

LOS ALAMOS PROTON STORAGE RING EXTRACTION SYSTEM\*

Daniel W. Hudgings and Andrew J. Jason

Los Alamos National Laboratory, Los Alamos, NM 87545

Summary

The unprecedented peak and average proton currents and extraction rates from the Proton Storage Ring (PSR) under construction at the Los Alamos National Laboratory present new problems in beam extraction. Activation caused by beam spill must be minimal to permit hands-on maintenance. Timing requirements are uncommonly stringent. Solutions to these problems are outlined below.

Introduction

The Proton Storage Ring<sup>1</sup> will be part of the upgraded Weapons Neutron Research (WNR) spallation neutron source. The 800-MeV negative hydrogen ion beam from the LAMPF linac will be accumulated by a novel charge-changing injection technique<sup>2</sup> and extracted for delivery to the neutron production target. The purpose of the PSR is to change the temporal structure of the LAMPF beam to structures more suitable for time-of-flight neutron measurements while still maintaining high peak and high average neutron fluxes.

Two operating modes are provided. A short-bunch high-frequency (SBHF) mode (for basic nuclear physics research with fast neutrons) accumulates and stores six 1-ns bunches of  $10^{11}$  protons. The bunches circulate at ~60-ns intervals. Accumulation occurs for 108  $\mu$ s every 8.3 ms with individual bunches extracted at 1.4-ms intervals. This mode presents the most stringent timing requirements of the extraction system.

A long-bunch low-frequency (LBLF) mode (for condensed matter research with thermal and epithermal neutrons) accumulates a single 270-ns bunch of  $5.2 \times 10^{13}$  protons in 750  $\mu$ s every 83 ms. The circulating proton beam is extracted promptly after accumulation. Beam spill allowances for the PSR are set by the LBLF mode's high currents: 46-A peak circulating current, 105-mA average circulating current, 100- $\mu$ A average extraction line current. At the space-charge limit for 46 A circulating current, the beam emittance is  $\epsilon_x = 0.7 \text{ cm}\cdot\text{mrad}$  and  $\epsilon_y = 2.0 \text{ cm}\cdot\text{mrad}$ .

Figure 1 shows the circulating current beam profile in the middle of a straight section. The beam core is determined by the PSR lattice parameters and momentum spread ( $\delta p/p = 4 \times 10^{-3}$ ). The beam halo, which largely determines beam spill in the PSR and extraction line, is mainly due to the injected beam emittance and beam scattering in the injection stripping foil.

Extraction Kicker

In the SBHF mode the Landau damping time for coherent transverse motion of the bunch is of the order of microseconds. Thus if the extraction of one bunch perturbs the remaining circulating bunches, that coherent perturbation will rapidly become an incoherent growth in beam emittance. A 10% afterpulse ringout in the kicker for a single pass of the beam would double the beam emittance. The extraction timing budget shown in Fig. 2 specifies a 2% afterpulse ringout.

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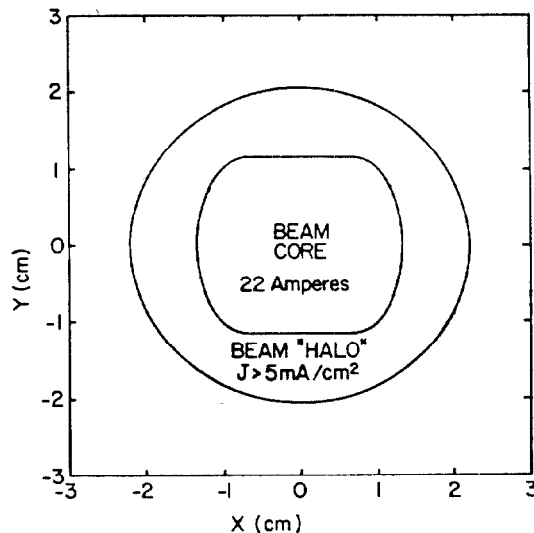


Fig. 1. Beam profile including effect of full-momentum bite ( $\delta p/p = 0.004$ ), in middle of straight section, LBLF mode. For any monoenergetic component of beam  $\epsilon_x = 0.7 \text{ cm}\cdot\text{mrad}$ ,  $\epsilon_y = 2.0 \text{ cm}\cdot\text{mrad}$ ,  $n_x = 1.92 \text{ m}$ .

