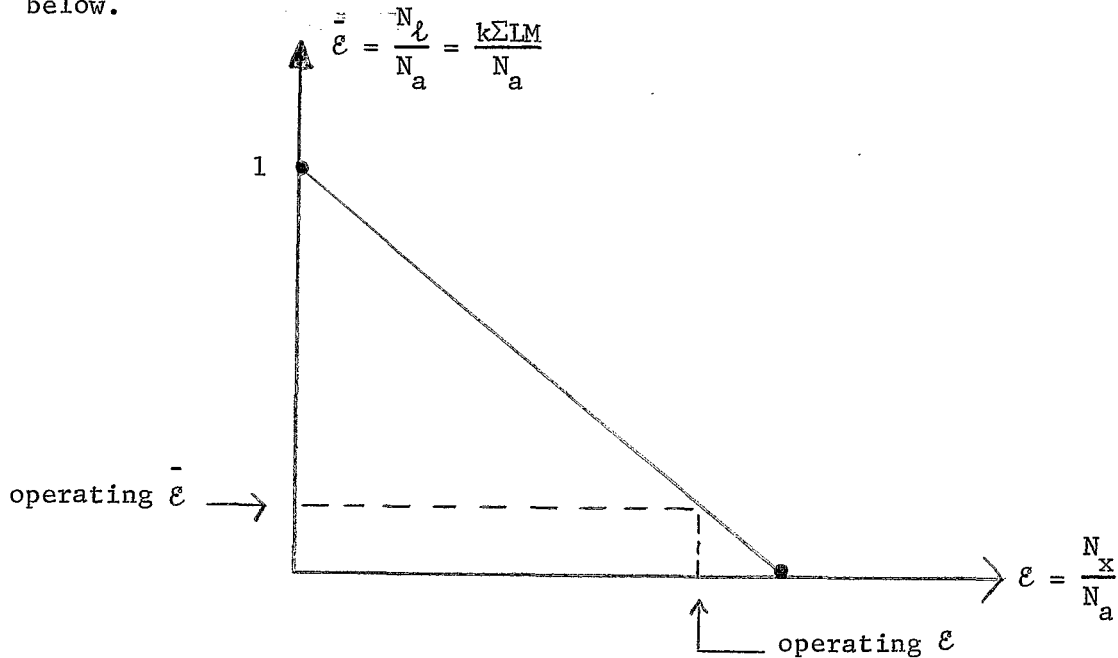
where $\mathcal{E} \equiv \frac{N_x}{N_a}$, the traditional extraction efficiency,

k = a constant to be experimentally determined,

ΣLM = the sum of the readings of the loss monitor system to be described,

$\bar{\mathcal{E}}$ = the inefficiency.

The above equations are merely straight lines between one intercept where the extraction efficiency is 100% (losses = 0) and the other intercept where extraction efficiency is 0% (losses = 100%) as indicated in the plot below.



The constant k is chosen to normalize the ordinate when the following experiment is done. The extraction channel is purposely detuned so that all the beam is lost in the extraction channel to satisfy the $\bar{\epsilon} = 1, \epsilon = 0$ condition. The corresponding LM readings and the accelerated beam are measured (N_x must equal 0). The k is calculated to make the expression $\frac{k \sum LM}{N_a}$ equal to the unity when all the beam is lost in the channel.

One can now retune the extraction system to the nominal operating parameter. Intermediate points may be taken to see if a straight line exists. Deviation from a straight line could indicate that other unmeasured losses exist, a nonlinearity in the external beam intensity monitor, or a nonlinearity in the loss monitor system itself. Should a straight line relationship exist, extrapolation to 100% extraction efficiency (losses $\equiv 0$) provides a check on the intercalibration of the internal and external intensity monitors, since with zero extraction losses both monitors must agree if no other losses exist. A supplementary measure of losses elsewhere in the machine could be used as further verification of this condition.

III. The Loss Monitor System

Three radiation loss monitors each 2 ft in length were located on the wall of the AGS enclosure near locations F5, F7, and F10 corresponding to the first extraction septum magnet, an intermediate area, and the second extraction septum magnet respectively. The loss monitors were judiciously placed with the hope that they would be sensitive to any losses in the extraction system and that the sum of their readings would be relatively independent of where the loss occurred. The extent to which this condition is satisfied can be determined experimentally by varying the dominant extraction loss location as septum magnet F5 and F10 are independently, remotely movable.

The electronics for the loss monitor consists of a gated integrate and hold circuit which was timed to integrate the beam loss monitor signals during extraction only. Following the end of extraction the voltages on the individual integrators were digitized and recorded.

