OVERVIEW AND STATUS OF THE LOS ALAMOS PSR INJECTION UPGRADE PROJECT*

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Abstract

An upgrade is in progress to the Los Alamos Proton Storage Ring (PSR) to allow direct injection of the H^- beam into the ring and provide a beam bump system to move the circulating beam off the stripper foil. The primary benefits of this upgrade are matching the transverse phase space of the injected beam to the PSR acceptance and reduction of foil hits by the circulating beam by a factor of ten. Foil thickness is optimized to minimize the combination of circulating-beam losses plus losses due to excited H^0 states produced at injection. An overall factor of five reduction in losses is expected. The project comprises extensive modifications of the injection line, the injection section of the ring, and the waste-beam transport line. We will discuss the goals of the project, present an overview of the technical design, and describe the status of the implementation plan.

1 INTRODUCTION

In the injection upgrade project, the overall performance objectives for PSR and the beam delivery system for the LANSCE neutron spallation source are:

- 100 µA @20 Hz routine operation
- Beam availability > 85%
- Less than 5% downtime from intervals > 8 hours

Beam losses at PSR and the resulting radioactivation of ring components are the dominant factors limiting average beam current, a significant cause of equipment failure, and a major element in repair times. Reducing the beam loss rate is key to achieving the performance improvements.

Losses of the circulating beam in PSR are primarily caused by nuclear and large-angle Coulomb scattering in the injection stripping foil. [1,2] These losses can be reduced by keeping the stored beam off the foil. The present, two-step injection process converts H^- to H^0 in a stripper magnet, then H^0 to H^+ in the stripper foil. This produces significant emittance growth in the bend plane of the stripper magnet and a substantial mismatch of the injected beam. Both factors severely limit the use of injection painting to keep the circulating beam off the foil. To eliminate these problems and implement effective injection painting we are replacing the two-step process by one-step (H^- to H^+) injection of the beam. Direct H^- injection provides the capability to tailor the injected beam parameters for optimal painting.

2 DESIGN

As shown in Fig. 1, we will implement direct H^- injection by using a dipole (which is part of the PSR lattice) to merge the incoming H^- beam with the circulating proton beam. A thin carbon foil after this dipole strips the H^- primarily to protons that are captured in the ring.

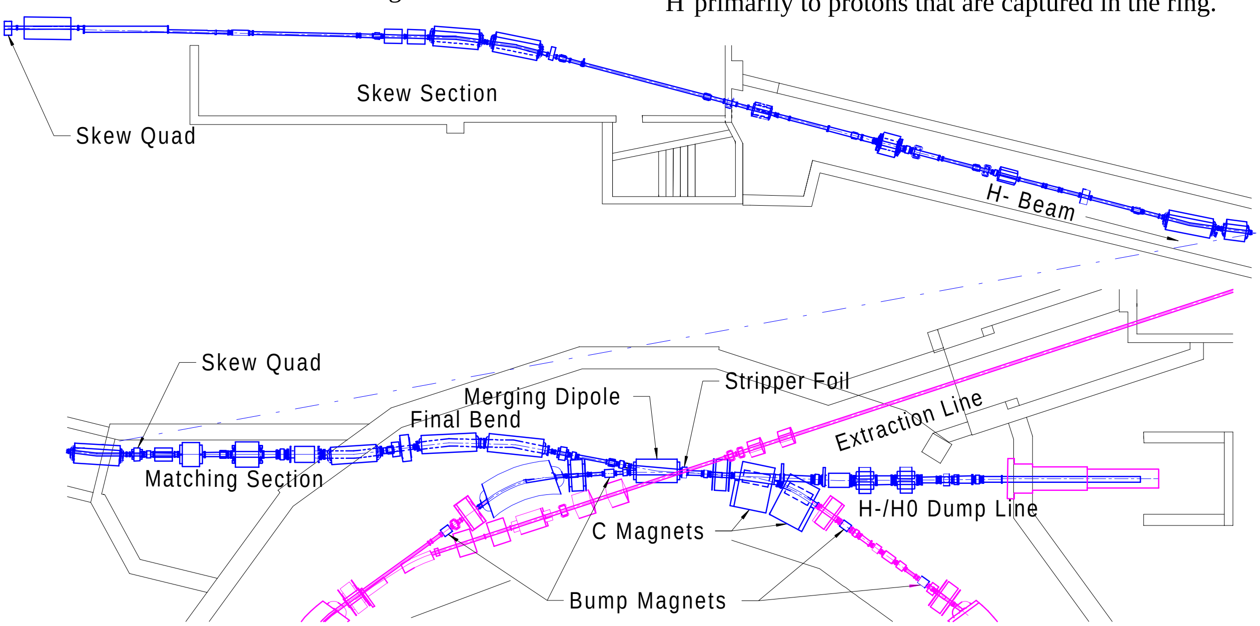

Figure 1. Layout for PSR Injection Upgrade

The project comprises extensive modifications of the injection line, PSR injection section, and H^-/H^0 dump line.

