ICANS-XIII
13th Meeting of the International Collaboration on
Advanced Neutron Sources
October 11-14, 1995
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

THE LOS ALAMOS LONG-PULSE-SPALLATION-SOURCE DRIVER

Andrew J. Jason

Accelerator Technology Division
Los Alamos National Laboratory
Los Alamos, NM 87544

ABSTRACT

A Los Alamos study has investigated the possibility of adapting the LANSCE facility to a 1-MW Long-Pulse Spallation Source (LPSS) delivering H^+ beam to a new spallation target in 1-ms long pulses at a repetition rate of 60 Hz, while maintaining the present short-pulse capabilities. The study noted limitations of the LANSCE linac and has specified a scheme for high-reliability operation with low beam loss. Such an upgrade would provide a very inexpensive spallation source equivalent to a large reactor. Novel aspects of the scheme are stressed.

1. Background

A schematic diagram of the LAMPF linac is shown in Fig. 1. Ion sources placed in three Cockroft-Walton generators produce H^+, H^-, and P^- (polarized H^-) beams. The beams are bunched into a 201.25-MHz time structure and merged (as well as chopped in the case of H^-) in the (approximately 12-meter-long) Low Energy Beam Transport (LEBT) system at an energy of 750 keV. Injection into a four-tank, 201.25-MHz Drift-Tube Linac (DTL) and acceleration to 100 MeV then follows. The beam is then matched transversely to an 805-MHz side-coupled linac (SCL) by elements in the Transition Region (TR). The TR has two magnetically separated beam paths for separate transverse matching and longitudinal phasing of positive and negative species. The SCL accelerates to a nominal 800 MeV in 44 modules and constitutes over 90% of the linac length. The 201.25-MHz "micropulse" structure formed by the linac constitutes the substructure of nominally 1-ms-length "macropulses," delivered at up to twice the line frequency, 120 Hz. Beam is partitioned by a "Switchyard" to the delivery areas. Presently the beam is delivered to three facilities:

- Area A (primarily nuclear physics) with H^+ beam at somewhat less than a megawatt to 120 Hz. The exact pulse structure depends on user requirements and the needs of PSR and WNR of beam power and with ~13 mA or higher of peak current at repetition rates of up 120 Hz, twice the line frequency.
- The proton Storage Ring (PSR) with less than 100 kW of H^- beam power at 20 Hz. The PSR drives the LANSCE neutron-spallation source.

Keywords: LANSCE, Linac, Long-pulse

- Weapons Neutron Research (WNR) with 16.7-MHz-chopped H^- beam delivered with the H^+ macropulse.

The linac performs well under these circumstances and has tolerable activation and over 90% reliability. As this and other studies (along with operational experience) have found, appreciable increases in the peak power at these duty factors promote rapidly increasing beam losses and decreased reliability.

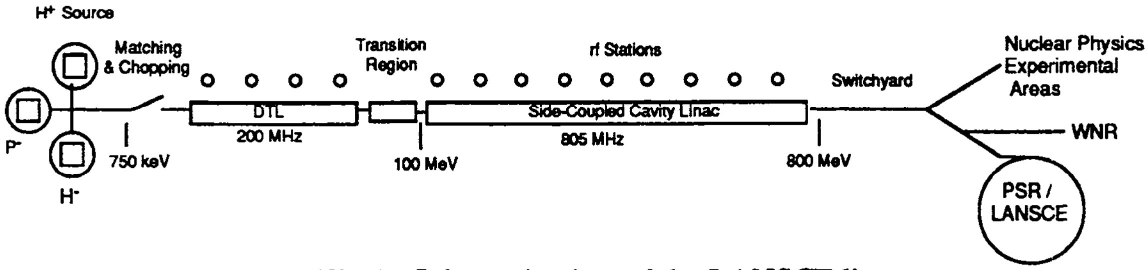

Fig.1. Schematic view of the LANSCE linac.

The LPSS requires 1-MW H^+ beam power delivered to the spallation target with macropulses of 1.0 ms length and 60 Hz repetition rate. This implies a peak output current of nearly 21 mA. Maintenance of interlaced PSR operation at from 20 to 60 Hz and WNR operation as requested is also required in the remaining 60 Hz.

