

A NEW SCHEME OF BEAM EXTRACTION OF THE ARGONNE
ZERO GRADIENT SYNCHROTRON*

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A new beam-extraction system with high efficiency was developed for fast extraction of protons from the Argonne Zero Gradient Synchrotron (ZGS). In this system, orbits of the circulating protons are shifted towards the energy-loss target by a pulsed deflecting magnet.¹ After hitting the target placed radially outside of the circulating beam, the particles jump into an ejection magnet, which is located at about a half wavelength of the horizontal betatron oscillation downstream in the ZGS. The beam extraction can be accomplished in periods of time ranging from 20 to several hundred microseconds. Details of the beam optics of the extraction system are given elsewhere.² The purpose of this paper is to describe the extraction system briefly and to report the recently obtained results concerning its performance.

The shift of equilibrium orbit caused by the pulsed magnet is shown in Figure 1. When the direction of the pulsed magnet field is the same as that of the ZGS octant magnets, the orbit center is moved toward a straight section, $\theta = 0$, where both the pulsed magnet and energy-loss target are located. In this diagram the entrance to the extraction channel is located at $\theta = \pi/\nu_r$ downstream from the energy-loss target. (The radial betatron frequency, ν_r , is about 0.8.) To a very good approximation the magnitude of the displacement at the position of the bumper magnet is

$$X_o = b(\cos \nu \pi) = \frac{BL}{2B_o \nu_r \tan \nu_r \pi}$$

In this expression, b is the maximum shift of the equilibrium orbit for a given B . B and B_o are the strengths of the pulsed magnet and synchrotron guide magnets, respectively. The effective length of the bumper magnet is L . It has been found to be necessary to correct the synchrotron RF corresponding to the disturbance in the orbiting frequency due to the pulsed magnet to prevent the loss of the beam from the RF buckets.

The radial phase space occupied by the circulating beam at full energy is usually a little more than 40 milliradian inches. There is a considerable slicing effect of this phase space as

the beam moves into the energy-loss target even at the fastest extraction. In actual practice the horizontal phase space occupied by the extracted beam is about 2.5 milliradian inches.

A comparison of the new system (I) with the conventional Piccioni system (II) may be made as follows:

a. Damping of the betatron oscillation amplitude is required in II, and it is performed by a lip attached to the energy-loss target. The damping process may not be satisfactory for a beam with large betatron oscillation amplitude. The use of a lip causes momentum spread, angular spread, and secondary particle production.

b. For rapid extractions, time for damping by the lip is not allowed resulting in lower efficiencies.

c. So far, the Piccioni system is restricted to slow beam spills and the new system to fast spills. The latter restriction results from the beam scraping the improperly aligned surface of the target when it is moved onto it too slowly.

Calculations were made of the acceptance of the extracting beam transport system.² The most restrictive conditions occur in the horizontal phase space and are indicated in Figure 2. The area labelled L-3 represents the horizontal beam emittance which includes 70% of the circulating beam for a spill time of 40 μ sec. The loss in the energy-loss target due to nucleon interactions should lower the overall efficiency to about 60%. An understanding of the straight-line barriers can be obtained by referring to Figure 3. The barriers a, b, c, and d in Figure 2 correspond to the physical obstructions A, B, C, and D in Figure 3. It should be recalled that S-1 in Figure 3 is one-half radial betatron wavelength downstream from the energy-loss target and the pulsed magnet.

This new system was first used for the Argonne neutrino experiment in which a fast beam spill of 50 to 100 μ sec was required. The average extraction efficiency during the run was between 50 to 60%, and the highest efficiency was 70%. This is compared to 25 to 35% for the Piccioni system installed in the ZGS. The most important parameter in this extraction is the parking position of the circulating beam before

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the pulsed magnet is energized. A typical optimization is shown in Figure 4 where the parking position is described in terms of the synchrotron RF frequency. The surface of the energy-loss target must be parallel to the beam entering the target. This is to prevent loss of beam by some of it passing through only a portion of the total target length and not receiving an adequate jump in energy. The target orientation was surveyed to be almost in the correct angular position in rotation about a vertical axis. Then, with the beam as a monitor, it was rotated to produce an optimization curve as shown in Figure 5.