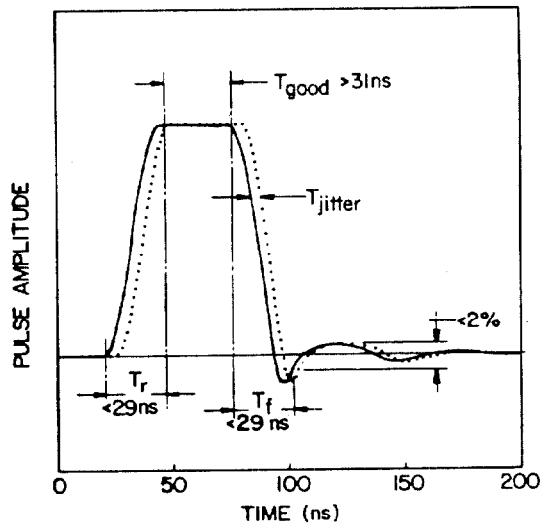


Fig. 2. Pulse for kickers. Amplitude is  $\pm 50 \text{ kV}$  across  $50 \Omega$ . Risettime plus jitter is less than 29 ns; flattop less twice jitter interval is greater than 31 ns; falltime, jitter, plus ringout to 2% level is less than 29 ns.

Parallel-plate transmission-line electrodes will be used to generate a backward-wave TEM pulse to deflect the circulating beam in the PSR past the extraction septum into the extraction line. This unconventional choice of kicker "magnet" is dictated by the stringent timing and afterpulse ringout requirements for SBHF operation.

Figure 3 shows the parallel-plate transmission-line geometry. The electric field amplitude at the beam is  $E = 2V_0/d$  where  $d$  is the electrode separation and  $V_0$  is the pulse voltage. For a TEM field  $B = E/c$  and the force on a proton with velocity moving opposite to

the pulse is  $F = q(E + \beta cB) = q\beta cB(1/\beta + 1)$ . For computational purposes an effective kicker magnetic field  $B_{eff}$  is used:  $B_{eff} = (2V_0/cd)(1/\beta + 1)$ . Values of 50 G to 100 G can be achieved for the PSR parameters ( $V_0 = 50$  kV,  $\beta = 0.84$ ,  $d = 0.075$  m to 0.14 m).

The pulse power supplies for providing the  $\pm 50$ -kV pulses to the kickers are somewhat unconventional (transformer-coupled, pulse-charged power supplies, ferrite-isolated double-Blumlein pulse-forming networks) and have been described in detail elsewhere.<sup>3</sup>

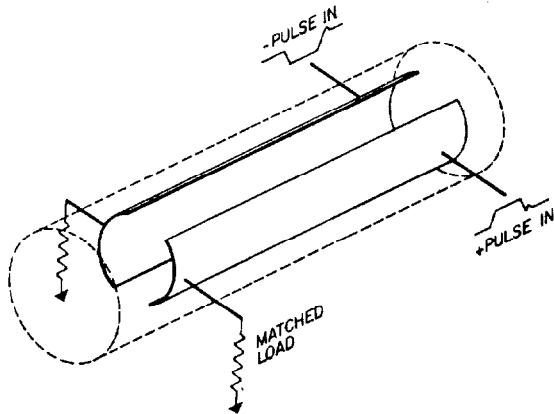


Fig. 3. Kicker electrode geometry. Pulses propagate opposite to beam bunches; symmetric push-pull excitation results in virtual ground at mid-plane. Matched terminations minimize reflections.

Figure 4 shows the placement of the kickers in the PSR. The 4-m kicker length is set by the timing budget. The kicker aperture is set by the requirement that the center of the beam be at least 3.75 cm from the electrode surface. A conventional current-sheet septum magnet is used. Because of the need to replace the septum with minimum difficulty, none of the current carrying elements are in vacuum.

