national accelerator laboratory

FN-252
1105.120

A METHOD AND A SIMPLE DEVICE TO PRECISELY MEASURE ACCELERATOR EXTRACTION EFFICIENCY AND BEAM LINE TRANSPORT EFFICIENCY

F. Hornstra and E. Bleser

April 26, 1973

I. Introduction

When accelerator extraction efficiency or beam line transport efficiency approaches 100 per cent, accurate measurement of either efficiency or beam losses becomes difficult. Typically, the ratio of the extracted beam to the accelerated beam is used to measure extraction efficiency. For beam line transport efficiency, the ratio of two intercalibrated intensity monitors is used, one intensity monitor being at the beginning and the other one at the end of the system. Aside from problems associated with measuring beam intensity in the presence of background radiation caused by beam losses, accurate loss measurement with the use of two intensity monitors requires precise intercalibration of the monitors as well as high resolution in the readings. For example, when efficiency is 95 per cent, knowing losses to a certainty of 10 per cent requires better than 0.25 per cent precision in the intensity measurements. As efficiency approaches 100 per cent, accurate measurements of the losses and efficiencies by this technique are virtually impossible. For this reason, a method and an instrument were devised to precisely measure extraction efficiency or transport efficiency with the use of but one intensity monitor.

II. The Device

Mounted along the ceiling of the transfer hall is a 400-foot long ionization chamber similar to the SLAC long

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

ionization chamber.[1] This device dubbed "The Loss Monitor", runs parallel to the accelerator extraction beam line components. As it spans the entire extraction system, the monitor is sensitive to losses occuring anywhere in the chain. The monitor signal goes to an integrating and digitizing circuit. A digital value representing the integrated signal acquired during extraction is compared to the number representing main ring accelerated beam intensity. This ratio is a useful measure of the relative extraction losses. Calibration of the monitor is described below.

III. The Method

One can write

$$Npe = Npa - Npl \qquad (1)$$

where

Npe = number of protons extracted
Npa = number of protons accelerated
Npl = number of protons lost,

and therefore,

$$1 = \frac{Npe}{Npa} + \frac{Npl}{Npa} \qquad (2)$$

$$1 = \varepsilon + k\,\frac{LM}{Npa} \qquad (3)$$

$$1 = \varepsilon + \bar{\varepsilon} \qquad (4)$$

where

$\varepsilon \equiv \frac{Npe}{Npa}$, the traditional extraction efficiency

k = a constant to be experimentally determined

LM = the loss monitor reading

$\bar{\varepsilon} \equiv$ inefficiency.

Equation (3) is plotted below with ε as the abscissa, and the ordinate as $k\frac{LM}{Npa}$.

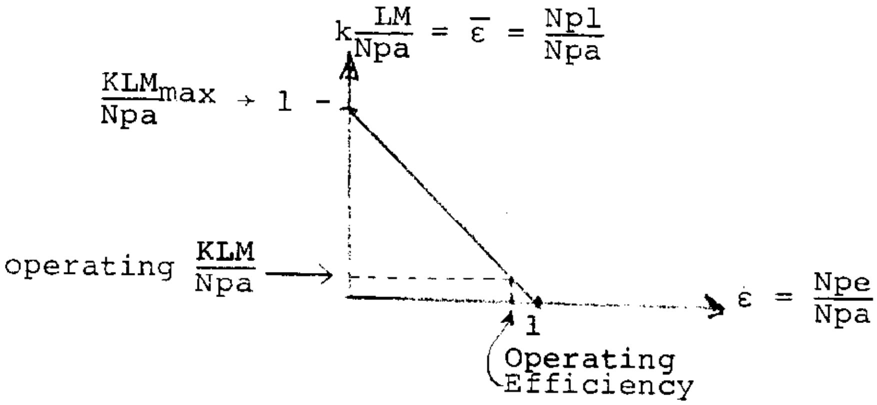

Figure 1

Theoretical Loss Monitor, Main Ring Intensity Ratio $\left(\frac{kLM}{Npa}\right)$ as a function of extraction efficiency $\left(\frac{Npe}{Npa}\right)$

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 channel. This means that $\varepsilon = 0$ and $\bar{\varepsilon} = 1$. The corresponding LM and the accelerated beam are measured. The constant k is calculated to make the expression $k \frac{LM}{Npa}max$ equal to unity when all beam is lost in the channel. The loss monitor is now calibrated.

