CONVERSION OF THE BNL 200 MeV LINAC TO H^- AND POLARIZED H^- ACCELERATION*

R. L. Witkover, J. Alessi, D. Barton, A. Kponou,
Y. Makdisi, A. McNerney

Brookhaven National Laboratory, Associated Universities, Inc.,
Upton, New York 11973 U.S.A.

Summary

Planning for the conversion of the AGS Linac to H^- acceleration was begun in 1979;[1] installation was completed in 1983. Discussion of this work and of the operational experience will be presented.

The AGS Polarized Beam Project was begun in 1980.[2] The design of the new H^- polarized source, the low Energy Beam Transport line (LEBT), and Radio-Frequency Quadrupole (RFQ) will be described. Current status and future plans will be presented.

H^- Acceleration in the Linac

The original 200 MeV Linac delivered a 60 mA, 200 μsec proton beam to the AGS. The success of H^- acceleration at FNAL[3] with nearly 100% transfer efficiency, showed a way of reducing injection losses and beam-loading rf power. Conversion of the AGS Linac has been completed, with both Cockcroft-Walton (CW) pits now able to deliver H^- beams.

Source Testing

The AGS Linac uses the magnetron H^- source developed at BNL by Sluyters, et al.[4] Redesigned at FNAL by Schmidt[5] to run in an operational environment, it provided 40-50 mA for 67 μsec at 15 pps (0.1% duty factor). Several FNAL sources were run in a 20 keV test stand at the AGS Linac rate of 5 pps, 200 μsec pulse-width.[6] While the beam produced was adequate, the machinable ceramic insulators were damaged, probably due to the higher peak temperatures during the longer pulse. Switching to alumina ceramics pervented this problem.

Adapting the source to the CW column proved more difficult than at FNAL due to the highly re-entrant BNL inner electrode design. The source had to be placed at the back-plate of the column, 0.5 M from the first electrode (Fig. 1). An improved 90° magnet reduced aberations. Its increased gradient index, coupled with a quadrupole-doublet, produced a double waist at the first electrode. After the souce was mounted in CW Pit II it was not possible to reproduce the test-stand source performance for longer than 8-10 hours. The discharge current fell and the voltage rose until the source impedance was three times the normal 1 Ω.

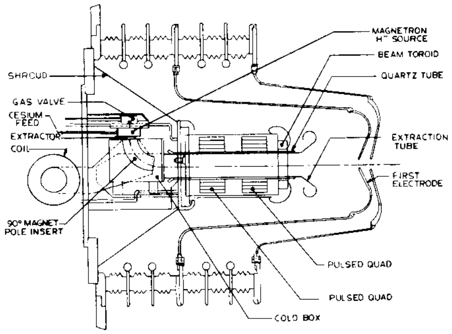

Fig. 1. Schematic Assembly of H^- source in BNL Column.

Sluyters and Alessi[7] showed that a magnetron with a grooved cathode run at reduced gas pressure produced more H^- beam at lower discharge current than the flat cathode. Based on this work, a grooved cathode which focused 4-times the surface area onto the anode slit was installed. As the source conditioned, the gas pressure, cesium temperature and discharge power supply voltage were reduced while the pulse width was increased to keep the source hot. The beam current rose to a sustained 45mA with the discharge current 45 A and the voltage 130 V. The source was run on a 24-hour schedule for 2 and 1/2 months at almost three times the original duty factor. Upon disassembly, some cathode erosion was found, but the source was cleaner than after a two week run in the high discharge current mode.[8]

Additional improvements were made to the equipment.[9] The discharge pulser was modified to increase the maximum pulse width to 600 μsec allowing a duty factor of 0.3%. A regulator circuit was built which keeps the pulsed gas pressure within 0.2 μTorr by adjusting the width of the 150 V pulse aplied to the gas valve. The averaged vacuum readout is used as the servo input, which does not allow the pulsed gas level to be distinguished from the background. A new circuit being tested should accomplsh this. The original pulsed gas valve was difficult to adjust mechanically. A new design installed in Pit I uses a 10:1 lever-arrangement to make the adjustment easy to set.

Another servo-loop maintains the cesium boiler temperature within 0.2°C. A new reusable stainless boiler was developed which eliminated problems with non-reproducible cesium introduction and possible contamination from the original copper boiler. The internally heated feedtube which carries cesium to the source was enlarged to reduce the possibility of clogging. This also lowered the boiler temperature to 140° C.

