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AN OVERVIEW OF THE PROTON STORAGE RING UPGRADE AT LANSCE*

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Abstract

The Los Alamos Neutron Science Center (LANSCE) is one of the oldest operating high-average-power accelerators in the United States, having recently celebrated its 50th anniversary of operation. LANSCE is comprised of an 800-MeV linac capable of concurrently accelerating both H+ and H- ions, and can presently provide beam to six separate user stations.

The core components of the Los Alamos Neutron Science Center (LANSCE) accelerator complex – the beam source area, drift-tube and cavity-coupled linear accelerators – are more than 50 years old; a critical subsystem for beam delivery to the Lujan Center, the proton storage ring (PSR), is more than 40 years old. This paper describes a proposed update and modernization pathway for the PSR.

INTRODUCTION

The LANSCE accelerator complex, see Figure 1, provides beams of 100-MeV H^+ and 800-MeV H^- to five independent user facilities. The proton storage ring (PSR, Figure 2) acts as a pulse-stacker, providing intense bunches of protons to the Lujan Neutron Scattering Center target, and in special operating modes, to the Weapons Neutron Research (WNR) spallation neutron targets.

Critical subsystems have become increasingly difficult to maintain due to spare parts availability; more generally, the PSR contributes significantly to our annual maintenance duration due to beam spill and component activation. The updates and modernizations under consideration would extend the operating lifetime and improve the operational characteristics of the PSR via increasing the physical aperture by 50%; modernizing and improving the performance of the RF buncher system, extraction kickers and impedance inserts; and updating the injection line and stripper foil system for reduced injection losses and improved maintainability. This paper provides a brief overview of the upgrade and modernization paths under consideration for the PSR.

INITIAL STUDIES

An initial evaluation was performed from July – September 2023, incorporating initial beam dynamics stidues and surveying technology options for potential upgrades to all PSR-related systems, including complete replacement of the magnetic lattice with larger-bore magnets [1]. Below, we briefly discuss upgrade and enhancement options for major subsystems of the PSR as studied in the report.

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Ring Injection Line

The Ring Injection line extends from the end of the LASNCE cavity-coupled linac (CCL) to the PSR's charge-exchange stripper foil [2]. The transport line and injection approach has undergone one major upgrade since the PSR's initial commissioning [3]. Potential performance enhancement options include adding diagnostics for better beam characterization and automated steering control; and the addition of collimators to remove beam tails and reduce beam losses within the PSR vault.

Beam Injection and Electron Stripping

The PSR utilizes a charge-exchange injection system, wherein an incoming beam of H^- ions is stripped to H^+ in a thin foil, thereby avoiding the requirement for fast-injection kickers and helping to avoid limitations on pulse-stacking imposed by Liouiville's Theorem. While laser-based stripping schemes [4] are very attractive in several respects, the technical challenges suggest maintaining a foil-based stripper for the moment.

We are considering options to upgrade the stripper foil exchange system. Primary goals of such an upgrade are to increase reliability and capacity versus the PSR's present system. Incorporation of a cartridge- or cassette-based system, in which a set of foils can be removed and installed separately from the foil insertion mechanism, is a highly desirable design feature.

As part of the upgrade process we also wish to establish a beam-based foil test area making use of 800-MeV beam from the LANSCE linac. This would enable us to characterize the stripping performance of new foils independently from the PSR.

PSR Beampipe Size Increase

The PSR is a nominally 10-fold symmetric accumulator ring, with the symmetry broken by the injection and extraction sectors. The beampipe diameter through the majority of the ring is 4" (10 cm). Expanding the beampipe diameter to 6" (15 cm) as a loss-reduction measure would require replacement of all magnetic elements, RF buncher, beam position monitors (BPMs), extraction kickers, and other ancillary components: in effect, creation of an entirely new ring with essentially no reuse of existing components.

The PSR dipoles presently operate at a field of approximately 1 T. Initial scoping simulations indicate that dipoles with 50% larger gaps would not suffer from significant saturation effects, but the required coil current would approximately double; this would likely necessitate new power supplies, and potentially require an upgrade to the PSR water cooling systems.