When the extraction line is tuned, the normalized loss monitor reading, i.e. the operating $k \frac{LM}{Npa}$ is monitored. The corresponding operating efficiency, ε, is readily determined from equation (4) or graphically determined as indicated above. Since this calculation involves subtracting a relatively small number from one, an accurate result is possible.

Note that, in principle, extraction efficiency measured by this method requires no external beam intensity monitor. However, the presence of an external beam monitor allows one to check the above theory by plotting $k \frac{LM}{Npa}$ as a function of ε, determined by the ratio of $\frac{Npe}{Npa}$. This experiment has been done, and the result is attached as Figure 2. Npe was measured with a secondary emission monitor in the extracted beam, and Npa was measured with a beam current torroid in the accelerator. This plot gives $k \approx 0.05$ for "The Loss Monitor" for 300-GeV protons. Some scattering of the points was expected as varying amounts of beam were aborted, which was not accounted in these measurements; nevertheless, the curve is in agreement with the theory.

IV. A Variation

As mentioned above the loss monitor concept offers a way to measure extraction efficiency without the necessity of an external intensity monitor. Conversely, the technique offers a way of checking the MR internal beam intensity if a calibrated external monitor and a calibrated loss monitor exists. It is possible to simply add the loss, with the appropriate multiplier, to the external monitor reading to determine internal intensity. Previously, such intercalibration required 100 per cent extraction efficiency.

V. Beam Transport Efficiency

In a similar manner, beam transport efficiency through a beam line may be measured. Consider a beam transport