IV. The Experiment

The extraction channel was systematically detuned in a manner to increase the losses in the extraction channel. At each operating point, readings were recorded for the AGS internal intensity monitor, the external intensity monitor, and the individual loss monitor readings. In the limit, $\epsilon = 0, \bar{\epsilon} = 1,$

all accelerated beam was lost in the channel by moving either the F5 septum magnet or the F10 septum magnet into the beam and turning off the magnetic field in the latter. Unless this field was turned down, approximately 2% of the beam would leak out under the most unfavorable extraction condition which could be contrived. The dependence of the sum of the loss monitor readings could be determined by changing the location of the dominate beam loss from F5 to F10.

The readings of BNL loss monitors on the extraction system were also recorded in the experiment.

In the data which follow "CBM" (1 count per 10^{10} protons) designates the reading of the AGS internal intensity, "SEC" (1 count per 10^9 protons) designates the reading of the external secondary emission chamber, and Σ LM designates the sum of the individual loss monitor readings.

V. Results

The results of this experiment are illustrated in the attached graph where the average of five or more data at each operating point is plotted.

The Σ LM at $\bar{e} = 1$, where all the beam was lost in the extraction channel, were relatively independent (within 2%) of whether the beam was lost predominantly at F5 or at F10. We were apparently lucky in mounting the loss monitors at good locations; however, should a dependence have been noted, it would have been possible to adjust electronically (weight) the gains of the individual loss monitors so that the Σ LM would be independent of the loss location.

The points derived from the newly installed loss monitor system (indicated as Hornstra L.M.) very nearly lie in a straight line. Extrapolation of this line to the abscissa (Σ LM equal zero) shows an SEC/I ratio of approximately 0.68 suggesting that an intercalibration adjustment is required or 1 CBM proton equals 1.47 SEC protons. The calibration of the loss monitor system is $\sim 2.7 (10)^9$ protons count⁻¹ when all three loss monitor readings are summed.

This result is comparable to the results of in ring foil measurements that gave 1 CBM proton = 1.32 foil protons⁽¹⁾. The SEC was last calibrated by foils in August 1973. This result could be invalidated if during normal extraction beam is lost outside the area observed by the Loss Monitors used. The various radiation monitors

(1) L. Blumberg, J. Gabusi, J.W. Glenn, G. Levine, D. Rahm
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around the ring were observed during normal HEP running (with $\sim 1.5 \times 10^{11}$ on G10). Of the radiation noted $\sim 90\%$ was concentrated in the F5 to F10 region and $\sim 10\%$ was elsewhere including the G10 area.

The best efficiency obtained during the tests on August 21 was 85% but the bump for G10 targetting was off and the SEB was not returned to the new orbit. On August 28 the Σ LM's CBM and SEC were recorded with no beam on G10 but the G10 bump on. The inefficiency was 10% but the efficiency was 96% (the point marked X on fig. 1). At this time the external beam was steered to put all the protons at C station, and it is felt that the efficiency was actually 90% ($1 - \bar{\epsilon}$) while the SEC was reading 6% high due to the fact the beam was traversing the SEC at an atypical location. During normal HEP operation in the latter part of August, with normal steering, the efficiency was calculated on a pulse by pulse basis using a formula or $\epsilon = \text{SEC} * 14.3 / (\text{CBM} - (\text{G10 Tell}) / 11.)$. (The constant 14.3 is 100/7.) This "efficiency" often went as high as 93%. Unfortunately the Σ LM was not recorded during this time.

The BNL loss monitors roughly indicate the same condition as above; however, a considerable scatter existed in the readings at $\bar{\epsilon} = 1$. It should be noted that these loss monitors were not mounted with this experiment in mind and in general are highly sensitive to local losses.

VI. Discussion

If one assumes that the above experiment is consistent, then other information can be determined. Although one can calculate the extraction inefficiency from the ratio of $k\Sigma$ LM to internal intensity, it is better, from a practical point of view, to calculate the inefficiency in terms of the extracted beam intensity, N_x . If in Eq. (2) one substitutes for $N_a = N_x + N_{lx}$ (Eq. 1) then

$$I = \frac{N_x}{N_x + N_{lx}} + \frac{N_{lx}}{N_x + N_{lx}} \quad (5)$$

or

$$\epsilon = \frac{N_x}{N_x + N_{lx}} \quad ; \quad \bar{\epsilon} = \frac{N_{lx}}{N_x + N_{lx}} \quad (6)$$

Calculating the extraction efficiency or inefficiency from Eq. (6), avoids an error which could come if the calculation were based on N_a since it is possible for accelerated protons to be lost other than in the extraction system. In particular if G10 target is used, the calculations from Eq. (6) must be used.