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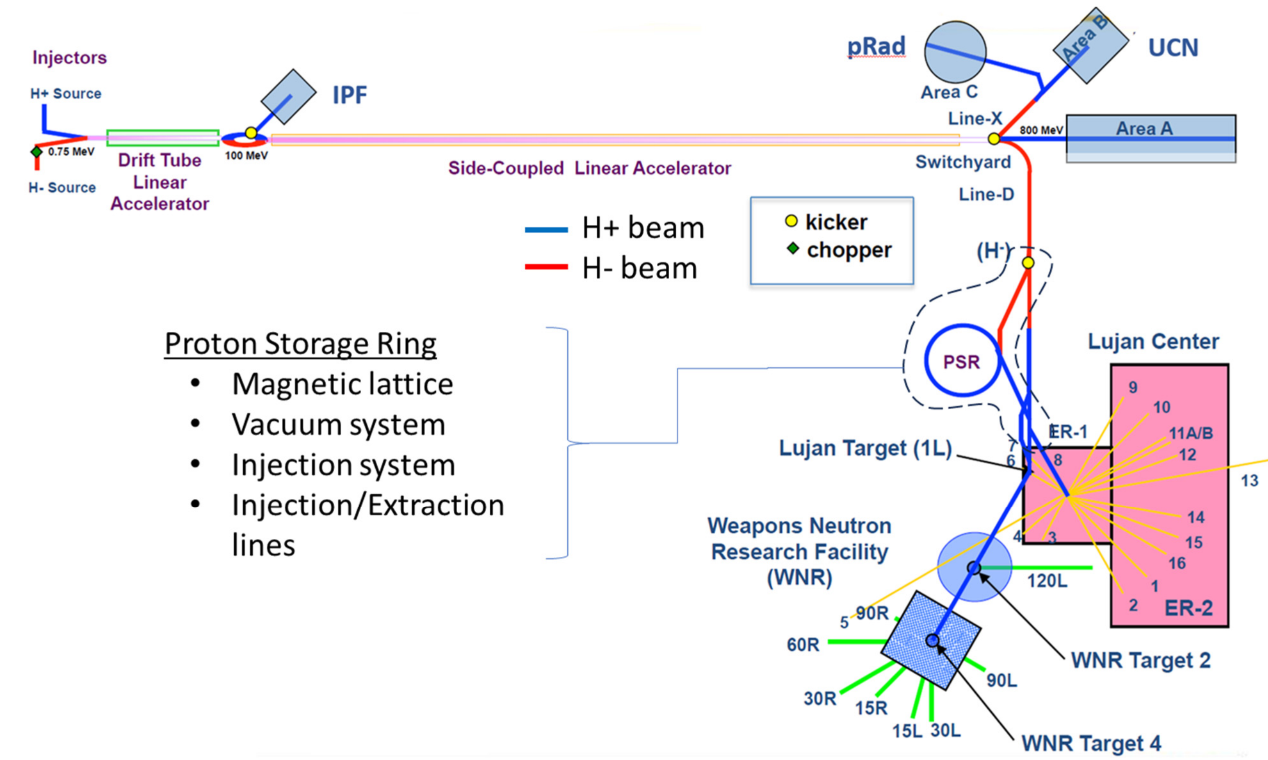

Figure 1: Layout of the LANSCE accelerator complex.

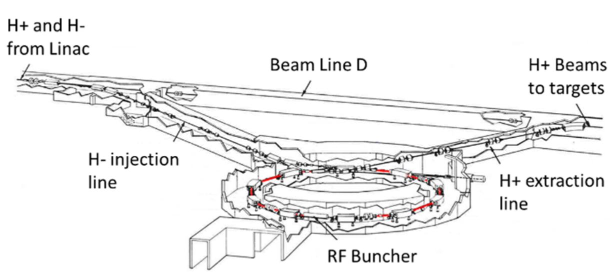

Figure 2: Perspective view of the PSR.

RF Buncher System

The current buncher for the PSR [5], resonant at 2 MHz, provides for a single bunch in the ring. The ferrite material used to inductively load the existing buncher, and many of the components of the RF system used to drive it, are no longer commercially available. We are evaluating options for enhanced upgrades and replacements for both the buncher cavity and its RF drive system; this includes the potential addition of another harmonic buncher to reduce the peak circulating beam current, or other harmonic systems to provide additional beam manipulation and bunching options for new modes of operation. Specifically, enabling the PSR to store multiple bunches and provide accumulated bunches "on-demand" (see below re extraction kickers) would facilitate developing new operational modes for the LANSE facility.

Inductive Inserts

The PSR uses inductive inserts [6] to help mitigate the effects of space-charge and circulating beam current. We are considering the potential for new inserts, based around the use of presently available ferrite materials, and with improved options for tuning the inserts to provide better and more flexible performance.