#### Extraction-Line Configuration and Constraints

After passage through the septum magnet, the beam is directed onto the WNR spallation target through a transport line whose configuration is determined by LAMPF line D, an existing low-current transport

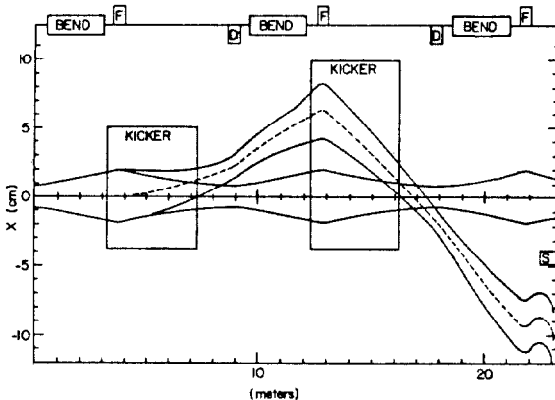


Fig. 4. Beam envelopes. Note placement and apertures of kickers and septum. Because kicker "magnets" contain no ferrite, they can pass through quadrupoles to include maxima of  $\beta_x$ . One period of PSR lattice is 9.022 m long.

system. The relation of the PSR to line D and the WNR target is shown in Fig. 5. The existing architectural and optical structure of line D imposes constraints on the line design. In particular the point of intersection of the line labeled A in Fig. 5 with line D (sections B-F) is fixed by structural considerations involving the existing line D tunnel. A skew magnet system M1 ( $15^\circ$  bend) and M3 ( $19^\circ$  bend) is used to orient the beam along section B. From section B the beam path is steered  $30^\circ$  horizontally by magnet M4 through section C and thence through three  $30^\circ$  magnets (M5, 6, and 7) for a vertical approach to the target, T.

Beam spill throughout the transport line is limited by requiring a minimum acceptance of  $5 \text{ cm} \cdot \text{mrad}$  (that is, apertures no less than three times the beam core). The problem of matching the beam to the 7.5-cm aperture of existing magnets M4-M7, as well as the dispersion induced by these magnets, dominates the constraints on beam optics. Additionally, the beam is to be focused within a 2-cm-diam area on the target. The line is required to carry beams containing varied charge densities, with peak currents of 46 A in the LBLF mode but must be tuned with low peak currents. Hence space-charge effects have a first-order influence on line optics.

#### Beam Optics

In addition to having a substantial momentum spread, the extracted beam is described by an initial dispersion in the x (horizontal) direction of magnitude comparable to the vectors bounding the undispersed beam envelope. Specifically, the initial dispersion vector is  $[0.85 \text{ cm}, 2.73 \text{ mrad}]$  at the extraction point in the LBLF mode, for the conditions of Fig. 1. Figure 6 shows an acceptable solution for the extraction-line optics. The first set of four quadrupoles after the lower skew magnet M1 match the extracted beam to a periodic  $90^\circ$  FODO configuration; four quadrupoles are required to accommodate a range of ring tunes and are arranged at optimum separations for this purpose.

The solution in sections B and C is dominated by the requirement of matching to the  $90^\circ$  vertical bend and target. A first-order solution cancels horizontal dispersion at M4 and sets the conditions for a narrow waist through M4 as well as a waist in the  $90^\circ$  bend. A small y dispersion (local vertical) arises from the skew configuration and becomes large in the  $90^\circ$  bend. Solutions that match to the target and cancel the y dispersion in the bend magnets or at the target lead to unacceptably large beam envelopes; an optimum solution, incorporating a partial contribution of dispersion to the target spot, has been obtained with acceptable beam sizes at all points.

Addition of space charge to the beam drastically changes the nature of the solutions. Final optimization makes the target spot size a monotonically increasing function of beam current and emittance. Acceptable spot and envelope sizes are achieved for currents from 0 to more than 70 A. A tuning algorithm for the line has been partially devised to exploit the sensitivities of beam sizes to lens strengths as viewed on beam profile monitors located at critical points in the line.

Other options to the line configurations were considered. In particular, a phase-space rotator would prove useful in manipulating dispersion. Such a device (that is, a solenoid or quadrupole rotator) has proven impractical for our application in terms of device size or beam spreading during the rotation process.

