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MEASUREMENT OF THE SYNCHROPHASOTRON SLOW-EXTRACTION EFFICIENCY

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When the extraction efficiency is about 100 per cent difficulties arise in its measurement with sufficient accuracy. A measurement of the extracted and circulating (accelerated) beam intensities, the ratio of which determines the efficiency, is done with an accuracy not better than 5–10 per cent.

This paper proposes a method for determining the efficiency with high enough accuracy. It is based on the fact that a total flux of secondary particles radiated by the accelerator into the surroundings is proportional to the number of accelerated particles lost inside the vacuum chamber. This was confirmed at the synchrophasotron by measuring the number of pulses produced by the flux of secondary particles in scintillation counters placed around the accelerator. Measurements were performed for different conditions of the beam spill on the internal target and vacuum chamber walls at a constant intensity of the accelerator beam. In all cases the total counting rate was constant within ± 5 per cent.

Thus, when the extraction system operates, the secondary radiation detectors record a value corresponding to the beam part not ejected out of the accelerator. When the extraction system is turned off they detect a value corresponding to the total intensity of the accelerator beam. The secondary particle flux measurement with extraction and without it makes it possible to find the extraction efficiency in case of the linearity of detectors:

$$E_f = 1 - \bar{N}_\Sigma{}^l / \bar{N}_\Sigma{}^0$$

where $\bar{N}_\Sigma{}^l$ is the average number of pulses detected when the extraction system is on, $\bar{N}_\Sigma{}^0$ is a similar value when the system is off.

Consequently, when measuring the values $\bar{N}_\Sigma{}^0$ and $\bar{N}_\Sigma{}^l$ with rather large errors (5–10 per cent) it is possible to determine the efficiency with a good accuracy that rises with increasing efficiency.

The measurement of the slow extraction efficiency at the Dubna synchrophasotron has been done by this method and is equal to 94 ± 0.5 per cent.

The extraction efficiency can be measured in two ways:

1) From the ratio of the number of particles extracted from the chamber I_e to the total number of accelerated particles I_0,

$$E_{\text{eff}} = I_e / I_0. \tag{1}$$

2) From the ratio of the number of particles remaining in the chamber after the extraction I_l to the total number of accelerated particles,

$$E_{\text{eff}} = 1 - I_l / I_0 \tag{2}$$

(since $I_e = I_0 - I_l$).

If the extraction efficiency is nearly 100 per cent, the first method requires very precise measurement of the quantities in expression (1). However, the currently available detectors for measuring the intensity of the extracted and circulating beams produce an error of $\gtrsim 5$–10 per cent.[1]

The extraction efficiency can be determined much more accurately with expression (2), since the second method allows a measurement error for I_l and I_0 of this order of magnitude. However, with this method it is difficult to measure the small fraction of particles scattered by an extraction system or by an accelerator chamber.

Baconnier *et al.*[2] measured I_l with use of ionization chambers calibrated for the absolute loss of protons in a slow-extraction system. Since it is rather difficult to calibrate the chambers, the measurement error of I_l is large.

In this paper we propose a method[3] for measuring the extraction efficiency based on the assumption that the total activity of the threshold detectors situated around the accelerator ring is proportional to the total number of protons lost in the accelerator.[4] We used the proton synchrotron of the

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J.I.N.R. to verify our assumption by measuring the total number of pulses $\bar{N}_\Sigma$ induced by a flux of secondary particles in scintillation detectors placed around the accelerator ring:

$$\bar{N}_\Sigma = \sum_{i=1}^{k} \frac{\Delta s}{S} \bar{N}_i \alpha_i, \tag{3}$$

where $\bar{N}_i$ is the average number of pulses per cycle for the ith detector ($i = 1, \ldots, k$), α_i is the relative calibration factor for a detector in a flux of secondary radiation,[5] S is the distribution perimeter for the detectors, and Δs is the spacing between the detectors.

The value of $\bar{N}_\Sigma$ was determined for different modes of beam dumping on thin and thick targets and also for diversion of the beam to the chamber walls. The measurements were carried out by the 'system for monitoring the loss of particles'[5,6] during a time interval of ≈ 300 msec at the end of the acceleration cycle at constant intensity I_0. The detectors were mounted on the outside and inside walls of the chamber. The total value of $\bar{N}_\Sigma$ was determined from 30+4 points (four additional measurements were made in the region of the septum magnet), which were obtained by shifting 15 counters by $\approx \Delta s/2$ along the azimuth.