2. Limitations of the present facility

Limitations of the LANSCE linac in achieving reliable operation with low equipment activation, under the LPSS beam requirements, stem from four major causes:

1) Limitations in the present 201.25-MHz rf system. The present system cannot provide the required peak power at the required duty factor.

2) The inability of the LEBT bunching system to provide a clean longitudinal match to the DTL causing subsequent losses in the TR and SCL. Such losses increase rapidly with peak current and would result in very high activation for the levels here proposed.

3) The lack of provision for longitudinal matching of the TR to the linac.

4) The speed of the 805-MHz control loops in the SCL rf system. Substantial loss is generated by the macropulse turn-on transient.

The first of these items relates to the limitations of the 7835 power triodes that constitute the final amplifiers of the 201.25 MHz DTL rf system. The maximum safe plate dissipation of the tubes is 250 kW. The DTL consists of four Alvarez tanks driven by four nearly identical RF power systems with energy gain in each tank of 4.64, 35.94, 31.39, and 27.28 MeV in that order. With present operating parameters, the peak rf loads approach 3 MW with plate dissipations hovering around the 250 kW limit. The increased LPSS current requires nearly 4- MW peak power that, combined with the PSR duty factor cause a plate dissipation of over 300 kW in three of the amplifiers. The higher peak powers also stress the present modulators tubes because of the higher plate voltage required. Additionally, it is feared that adequate replacements for the triodes will not be available in the future. A redesign of the rf system is needed for LPSS operation.

The second item, bunching in the LEBT, is done by a pair of 201.25-MHz resonant cavities at 750 keV. The single frequency cavities are inherently incapable of compressing the dc beam into a small region of longitudinal phase space. Hence, a substantial fraction of the particles (~25%) fall outside the DTL phase acceptance and are not accelerated, to be lost in tank 1. A further fraction (several percent) are injected into a nonlinear region of the DTL acceptance and cannot be longitudinally matched to the smaller SCL 850 MHz bucket. These particles are lost near the entrance of the SCL at 100 MeV and at a transition in the focusing lattice near 212 MeV. This picture is substantiated by the SCL activation pattern and loss monitor data as well as by beam dynamics simulations. Such loss increases rapidly with peak current. Hence, a better bunching scheme is required to implement the LPSS scheme.

The lack of a linear longitudinal match to the SCL also causes an appreciable part of the beam loss. This is distinct from the nonlinear phenomena described above, which cannot be aided by a better linear match.

It is to be noted that the SCL, which constitutes 90% of the linac, is very robust. Tests at 27-mA peak current (but with low duty factor) demonstrate the controllability and confirm its peak-current capacity despite heavy loading of the cavities.

3. Upgrade Recommendations

Several recommendations were made by the study to allow peak current increase to the LPSS levels and to maintain operation of WNR and PSR.

1) Replace the present injectors and DTL first tank with a 201.25-MHz Radio-Frequency Quadrupole (RFQ) linac to accelerate to an energy of 5.395 MeV. The H^+ and H^- beams are focused, chopped, and merged by a new LEBT at 100 keV before the RFQ. A two-buncher matching section is placed after the RFQ. This arrangement produces the appropriate transverse and longitudinal match to the second tank of the DTL.

2) Replace the 201.25 MHz rf system with a modern version that will produce adequate peak and average power.

3) Install an 805-MHz bunch rotator cavity in the TR that will provide a good longitudinal match to the SCL.

4) Upgrade the low-level rf-control system on SCL for removal of initial transient loss on the macropulse, and .operational ease.

5) An upgraded set of beam-diagnostic systems for better and more rapid machine tuning.
6) Provide transport to the LPSS target.

7) Install a laser-system that neutralizes H^- beam to provide for WNR operation.

8) A computer-control-system upgrade in support of the modifications.

With these modifications, a peak beam current of more than 25-mA can be supplied to the LPSS target to provide over 1.2 MW of beam power delivered at 60 Hz with a 1.0-ms macropulse length. A schematic drawing of the modified linac is shown in Fig. 2.