Extraction Kicker System

The PSR's current extraction kickers are based around the use of Blumlein-type transmission line modulators to drive two sets of parallel-plate kickers at a rep rate of 20 Hz [7]. The present kicker modulators can only provide fixed-width output pulses, and availability of key components such as thyratrons [8] and charging cables is becoming problematic.

Adoption of inductive voltage adders (IVAs) as kicker modulators is attractive for several reasons. From a performance standpoint, IVAs offer the potential for flexible output pulse duration and high repetition rates, offering pathways to enhancing the PSR's performance in terms of multipulse operation and, potentially, serving multiple user facilities. From an institutional standpoint, LANL has significant experience with IVAs via the ASD/Scorpius project [9], and the technology is of high interest to other LANL facilities such as potential upgrades for DARHT [10].

Should the PSR beampipe size be increased by 50%, all else equal, the extraction kicker voltage would also need to increase from ±50 kV, to ±75 kV. This represents a potential challenge, no matter the adopted modulator technology.

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Diagnostics

The primary diagnostics within the PSR are beam position monitors (BPMs). Presently, the PSR BPMs are located within the quadrupole magnet bores. While this natively places the BPMs at the locations of beta function maxima, it significantly complicates maintenance and repair. BPMs are not typically high-failure-rate components. Over their lifespan, however, the PSR BPMs have shown characteristic failure modes that cannot readily be addressed without removing them. Future upgrades to the PSR BPM system would include modification of the BPM design to eliminate the failure mode of the present design (e.g. shorting of a termination resistor), and relocating the BPMs to allow for easier replacement should the need arise.

Options for monitoring the formation of beam halo in the ring, as well as in the injection transport line, are also of interest. Diamond array detectors [11] have also been used to monitor x-ray beam profiles, and in the context of a beam transport line could provide additional insight into beam halo magnitude and evolution during operations. In the PSR proper, diamond detectors could potentially help to better characterize losses associated with beam injection.

We are also considering diagnostics options to be integrated into a new injection foil system (e.g. thermal imaging) to help improve start-up times and foil condition monitoring.

Finally, a bunch shape monitor, potentially of a type already in service at the LANSCE accelerator [12], installed in the PSR extraction line would allow improved characterization of temporal bunch profiles as delivered to user facilities, and could facilitate improved tuneup of the PSR's buncher system.

Secondary Emission Yield Coating

The PSR is subject to electron cloud effects [13]. The PSR has, over its operating history, been used as a testbed for evaluating mitigation strategies [14]. As part of an upgrade plan, the PSR beampipe would be coated with a secondary emission yield suppression coating. Based on measurements performed on samples and on published results, our baseline is presently seen as TiN coating. However, we will continue to monitor progress on other coatings, such as diamond-like carbon and TiZrV.

Ring Extraction Line

As with the ring injection line, the extraction line would benefit from an improved and expanded diagnostics suite. Addition of a kicker dipole, and potentially additional steering and focusing magnets, would allow faster transitioning between the normal operation mode of the PSR, e.g. to the Lujan Center target, and special operating modes, e.g. delivering PSR beam to WNR targets.

PATH FORWARD

The initial studies and survey conducted in FY2023, as summarized above, did not uncover any major physics-related challenges to significantly upgrading the PSR. In FY24, we are extending our efforts as described above with significantly expanded modelling and simulation.

Our team has begun detailed tracking studies to model beam injection (including foil scattering, and including unstripped (H^-) and partially stripped (H^0) beam loss modeling) and accumulation. Several of these studies are presenting their initial results in parallel with this work. Additionally, plans for foil test stands, both laboratory thermal testing and an in-tunnel stripping test station, are being developed, and a kicker test stand is under construction. Error and tolerance studies for various beamlines have also begun.

In FY25, we intend to continue physics model development and refinement, and to begin preliminary engineering design on upgrades for major subsystems, for instance a new stripper foil exchange mechanism, and new inductive inserts.

CONCLUSIONS

In FY23, an initial survey and performance study was conducted, and found that there are no major physics obstacles to implementing the proposed upgrade path for the PSR. Engineering challenges relate mostly to the proposed 50% increase in beampipe size, and the associated increase in power and cooling requirements. Studies continue in FY24, with an emphasis on beam dynamics calculations; in FY25 we anticipate beginning engineering designs on critical subsystems.

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