Operating Experience

The Linac has operated as an H^- accelerator since September 1982. Initial operation was from Pit II via a relatively long LEBT line in which space charge neutralization effects have been observed (Fig. 2). In April 1983, Pit I delivered H^- beam and became the primary preinjector, with Pit II as back-up. About 10% more beam reaches the Linac from Pit I due to its shorter length and lack of dispersion.

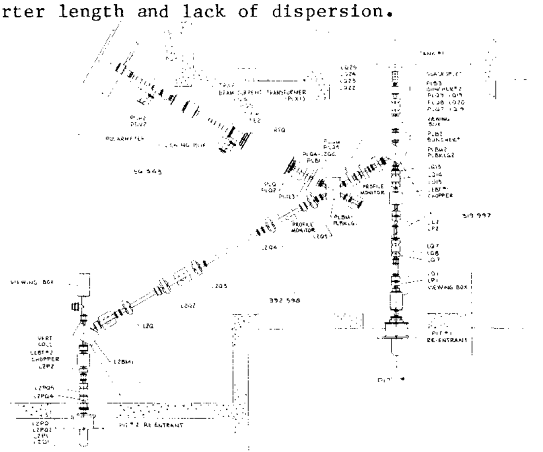

Fig. 2. LEBT AREA - The Polarized H^- source is shown upper left and the Linac at the upper right.

---

*Work performed under the auspcies of the U.S. Department of Energy

Typically half the 20 keV beam reaches 200 MeV (25-30 mA). A maximum of 85 mA has been attained in the dome by lowering the gas pressure, but the column acceptance limits the 760 keV beam to 45 mA. Lost beam loads the electrodes and CW arcing may result. Maximum transmission thru the column is 90%. Emittances measured at 760 keV are larger than those at FNAL by a factor of 1.5 to 2. Since both the flat and grooved cathodes gave nearly the same results, space charge growth in the 20 keV transport may be the cause. It is possible that a source mounted closer to the first column electrode might pass more beam.

The source was run continually for operations for 5 and 1/2 months. On inspection the cathode was noticeably eroded near the cesium inlet and had an etched image of the anode slit 1/2 mm deep. The gas inlet was 70% closed by cesium hydride deposits. Flakes of molybdenum were present but didn't affect the behavior. When shut off, the current was higher than when first conditioned. By contrast, with the flat cathode in the high discharge current mode, H^- current drops to half in 8 weeks. Cesium usage was considerably reduced, as might be expected from the lower boiler temperature (110°C) required with the grooved cathode. A fill of four grams should easily last one year.

As a direct result of H^- injection and changes to the ring rf, the AGS reached intensities 40% higher than with proton injection. Further increases require improvements to the AGS rf. While the total Linac rf beam-power was reduced by 7 MW, the hoped-for increase in 7835 rf power-tube life has been slight. However, the anode capacitor bank voltage has been lowered by 2 kV, which has improved the reliability of the rf modulators and reduced the number of anode-cathode arcs in the 7835's.

The reliability of the H^- preinjector has not been as good as with protons. The first year of operation averaged 15 hours of down time per month. Twice, shorts developed requiring quadrupole replacement. The feedtube heater, which failed several times, has been replaced by a fully sealed unit. Operation for the second year has shown an improvement in source support equipment reliability. The major problem seems to be beam-induced CW arcing. A new source test stand is being constructed which will be used to study source parameters to reduce this.

The Polarized Proton Project

The Ion Source

To take advantage of the higher efficiency and longer pulse-width injection capability, a new polarized H^- source was developed based on the colliding beam method developed by Haeberli.[10] This source has been a joint effort. Much of the atomic beam portion was supplied by ANAC Inc. Initial work pulsing and cooling the atomic beam and on the Cs° beam was done by ANL and Yale University. A new Cs source and neutralizer was designed and most of the operational development was done at BNL.

A polarized H° beam is fired collinear with a Cs° beam, with ionization occuring by charge exchange to yield polarized H^- (Figs. 3 and 4). The polarized H° beam is produced in a conventional ground-state atomic beam apparatus using an rf-dissociator with the nozzle cooled to about 100° K to reduce the velocity of the atoms. Both the Cs has and the rf are pulsed. Four sextupoles provide an electron-polarized beam. Two rf-transition units convert this to alternating nuclear polarizations on a pulse-to pulse basis.