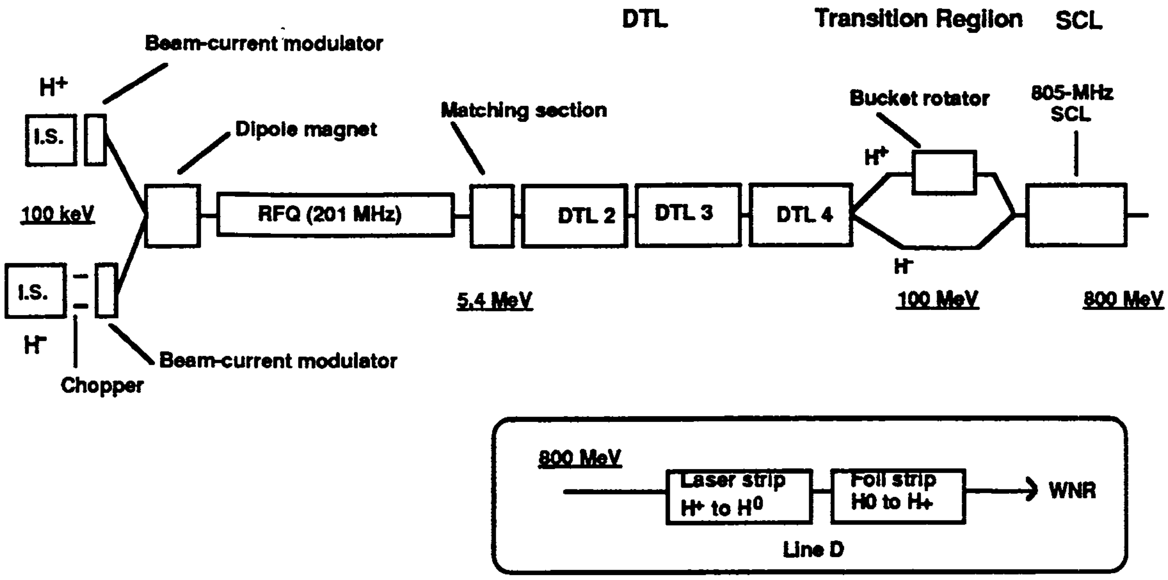

Fig. 2. Schematic of the LPSS linac upgrade

3.1 Injector and chopping

Adequate ion sources currently exist for both the H^- and H^+ beams. However, 2.8-MHz chopping at a duty factor of 75% for the 15-mA-peak-current H^- beam that supplies the PSR must be addressed. Currently, beam is chopped in the LEBT by a traveling-wave deflector that has a rise time of under 5 ns. Replacement of the LEBT by an RFQ requires a different chopping scheme. Post-RFQ chopping is quite feasible but would require an expensive installation. Chopping before the RFQ is seen as difficult because of the high beam neutralization and subsequent interaction between an oscillating positive-ion column and negative beam that distorts the transmitted beam, with a substantial emittance increase. This latter chopping scheme is believed to be feasible at a high energy (100 kV) and at the relatively low H^- currents needed.

We have devised an alternative pre-RFQ chopping method that removes beam neutralization by electrostatic focusing. To prevent neutralization in the deflector and maintain beam focusing, a novel quadrupole deflector is to be used. This traveling-wave structure is shown in Fig. 3. Undeflected beam is focused through a defining aperture by a constant quadrupole bias V on the side electrodes, with the deflector electrodes (upper electrodes in Fig. 3) set at ground potential. Activation of the deflector electrodes to ±V, moves the beam off the defining slit, with substantial beam distortion by the sextupole field inherent in the deflecting arrangement. Despite this distortion the beam is completely chopped by the at the defining aperture.

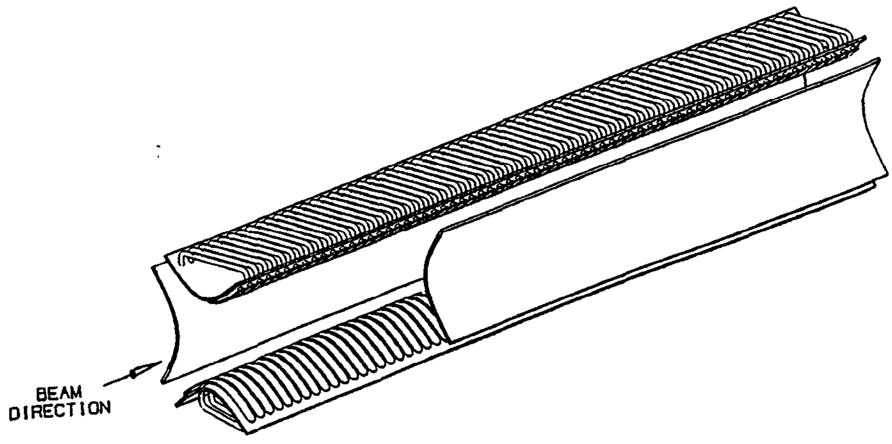

Fig. 3. Quadrupole traveling-wave deflector for use in an electrostatic LEBT. The device is 0.7-m long and sustains a deflecting voltage of just under a kilovolt across a gap of 19 cm.

