Status of the PSR Improvement Program*

R. J. Macek, D. H. Fitzgerald, M. Hoehn, R. Ryder, and R. York
Medium Energy Physics Division, Los Alamos National Laboratory, Los Alamos NM, 87545

Abstract

A program of improvements to increase intensity and improve reliability of the Los Alamos Proton Storage Ring (PSR) has been under way for several years. Reduction of stored beam loss rates by a factor of 4.6 since 1987 through exploitation of H^0 injection has allowed the average intensity to increase by a factor of two to 75 μA. Reliability of the PSR and associated beam delivery systems has been improved by extensive rework of numerous subsystems. Radiation protection has been improved by additional shielding of Line D and extensive use of relatively fail-safe radiation detectors incorporated into an improved radiation security system.

I. INTRODUCTION

PSR was designed as an 800 MeV pulse compressor ring to accumulate a large fraction of a LAMPF macropulse (~800 μs) and provide short (0.25 μs), intense pulses to a spallation neutron target. After two years of commissioning and initial operation, the limitations on performance due to beam losses and hardware reliability were evident. Radioactivation of the ring components limited the average current to about 30 μA. Peak intensity was and still is limited to ~3.5×10^{13} protons per pulse by a transverse instability, now thought to be caused by coupled e-p oscillations. [1] Concerns about the adequacy of the shielding required exclusion of users from the LANSCE (Los Alamos Neutron Scattering Center) experimental hall (ER-1) when beam was on. Overall beam availability on target was ~55% (1988) and judged to be inadequate for a national users program.

By 1988, the mechanisms for the stored beam losses had been identified, the potential for significant improvement recognized, and an improvement program initiated which had as its main goals safe, reliable, 100-μA operation at 20-Hz repetition rate. Longer term, there was the possibility to increase the repetition rate to 60 Hz and thereby achieve average currents up to 300 μA.

II. INTENSITY IMPROVEMENTS

The initial intensity upgrade plan was to first exploit H^0 injection by a number of incremental improvements and an upgrade of the H^- ion source before undertaking more fundamental and costly changes to PSR injection or the full aperture extraction upgrade.

Injection into PSR is a two-step process, as depicted in Figure 1. The 800-MeV H^- beam is completely stripped to H^0 in a high-field stripping magnet then passes through a hole in the yoke of a ring dipole. The H^0 beam strikes a 200-mg/cm^2 carbon foil where most of it (~93%) is stripped to H^+ and captured in the ring. Beam is accumulated for typically 1700 turns and extracted in a single turn.

A. Beam Losses

The requirement for hands-on-maintenance limits localized losses (over distances of ~1 m) to about 100-200 nA average. For the loss patterns in PSR, this implies keeping the total losses to less than 500 nA.

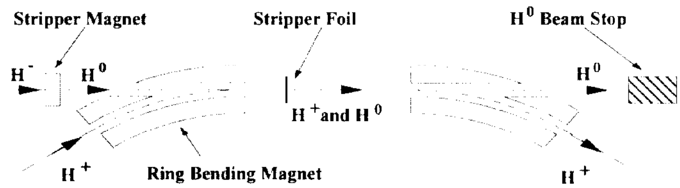

Figure 1. Layout of injection region in the PSR.

The "slow" beam-loss current is well described by two terms: a constant term (1st turn) proportional to the injected current, I_{in}, and a term increasing linearly in time and proportional to the stored beam current, $I_{in}\cdot N(t)$, where N is the number of turns injected. The losses of 0.2-0.3% on the first turn after injection are now thought to be predominately caused by production of excited states of H^0 with principle quantum number ≥ 3, which subsequently strip part way through the fringe field of the first dipole downstream of the stripper foil and fall outside the acceptance of the ring. [2] Stored beam losses arise primarily from nuclear and Coulomb scattering of the protons through repeated traversals of the stripper foil and from the increase in beam size due to the increase in momentum spread produced by action of the RF buncher. [3]

The key to reducing the stored beam losses is to minimize beam scattering at the stripper foil. Most options for increasing the current aim to reduce the number of times the stored protons hit the foil; many use an improved scheme of phase-space "painting" at injection to reduce foil hits.