2.1 Beam Injection

The beam from the linear accelerator has a non-Gaussian transverse distribution, but it is bounded by an ellipse with rms emittance 0.8 π mm mrad. This emittance was used in the design calculations, together with a total momentum spread of ±0.5% (a generous postulate).

The beam injection design is described in detail in Ref. 3. Three sections compose the injection line shown in Fig. 1. A skew section transports the beam from the H^- transfer line to PSR level. The skew section is rolled by approximately 27° to accomplish an elevation change of 3.35 m. A four-quadrupole matching section is used to tailor the beam at the stripper foil to optimize phase space painting. A final bend diverts the beam around a PSR dipole and injects the beam into the merging dipole.

The skew section is achromatic to prevent dispersion-related emittance growth and beam centroid motion caused by beam energy shifts. A general drawback of skew lines is that skewed beam-line elements couple the transverse planes, leading to projected emittance growth. In this design, skew quadrupoles upstream and downstream of the skew section are set, together with a quadrupole at the dispersion crossover point, to uncouple the beam transfer matrix and so avoid emittance growth for all input beams.

The matching section is in a dispersionless region in order to decouple tuning of transverse and longitudinal beam parameters. The nominal injected beam has upright transverse phase space ellipses with rms parameters: x = 1.0 mm, x' = 0.80 mrad and y = 1.6 mm, y' = 0.50 mrad. The injected beam is offset by: x_0 = 7.21 mm, x_0' = -1.96 mrad, y_0 = 22.5 mm, y_0' = 3.10 mrad. Zero-dispersion injection is used to reduce the injected beam size and, thus, the number of foil hits by the circulating beam. The matching section has sufficient tuning flexibility to accommodate the normal range of input beams and to produce an adequate range of beam parameters at injection in PSR.

Hands-on maintenance of the injection line components requires minimal beam losses. In general, losses occur because the beam is too large for the aperture, or is mis-steered, or because H^- is stripped in the magnetic fields. The nominal aperture in the injection line is at least 6.6 times the rms beam size including momentum spread. Thus, scraping losses should be negligible, even with reasonable steering errors. Dipole fields have been kept below 3.8 kGauss and quadrupole fields have been kept correspondingly low to avoid excessive losses. [3]

Alignment or field errors can cause emittance growth or steering errors, leading to incorrect injection match and increased beam losses in PSR. The effects of injection-line errors were studied using particle-tracking codes in the injection line and PSR. Alignment and field errors twice the design tolerances (see below) were used in the simulations. Circulating beam losses from foil hits and scraping did not increase, while the fraction of injected beam missing the foil increased insignificantly (<1%).

2.2 PSR Reconfiguration and Beam-Loss Reduction

Changes to PSR include the 6.8° injection dipole, bump magnets to produce the closed orbit bump and the replacement of the first dipole downstream of injection by two C magnets. To accommodate the merging dipole, the bend angles of the dipoles on either end of the straight section must be reduced. The net result is an increase in the PSR circumference of 2.8 cm, requiring an increase of 2 MeV in the beam central energy, i.e., to 799 MeV.

The design for offset injection and closed-orbit bump was optimized by simultaneously minimizing foil hits by the circulating beam while keeping the injected beam ellipse completely inside the ring acceptance ellipse. Injection is offset in both planes, and the vertical closed-orbit bump in the injection section is collapsed linearly to zero by the end of injection, as shown in Fig. 2.

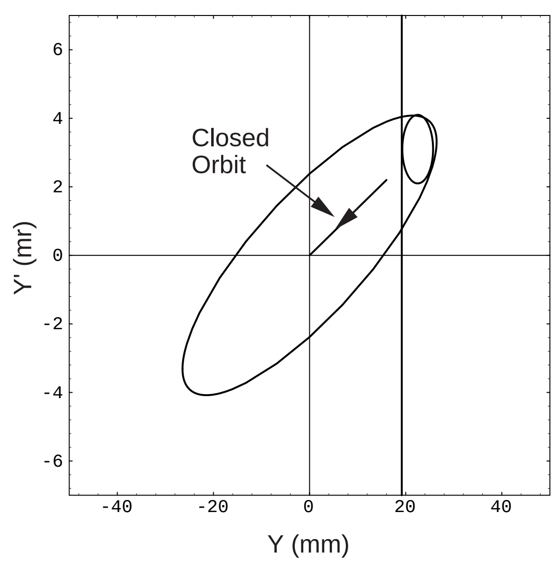

Figure 2. Closed orbit bump is collapsed linearly to zero during the injection period.

ACCSIM simulations show that offset injection and painting reduce the average number of foil hits by the circulating beam to 35 for 2300 turns injected, a ten-fold reduction over H^0 injection. A second source of PSR losses is excited H^0 states produced at injection and stripped in the first ring dipole. These losses are minimized by increasing the thickness of the foil. Fig. 3 shows the results of an optimization study of losses *vs.* foil thickness. With an optimized foil thickness of 400 $\mu g/cm^2$, losses are reduced by a factor of 5 from that for present PSR operation with a 200 $\mu g/cm^2$ foil.