The 2.6-m long line consists of an initial solenoid after the source, four electrostatic quadrupole matching lenses, the deflector, followed immediately by a defining aperture, and a final solenoid for matching into the RFQ. Simulations show that with a neutralized beam, substantial transmitted-beam distortion occurs. With the same simulation, using codes that have proven useful in linac design, the unneutralized case is adequately transported with currents over 30 mA. While the technique appears promising, experimental verification is needed.

3.2 RFQ

A 9.65-m long 201.25-MHz RFQ has been designed as the critical element in avoiding beam losses at the SCL entrance. The RFQ accelerates the beam from 100 kV to 5.4 MeV, replacing the LEBT and the first DTL tank. The less than 1-MW peak power required will be supplied by the original first-tank supply.

The RFQ provides excellent bunching. Beam dynamics results are summarized in Fig 4, which shows calculated results for the beam emerging from the DTL in the present configuration and with addition of the RFQ. Losses due the longitudinal tail in the present configuration are substantially reduced and DTL transmission increased. SCL losses for the LPSS are expected to decrease by a factor of over 300 from present nominal operation if longitudinal matching is done in the transition region. An alternative and less expensive scheme, using additional higher harmonics in the LEBT to enhance bunching can alleviate the loss somewhat.

3.3 201.25 MHz system

The main problem in the DTL-rf upgrade is the selection of an adequate final amplifier tube. A modern tetrode made by Thomson, the TH526, with many desirable features, is in production. Two such tubes in combination with a hybrid coupler would reliably supply the LPSS DTL at 18-mA peak current during development and commissioning. The final power amplifiers would later be upgraded to 6-MW peak power with a double-ended tetrode currently under development, the D28 Diacrode, having the same lower socket as the TH526.

Addition of a top slave cavity section would then be required. The present low-power portion of the system, recently upgraded, as well as the power supplies, would be used in this scheme.

Two options are under consideration for the rf window in each DTL tank. The present Rexolite windows function with rare arc overs at the present average power of over 350 kW. The upgrade requires a 33% increase in this average transmitted power, hence the window will be upgraded to a larger diameter with improved geometry and materials. Otherwise, the tank could be fed from two windows, with lower power requirements than at present, but tank retuning would be required.

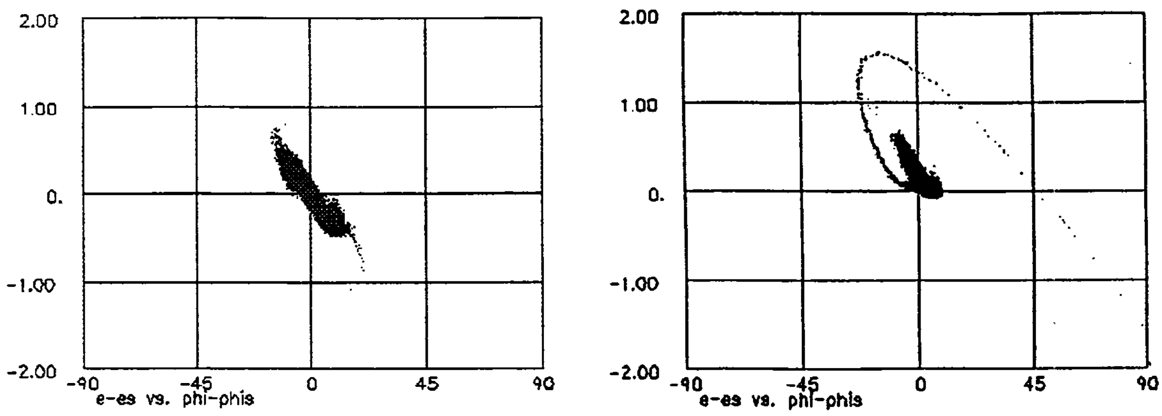

Fig. 4. Longitudinal phase space at 100 MeV for the present linac (left) and for the upgraded linac that utilizes an RFQ. Both plots are at 18 mA into the DTL. Vertical scales show energy in MeV while horizontal scales show phase in degrees