It was found that the total number of pulses determined according to expression (3) was in all cases the same to within ± 5 per cent.

Thus, when the extraction system is operating, the detectors will record the quantity corresponding to the fraction of the beam of particles not extracted from the accelerator, and when the extraction system is turned off, the detectors will record the total intensity of the accelerated beam. Henceforth the ratio I_l/I_0 can be obtained in two ways. The first consists in measuring the number $\bar{N}_\Sigma{}^l$ corresponding to the given intensity I_0 when the extraction system is operating. After the system is turned off, the beam intensity in the accelerator is decreased to the level of I_{0l}, at which the total number of counts is equal to $\bar{N}_\Sigma{}^l$. In this case $I_l = I_{0l}$. This method is preferred if the error in measuring the circulating beam intensity is fairly small.

In using this method to determine the slow-extraction efficiency of the Dubna Synchrophasotron,[7] we obtained a tentative plot of $\bar{N}_\Sigma$ vs I_0, shown in Figure 1. I_l was taken from the plot on the basis of the total count $\bar{N}_\Sigma{}^l$ when the extraction system was

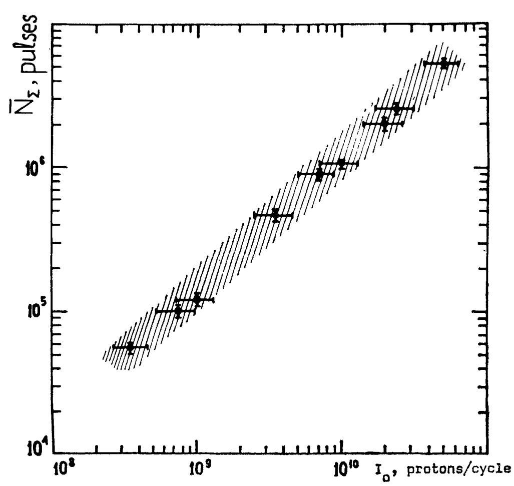

FIGURE 1 Dependence of the total number of pulses on the intensity of the proton synchrotron.

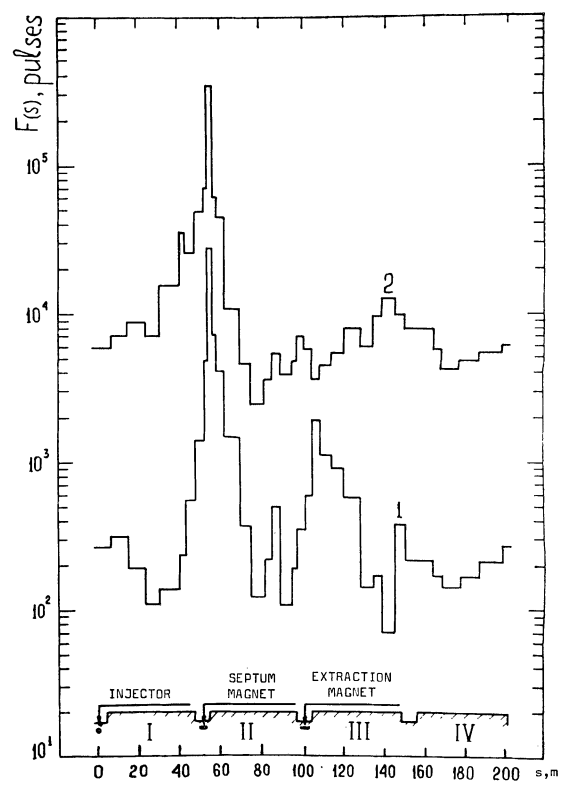

FIGURE 2 Number of pulses as a function of the proton synchrotron azimuth (34 detectors were used with delta plates 0.6 g/cm² thick); 1, slow extraction mode; 2, diversion to the septum of the first extraction magnet.

operating. The ± 5 per cent error in the efficiency is primarily attributable to the error of the pickup electrodes in determining the intensity.