B. Exploitation of H^o Injection

Offset injection in the vertical plane exploited the unfilled vertical acceptance in the PSR and used betatron oscillations to paint in the (y,y') phase plane, as shown in Figure 2. The stripper foil material need only cover the area of the H^o beam; any extra foil material adds to the losses by intercepting more of the stored beam. To exploit this idea, a minimum area carbon foil supported by thin (5 micron) carbon fibers, the so-called "postage stamp" foil, was developed and has been used successfully for several years.

Studies of beam losses as a function of the betatron tunes, ν_x and ν_y, showed increased loss when crossing the 5th-order resonances. Operating below the 5th-order resonances reduced the stored beam loss rate by about 30%.

Halo collimation concepts were studied and tests performed with tungsten scrapers in the ring. Preliminary

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results were discouraging. Two problems were recognized: (1) Scattering from the edges of the scraper/collimator produces losses elsewhere; thus, for collimators to be beneficial, slit scattering must be less than the losses prevented elsewhere by the collimator. (2) A good optics location for the collimator, where the limiting aperture (septum magnet) is shadowed by a dispersion-free image of the collimator, was not found in the existing lattice.

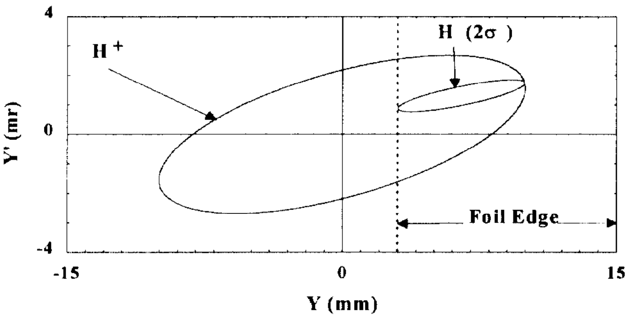

Figure 2. Y,Y' phase-space ellipses at the stripper foil.

Reductions in the stored beam-loss rate for various measures implemented since 1987 are listed below.

Measure	Loss Reduction Factor
Vertical Offset Injection	~1.7
"Postage Stamp" Foil	~1.5
Lower Operating Point	~1.3
Miscellaneous Improvements	~1.4
Overall Improvement	~4.6

C. H^- Ion Source Upgrade

Injection of higher peak current into the PSR will reduce the number of turns needed to accumulate a given charge and the number of foil traversals. Development of a volume H^- source with twice the peak intensity and half the emittance of the present cusp-field source was judged to be feasible and considered to be the most cost-effective next step toward increased intensity. It has the added benefit of reducing the linac duty factor needed to serve the LANSCE program. A major effort is under way at Los Alamos to test and evaluate two promising options (a design from Berkeley and a version of the BNL design engineered for high duty factor operation) and the use of RF to excite the source plasma. Results to date are encouraging; details can be found in a companion paper at this conference. [4]

D. Direct H^- Injection

The H^0 injection method at the PSR suffers from two problems: growth of emittance (factor of ~3) in the bend plane of the stripper magnet and the large horizontal mismatch, which arises from fundamental constraints (small beam spot size) at the stripper magnet and lack of flexibility in tuning the beam parameters at the injection foil. A way around both of these difficulties is to inject the H^- directly, as shown in the proposed layout of Figure 3.

The H^- beam enters a low-field (0.38 Tesla), 6° dipole in the ring at a position and angle such that it will emerge on the same trajectory as the stored H^+ beam. A foil stripper to convert H^- to H^+ follows. Bump magnets in the ring provide a programmed closed-orbit bump for optimized injection painting. Some H^0 will emerge from the stripper foil; in addition, some H^- will miss the foil and be stripped to H^0 in the fringe field of the ring dipole. Provisions are made to transport both H^0 beams to the existing H^0 dump. Of all the upgrades considered, the direct H^- injection option was expected to provide the greatest reduction in beam losses, but lack of funding has prevented its implementation.