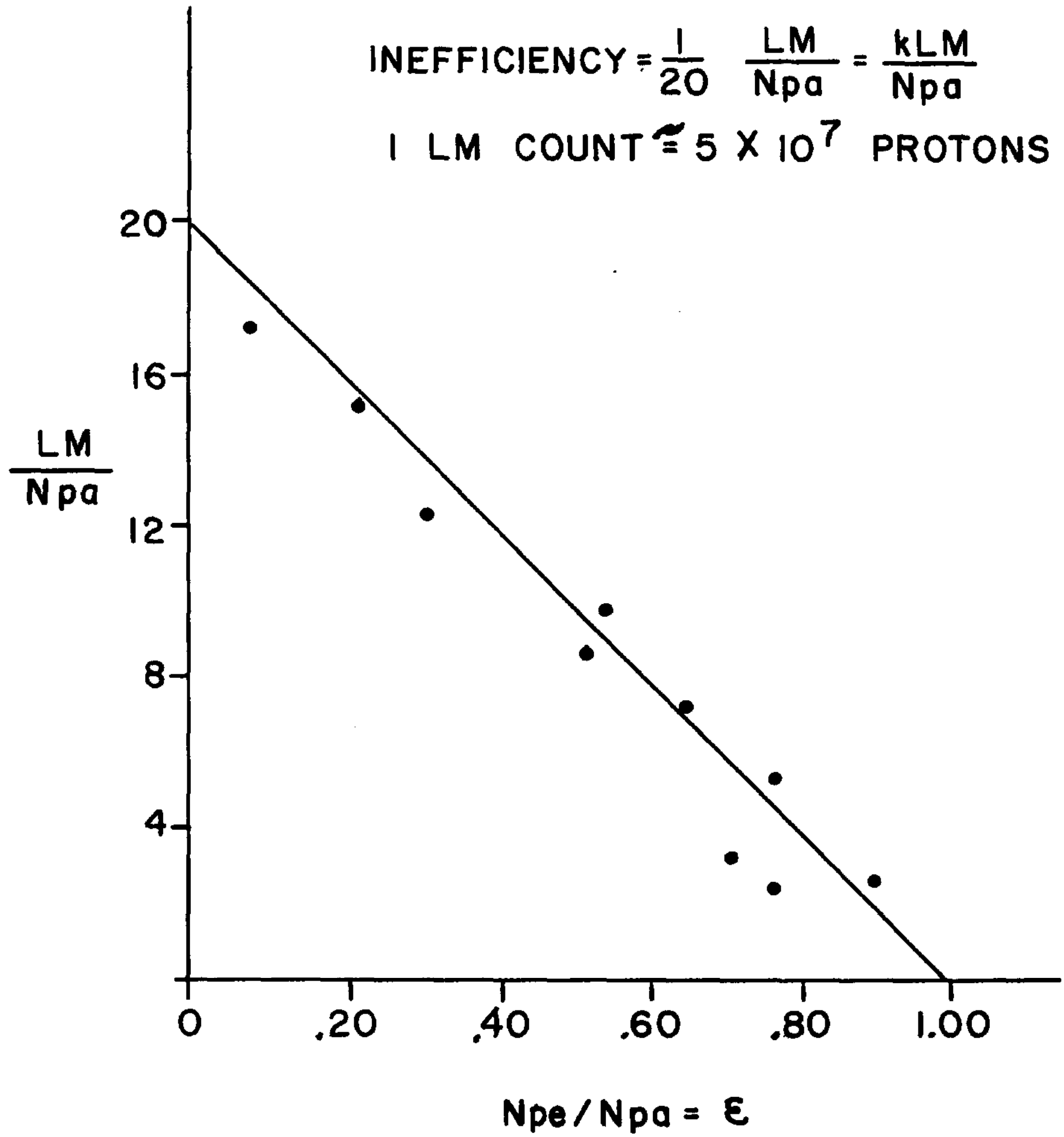

Figure 2
Actual Loss Monitor, Main Ring Intensity Ratio $\left(\frac{LM}{Npa}\right)$ as a *function of extraction efficiency.*

system such as depicted below consisting of an intensity monitor followed by "collimators", followed by a location at which a knowledge of the beam intensity may be desired.