3.3 Transition region

The transition region contains two legs defined by dipole bends to form chicanes. Its purpose is to transversely match the 100-MeV H^- and H^+ beams to the SCL as well as providing a small path difference for the two species. Part of the beam that is not accelerated to full energy by the DTL is lost in the bends causing considerable activation. Addition of a single longitudinal cavity into the present configuration is ineffective in decreasing losses. With the upgrade, a single cavity dissipating 56 kW with an E_0TL of 1.0 MV provides good longitudinal matching. Whether or not to retain the present two-legged structure is to be determined; a straight-through configuration can serve both beams with proper rf phasing.

3.4 805-MHz system

A substantial fraction of the loss (as high as 40%) occurs due to the speed of the 805-MHz control and subsequent transient loss at the start of the macropulse. An adaptive feed-forward control system developed at Los Alamos appears promising in substantially reducing this loss. The 44 1-MW klystrons that drive the present are limited in peak output power to 1.25 MW. Allowing for a 10 % control margin, the maximum current that could be transported by the present rf system is near 30 mA.

3.5 Transport to target

The LPSS target is located in area A, a large shielded structure that presently contains several beam lines for nuclear physics programs. A long transport line exists that functions well in bringing beam to the area and needs only be augmented by an expander section. It is perhaps noteworthy that the gaussian-distributed beam can be well matched to the target by adding nonlinear elements to the expander. Fig 5 shows contour plots demonstrating the transverse confinement to the target with the proposed expander.

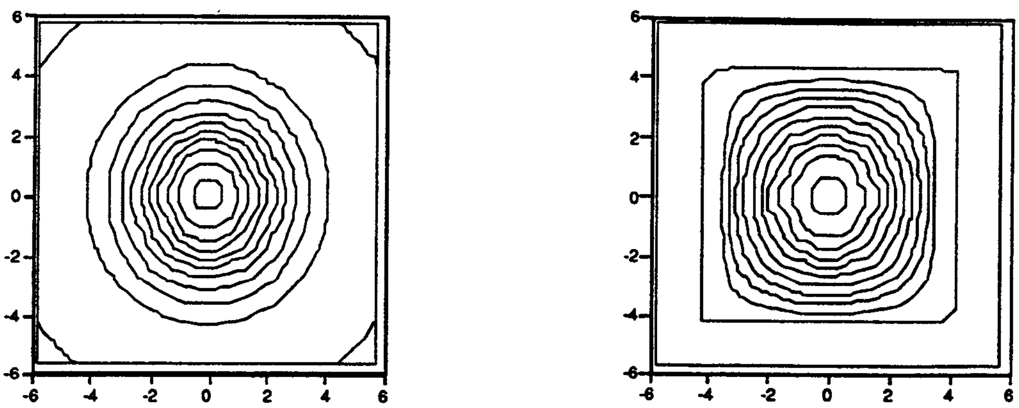

Fig. 5. Contours of beam intensity on the target for the linear expander (left) and the nonlinear expander (right).The contour lines are for relative intensities of 0.001, 0.1, 0.2,...1.0. The 1.0 contour corresponds to a current density of about 60 $\mu A/cm^2$ for a 1 MW beam. Dimensions are in cm.

3.6 Laser Chopping

The RFQ is incapable of accelerating single micropulses as required by WNR. The alternative scheme proposed uses a laser to neutralize single micropulses (~100 ps long) from the PSR beam at a rate of 555 kHz during the 800 ms macro pulse. The transport line to the PSR is configured so that such neutralized pulses will through a bend that directs the remainder of the beam into the ring. A thick stripper foil will then allow transport of the pulses to WNR.

Components that can be assembled to into a laser system exhibiting such performance are commercially available. A cw pumped mode-locked frequency-doubled Nd:YAG laser forms the driver for the system. Photon energy is 2.36 eV with 0.5 mJ per pulse for total laser power of 15 W. Transport of photons to the beam line may be stably accomplished by new fiber optics systems.

ACKNOWLEDGEMENTS

Work described here was performed by several individuals in AOT-Division. The support of the LANSCE ER office and the Los Alamos National Laboratory Directed Research and Development, under the auspices of the United States Department of Energy, is gratefully acknowledged.