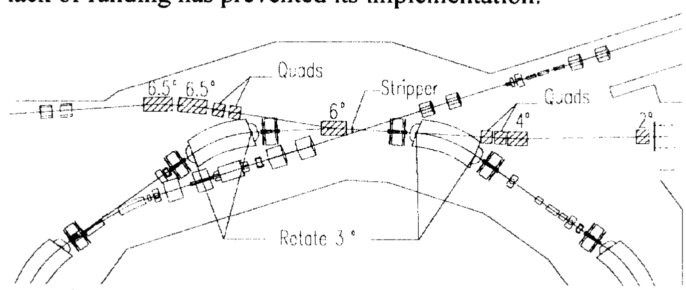

Figure 3. Layout for direct H^- injection.

E. Full-Aperture Extraction

The horizontal acceptance of the PSR is limited by the existing extraction system; 50% more horizontal aperture (2 times larger horizontal phase space acceptance) is available with more powerful extraction kickers. The larger aperture would have three main advantages: more of the beam scattered in the foil can be captured, thus reducing losses; injection painting can be made more effective in keeping the beam off the foil with either H^0 or direct H^- injection; and the increased horizontal beam size will reduce the beam density and associated space-charge effects.

R&D was started on a ferrite kicker system that would provide the larger kick needed for full-aperture extraction. A prototype pulser was designed and fabrication begun but was halted just short of completion for lack of funds.

III. RADIATION PROTECTION UPGRADES

Shielding and radiation protection issues have been among the most difficult problems to solve, in part because of the difficulty in developing lasting criteria in an environment of changing standards, but also because shielding retrofits are very difficult and expensive in the highly built up area around Line D (the H^- transfer line) and LANSCE. It would have been far easier and less costly to provide more shielding in the initial construction at the green-field site.

The problems originate with the criteria used for construction of LANSCE (WNR at the time) and Line D beam transport which was based on design losses of 0.04 nA/m (fractional loss 2×10^{-6}/m) from a 20-μA beam. Shielding was designed to keep the radiation levels in occupied areas below 2.5 mrem/h for the postulated beam loss. Beam-loss monitors interlocked with the beam were used to shut off the beam quickly in the event of errant beam spills. The criteria were accepted at Los Alamos at the time. The difficulty with these criteria is the extensive (critics claim excessive) reliance on instrumentation to prevent lethal doses in the event of a worst-case, full-power beam spill. Should the instrumentation fail during a full-power spill, dose rates as high as 10-50x10^3 rem/h are possible at the shielding surface for indeterminate lengths of time. Much of the Line-D shielding was not upgraded with the advent of the PSR and an upgraded WNR.

Improvement of radiation protection systems proceeded on several fronts. Reliability of the active protection system was greatly enhanced by the development and implementation of a three-layered radiation interlock system consisting of fail-safe beam-current limiters for the normally low-current portions of Line D, fail-safe spill monitors for all beam tunnels, and neutron radiation detectors in occupied areas. These were incorporated into an improved radiation security and beam shut-off system. LAMPF prompt radiation protection criteria were developed that called for a non-lethal cap on the maximum potential doses possible in occupied areas under worst-case accident scenarios, including failure of all the protection instrumentation. A comprehensive shielding assessment was undertaken, which included extensive beam-spill tests of shielding effectiveness. Most importantly, major augmentations of the shielding were implemented in Line-D where it passes over the LANSCE experimental room (ER-1) and in the region around the proton beam transport (1L Line) just before the beam enters the LANSCE target (see Figure 4). More shielding was added over the Line-D tunnel under a heavily traveled road , and at the Line-D entrance maze to the beam switchyard.