The second method consists in alternately measuring the counts $\bar{N}_{\Sigma}{}^{l}$ when the extraction system is operating and when it is turned off $\bar{N}_{\Sigma}{}^{0}$ at constant beam intensity in the accelerator. This makes it possible to substitute $\bar{N}_{\Sigma}{}^{l}/\bar{N}_{\Sigma}{}^{0}$ for I_l/I_0 in expression (2), if the detector readings are linear in the range $\bar{N}_{\Sigma}{}^{l}$ to $\bar{N}_{\Sigma}{}^{0}$:

$$E_{\text{eff}} = 1 - \bar{N}_{\Sigma}{}^{l}/\bar{N}_{\Sigma}{}^{0}. \tag{4}$$

The second method for measuring the slow-extraction efficiency of the proton synchrotron yielded a value of $E_{\text{eff}} = 94 \pm 0.5$ per cent.

Figure 2 is a plot of the distribution of the radiation flux of the secondary particles

$$F(s) = \frac{\Delta s}{S} \bar{N}_i \alpha_i \tag{5}$$

obtained in the extraction mode (histogram 1) and as a result of diverting the beam to the septum of the first extraction magnet (histogram 2). The measurements were performed during several cycles at stabilized accelerator intensity, for which the rms statistical error was $\leqq \pm 2$ per cent.

The statistical error in determining the number of pulses varied for different counters from ± 0.15 to ± 10 per cent. However, since $\bar{N}_{\Sigma}$ largely depends on the contribution of $\bar{N}_i$, which is close to the maximum value of $F(s)$, the contribution of the statistical weighted mean errors to the measurement error amounted to ± 1.5 per cent for $\bar{N}_{\Sigma}{}^{l}$ and ± 0.4 per cent for $\bar{N}_{\Sigma}{}^{0}$.

The error in determining the calibration factor α_i was about ± 0.6 per cent. The counting errors resulting from the secondary radiation flux of $\sim 10^6$ particles in 300–400 msec (extraction time) were $\leqq 5 \times 10^3$, i.e., 0.5 per cent. This error underestimates the measured efficiency.

The error of $\bar{N}_{\Sigma}$ depends on the number of detectors situated around the accelerator ring. As shown above, this error is well within the limits of ± 5 per cent.

The total error in measuring the efficiency, which depends on the errors mentioned above, according to expression (4), is ± 0.52 per cent.

It can be seen from Figure 2 that the septum of the first magnet is the principal source of secondary particles. In the initial measurements the beam was transmitted through 2 g/cm^2-thick measuring delta plates mounted at the entrance of the second internal magnet, which reduced the efficiency to 92.2 per cent. The efficiency increased to the value cited above after the plate thickness was reduced to 0.6 g/cm^2. However, as follows from Figure 2 (dependence 1), the measuring system is sufficiently sensitive to locally isolate these losses, which amount to several tenths of one per cent.

According to a calculation performed elsewhere,[7] the beam loss in the septum amounts to 3–4 per cent if the septum's effective thickness is assumed to be about 5 mm. The loss for the delta plates is estimated at about 0.8 per cent. Moreover, since by circulating the beam the intensity of the proton synchrotron is further reduced by several tenths of one per cent in ~ 300 msec,[5] we may assume that the calculated and measured efficiencies are in satisfactory agreement.

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REFERENCES

1. Ch. Iselin, CERN, MPS-SI/Note, MAE/68-2, 1968.
2. Y. Baconnier, O. Barbalat, and D. Dekkers, *Proc. of the VII International Conference on Charged-Particle Accelerators, Erevan, 1969*, p. 565.
3. I. B. Issinky and L. N. Zaitsev, Invention N1844346, Priority 9 Nov. 1972.
4. W. S. Gilbert *et al.*, Lawrence Berkeley Laboratory Report UCRL-17941, 1968.
5. V. Ya. Gvozdev *et al.*, JINR Report P16–6433, Dubna, 1972.
6. M. P. Belyakova *et al.*, *Proc. of the VI International Symposium on Nuclear Electronics, Warsaw, 1971*, p. 370 (JINR Report D13–6210, 1971).
7. I. B. Issinsky *et al.*, *Particle Accelerators*, **5**, 215 (1973).

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