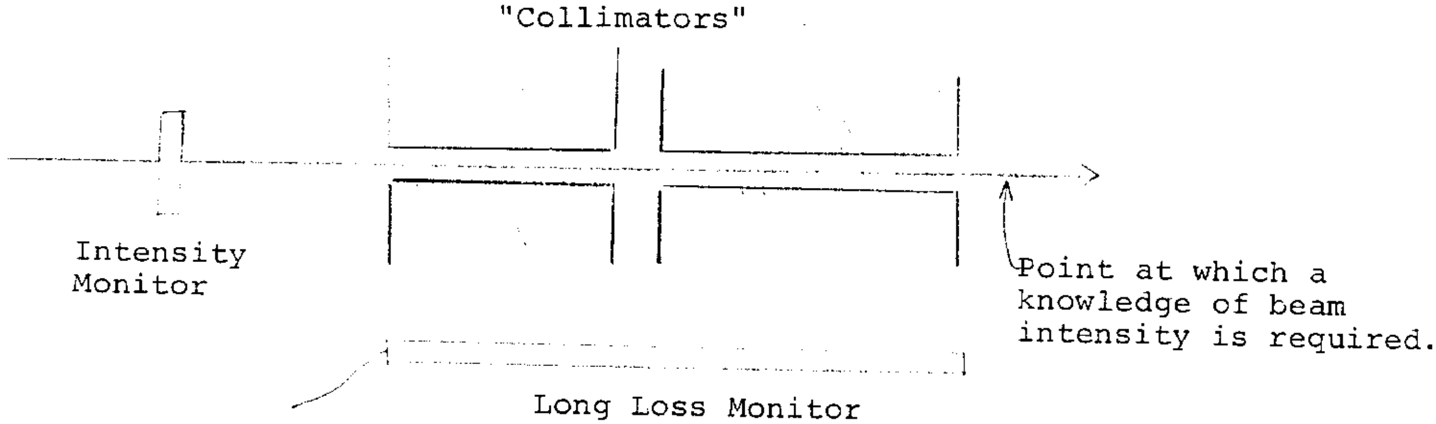

Figure 3

Typical Beam Transport System

The "collimators" always exist either intentionally or unintentionally as beam line components such as magnets, beam pipes, or other devices. In any case, a knowledge of the beam intensity at the entrance to the system and of the beam lost on the system allows one to determine the beam at the end of system in the following way.

The procedure, much as discussed previously, is to calibrate the loss monitor by purposely steering all the beam onto the "collimators" and obtaining the resulting ratio of the loss monitor reading to the intensity monitor reading. Call this result the absolute loss ratio, ALR. Next tune the beam for the desired operating conditions. Let the ratio of the loss monitor to the intensity monitor at any operating point be called the operating loss ratio OLR. A new ratio formed by the OLR to ALR is a direct measurement of the transport inefficiency, $\bar{\varepsilon}$, which when subtracted from 1 yields the transport efficiency.

In other words, it is necessary only to establish one point on the curve,

$$1 = \bar{\varepsilon}_\tau + \varepsilon_\tau \qquad (5)$$

by satisfying the boundary condition of $\varepsilon_\tau = 0$ so that $\bar{\varepsilon} = 1 = \frac{OLR}{ALR}max$ as indicated in the graph below. The other intercept is a canonical point, i.e.,by definition when $\varepsilon = 1$, the loss monitor must and will read 0!

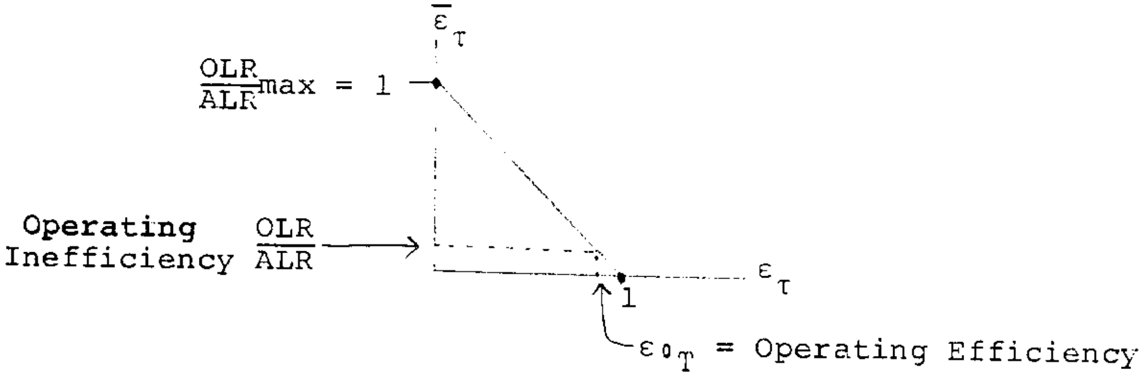

Figure 4

Transport Inefficiency as a function of Transport Efficiency

IV. Conclusion

The method presented here has been demonstrated to be of great value in monitoring and increasing accelerator extraction efficiency. Simple and economical to implement, the concept has also found other applications such as measuring and optimizing splitting station efficiency and aligning extraction channel components. Suggested additional uses include external target monitoring, beam dump monitoring, internal target monitoring, and beam abort system monitoring.

Reference

1. M. Fishman and D. Reagan, The SLAC Long Ion Chamber System for Machine Protection, IEEE TRANS NUCL SCI, NS-14-3, June 1967.