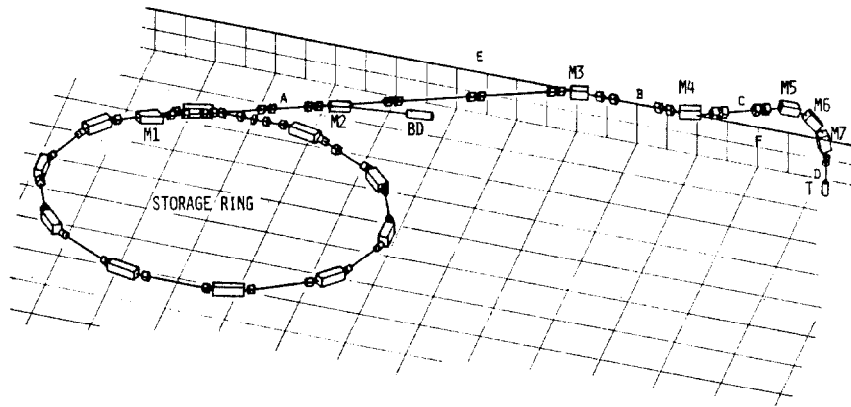


Fig. 5. PSR extraction line configuration. The transport line to existing line D is labeled "A." Beam from PSR follows path ABCD to target T. Line section E bypasses the ring; section F leads to an alternate target. Magnet M2 switches beam to a tuneup beam dump.

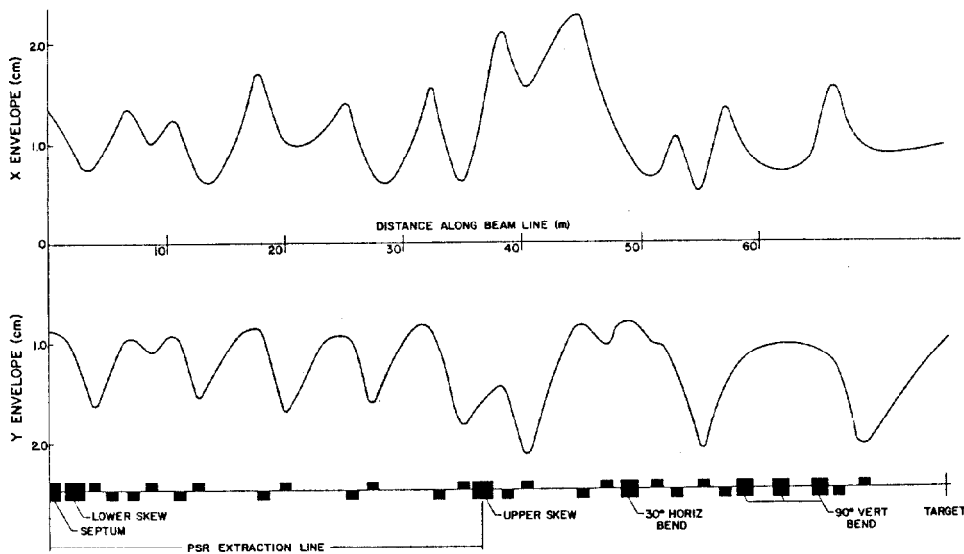


Fig. 6. An extraction line solution for 46-A beam current including dispersion. Beam envelopes are shown for the geodesic horizontal (x) direction and local vertical (y) direction versus distance along the beam trajectory. Horizontal-focusing quadrupole singlets are shown as boxes beneath the line in the lower part of the figure; vertical-focusing quads are shown above the line.

#### References

1. G. Lawrence, R. Cooper, D. Hudgings, G. Spalek, A. Jason, E. Higgins, and R. Gillis, "LASL High-Current Proton Storage Ring," Proc. of the XIth Int. Conf. on High Energy Accelerators, July 7-11, 1980, Geneva, Switzerland, 103.
2. D. Hudgings and A. Jason, "Injection System for the Proton Storage Ring at LASL," Proc. of the XIth Int. Conf. on High Energy Accelerators, July 7-11, 1980, Geneva, Switzerland, 277.
3. W. C. Nunnally, D. W. Hudgings, and W. J. Sarjeant, "Fast-Extraction Modulators for the Los Alamos Scientific Laboratory Proton Storage Ring," Proc. of 14th Pulse-Power Modulator Symp., June, 1980, Orlando, Florida.