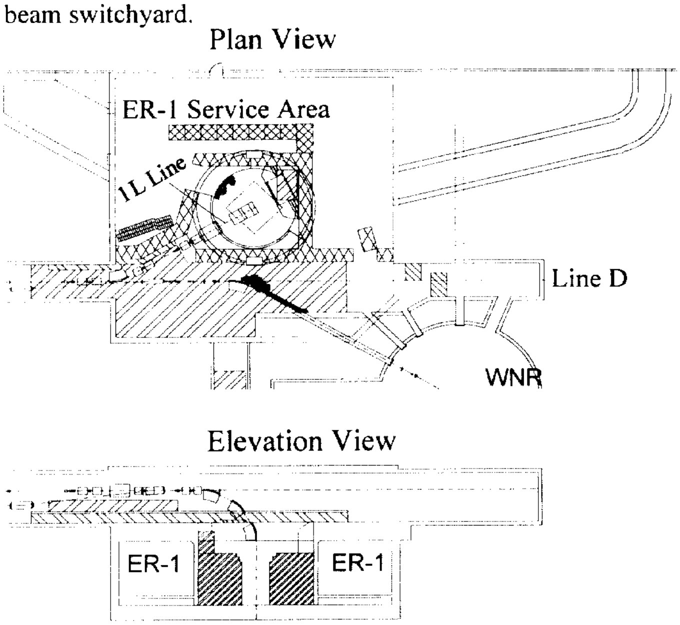

Figure 4. LANSCE target cell shielding.

The most pressing radiation protection issue remaining is the continuing need to exclude personnel access to ER-1 with beam on. The shielding added to the target cell was not sufficient to reduce the potential levels in ER-1 from a full-power beam spill to below 100 rem/h, as can be seen from the data displayed in Figure 5 for a spill at the top of the 90° bend. Calculation indicate that spills further down the bend lead to even higher levels. Time and funding limitations prohibit a retrofit that would reduce the potential hazard to levels that permit occupancy while beam is on.

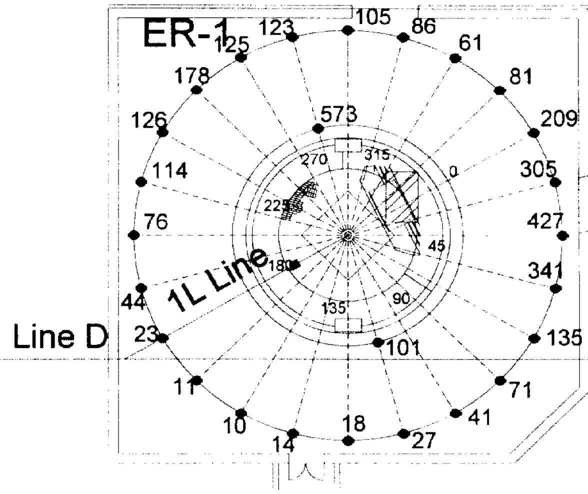

Figure 5. Radiation levels (rem/h) in ER-1 from a full-power spill (from data scaled to a 100 μA spill).

IV. RELIABILITY/AVAILABILITY

Availability of the PSR and the LANSCE beam delivery systems has improved greatly since 1988 through extensive rework of numerous subsystems, including magnet power supplies, deionized water, vacuum, pulsed power, beam diagnostics, and computer controls systems. Overall availability of beam (including the linac) to the users rose from ~55% in 1988 to ~75% in 1989 but has declined to ~65% in the past two years, primarily because of declining availability of the linac. The situation is complicated but is essentially caused by funding shortfalls for the LAMPF nuclear physics program, which funds the operation of the linac.

V. CONCLUSIONS

We conclude that there are no technical barriers to reliable, 100 μA operation of PSR which is the same conclusion reached by the external PSR Review Board. The menu of proposed improvements contains enough to reach the goal. We acknowledge the contributions of the entire PSR development and operations staff in the progress to date.

VI. REFERENCES

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[4] R. York et al, "Volume H^- Ion Source Development at LAMPF," these proceedings.