It is possible with the use of a calibrated extraction loss measuring system to assess how much beam is lost to other processes by noting the magnitude of any inequality of Eq. (1). If G10 targeting is the dominate source of other losses, the equation could be expanded as follows:

$$N_a = N_x + N_{lx} + N_{G10} \tag{7}$$

where N_{G10} represents the number of protons used in targeting at G10. Should a calibrated loss monitor system be placed at the G10 target, Eq. (7) would then be over constrained, and an expanded equation could be written as follows:

$$N_a = N_x + N_{lx} + N_{G10} + N_{other} ,$$

where N_{other} represents all unmeasured losses. A properly intercalibrated internal and external intensity monitor is assumed here and above.

It appears the Loss Monitor system is a more stable and sensitive measure of extraction efficiency. In all cases, the ratio formed $\frac{\sum LM}{N_x}$ is a useful ratio to monitor and minimize as a quality factor of the extraction system. A similar system should be installed on the fast extraction system where this concept would be more powerful as the extraction efficiency is closer to 100%.

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Figure 1

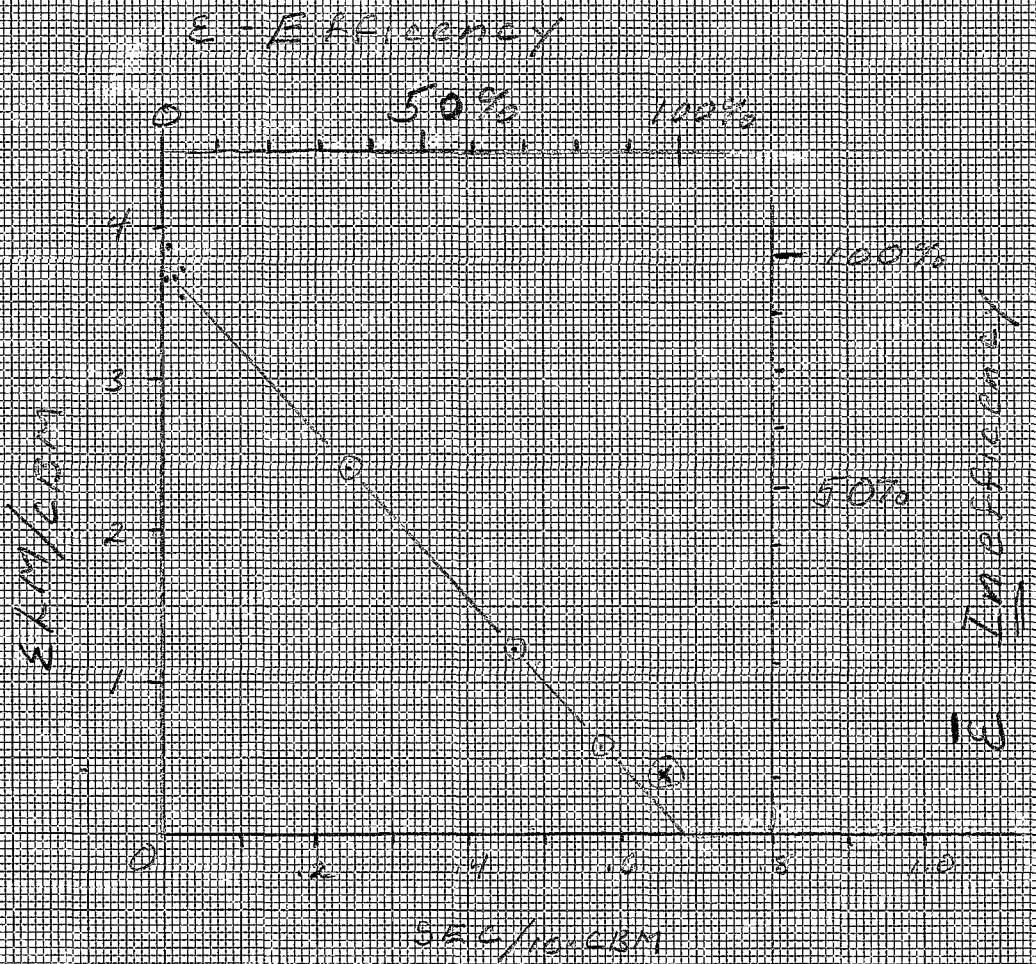


Fig. 1

Extraction Efficiency