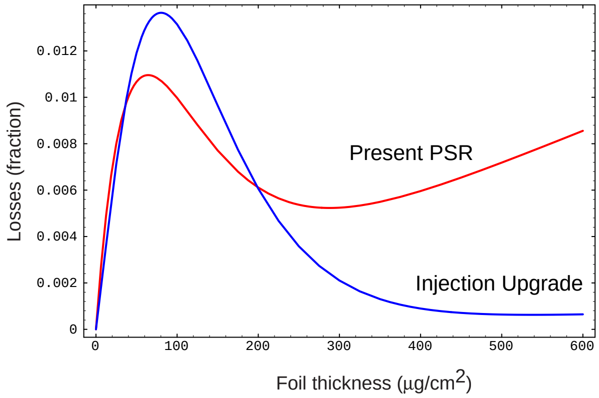

Figure 3. Total losses *vs.* foil thickness.

2.3 H/H^0 Beam Dump Line

The offset injected beam at the stripper foil requires increasing the aperture in the downstream bending magnet to accept H^0 produced in the foil and the unstripped H^-. Therefore, we are replacing the present dipole by two existing C magnets, the first having a 50% larger vertical aperture than the present dipole. In the dump line, the diverging H^- and H^0 beams must be combined and transported with minimum losses. To design this line, a particle tracking code was developed that takes into account the initial beam distributions and stripping distributions for H^- to H^0 in the first C magnet. The final design incorporates a dual-plane bending magnet to aim the beams at the beam dump and a quadrupole doublet to combine and focus the beams at the beam stop.

3 IMPLEMENTATION

To implement the upgrade requires: 11 dipoles (including two C magnets), one dual-axis bending magnet, 15 quadrupoles, and 11 steering magnets. To reduce costs we used existing magnets where possible, so only eight new magnets (five designs) are needed. The C magnets have the most stringent central-field quality requirements: 10^{-4}. All magnet power supply needs can be met from the existing pool, although 14 must be upgraded to improve regulation or better match the load. To satisfy design specifications, the C magnets will require power supply regulation of 10^{-5}, while the dipoles in the final bend require 2×10^{-5}. The required regulation for the quadrupoles is 10^{-3} except for the last quadrupole in the matching section, which requires 10^{-4}. The closed-orbit bump will be produced using four programmable, pulsed magnets [4] located as shown in Fig. 1.

In the particle-tracking studies the following critical alignment tolerances were found to be acceptable:

- Dipoles: 1 mm longitudinal, 1.7 mrad roll
- Quadrupoles: 0.25 mm transverse, 1.7 mrad roll

These required tolerances can be obtained by standard alignment techniques at LANSCE, which are capable of attaining 0.1 mm in position and <1 mrad in angle.

Procurement and fabrication are about half completed, and the project is on track for installation beginning in August 1997; commissioning is scheduled for May 1998.

4 TECHNICAL SPECIFICATIONS

Table I contains the PSR injection upgrade specifications

Table I. PSR Parameters After Injection Upgrade

Parameter	Value
Current, repetition rate	100 µA @ 20 Hz
Protons per pulse	3.1×10^{13} ppp
Beam energy	799 MeV
PSR accumulation time	825 µs
Injected beam time spread	250 ns
Input beam phase space Transverse Longitudinal	 0.8 π mm-mrad rms 0.063% dp/p rms
Injection line acceptance Transverse Longitudinal	 35 π mm-mrad ±0.5% δp/p
Injected beam offset (x_0,x_0') = (y_0,y_0') =	 7.21 mm, -1.96 mrad 22.5 mm, 3.10 mrad
Closed orbit bump (linear) from (y_0, y_0') = to (y_0, y_0') =	 16.0 mm, 2.2 mrad 0.0 mm, 0.0 mrad
Foil thickness	400 µg/cm^2
RF volts per turn, lin. ramp	6-10.5 kV
Harmonic no., freq. (time)	1, 2.795 MHz, (358 ns)
Tune	$\nu_x = 3.172$, $\nu_y = 2.142$
Max. tune depression	$\Delta\nu_x = -0.071$, $\Delta\nu_y = -0.106$
Stored beam 95% emittance ε_x = ε_y = dp/p =	 35 π mm-mrad 49 π mm-mrad ±0.34%
Frac. of beam missing foil	2.6%
H^- stripped to H^0	0.6%
Foil hits per proton	30.5
Stored beam loss (incl. 0.022% nucl. scatt.)	(0.046 ± 0.005%) total
Extraction losses	0.008%
Excited H^0 losses	0.048%

REFERENCES

[1] R. Macek, *et al*., Proceedings of the European Particle Accelerator Conference (1988) 1252.
[2] R. J. Macek, *et al*., Proceedings of the 1993 Particle Accelerator Conference (1993) 3739.
[3] Barbara Blind and Andrew J. Jason, 'PSR Injection Line Upgrade', these proceedings.
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