The successful operation of this new extraction system could not have taken place

without the close cooperation of R. E. Daniels, L. G. Ratner, and R. L. Martin. The essential assistance must be acknowledge of H. Varga and J. Weber who built the pulsed magnet.

References

- 1 An engineering description of this magnet is given in a companion paper, F. Hornstra, Jr., and H. J. Varga, "A Fast Sequencing Bipolar Energy Discharge System for the Beam Bumper Magnet."
- 2 S. Suwa and A. Yokosawa, "New Extraction System for a Synchrotron by a Pulsed Magnet and Energy Loss Target," to be published in Nuclear Instruments and Methods.

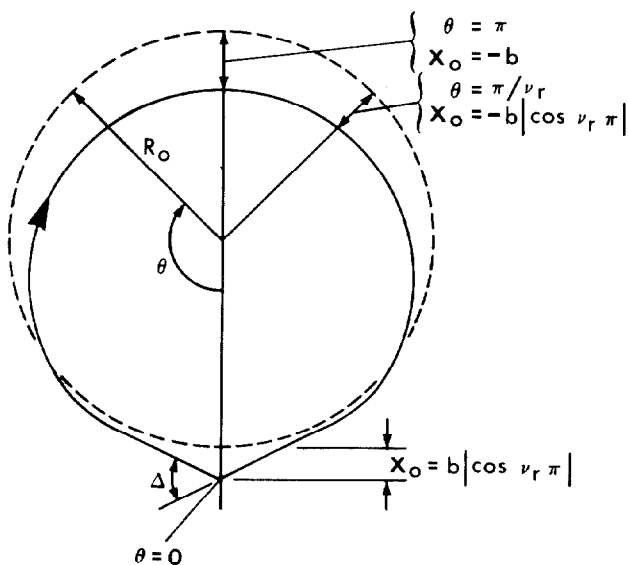


Fig. 1 Orbit Distortion and Displacement Due to Pulsed Magnet

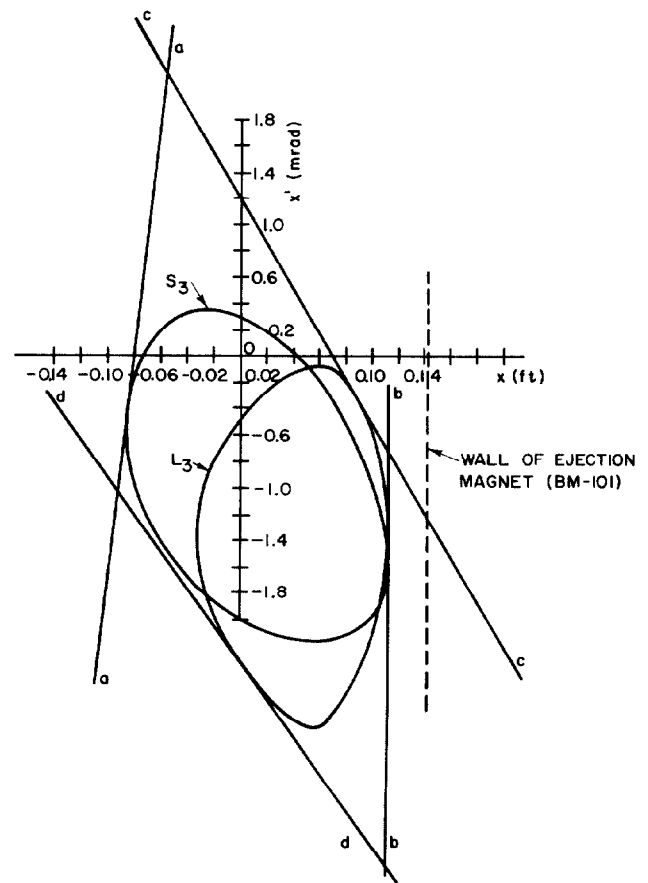


Fig. 2 Phase Space in the X-Coordinate Occupied by 60% of the Circulating Beam after Targeting

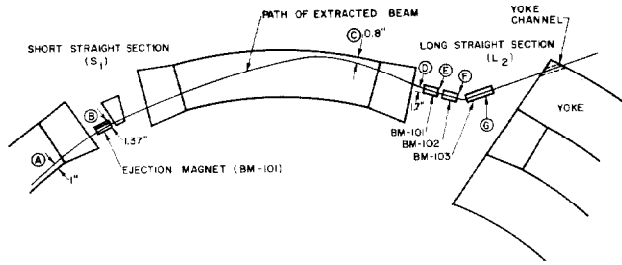


Fig. 3 Beam Extraction Channel Showing the Obstructions which Limit the Beam in the X-Coordinate

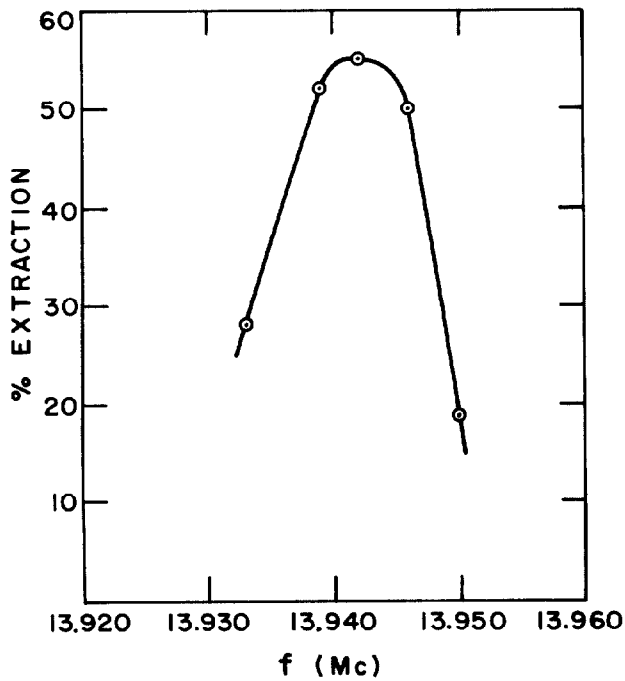


Fig. 4 Dependence of the Extraction Efficiency upon the Parking Radius of the Circulating Beam Measured in Terms of the ZGS Radio Frequency

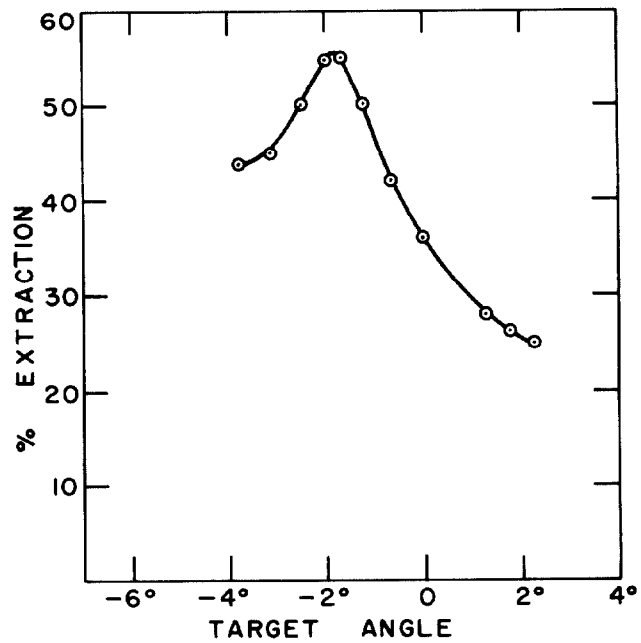


Fig. 5 Dependence of the Extraction Efficiency upon the Angular Position of the Energy-Absorption Target