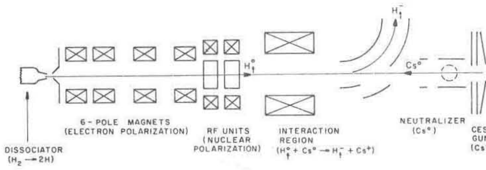

Fig. 3 Schematic of the Polarizd H^- source. A polarized H° beam produces polarized H^- through charge exchange with the Cs° beam.

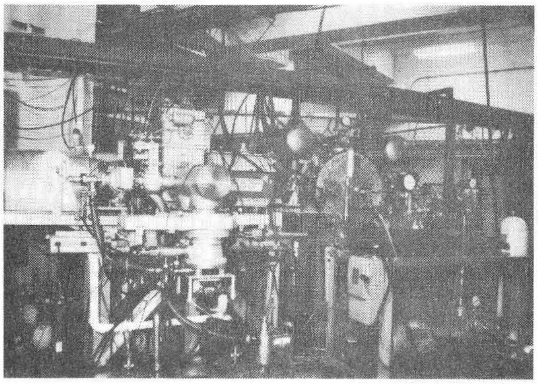

Fig. 4 Photograph of the Polarized H- Source.

A 10-15 mA, 40-50 keV pulsed Cs^+ beam is produced at the opposite end by surface ionization of Cs on a hot porous tungsten button. Cs^+ ions accumulate on the surface until the extraction pulse is applied, allowing high currents with low Cs consumption, since the boiler is at only 80-90°C. The Cs beam pulse shape is a sensitive function of button temperature, Cs boiler temperature and surface conditions,[11] making it often difficult to get the 400 μsec pulse width required. However, pulsing the Cs has the advantage of reducing power supply loading, coating of the surfaces with Cs and sputtering by the beam, resulting in a more reliable operation.

Conversion of the Cs^+ beam to Cs° takes place in a Cs-vapor neutralizer which is pulsed by means of a magnetic flapper valve in the Cs supply line. The stainless steel mesh walls of the neutralizer provide a wicking action to return the Cs to the reservior. This redesigned neutralizer has operated reliably for the last three months with seemingly low Cs consumption. Because of the stringent optical requirements, only about half of the Cs beam reaches the interaction region. H^- ions formed by charge exchange are focussed and accelerated to 20 keV, then deflected to the transport line by a 90° electrostatic mirror.

The Radio-Frequency Quadrupole

An RFQ accelerates the polarized beam from 20 keV to 760 keV. The vanes for the structure, based on a LASL design,[12] were machined at BNL. A full description of the electrical and mechanical design can be found in an accompanying paper in these Proceedings.[13]

Power for the RFQ is provided by a 200kW amplifier chain identical to that used for each linac tank. After installation in the beam-line, the RFQ conditioned rapidly. A 760 keV beam was detected after the 60° bending magnet immediately. It has performed flawlessly in the several months since that time. The measured power required for best capture and acceleration of the beam is about 110kW.

The Polarized LEBT Line

A new beam line was built in the LEBT area to take the beam from the polarized source thru the RFQ to the LEBT II line and into the Linac (Fig. 2). Design considerations included: maximum transmission of the polarized beam, and minimum imposition of one beam line upon the other. In addition, it was desired to provide a test facility for the polarized beam when not being used for operations.

The transverse phase-space beam line design allowed a 65% fill-factor, required the bend-section to be achromatic, and matched the beam emittance to the Linac acceptance. Since the source emittance was unknown when the line was designed, much flexibility was built in. Preliminary emittance measurements were limited by hardware problems but were sufficient to indicate roughly the settings. The 20 keV section of the line uses both electrostatic and magnetic lenses. The latter serve to diffuse the negative ion background form 15% to 1-2% at the RFQ.

In the 760 keV line, a third buncher at the same frequency as the original two, was added to retain the bunched beam from the RFQ to the Linac. It reduces the energy spread from the RFQ by a factor of three and reduces transverse beam growth between the bending magnets. The second buncher, in the LEBT I line, retards the growth of phase spread in the center of the bunch. The last buncher restores the ΔE spread which causes phase rebunching at the Linac entrance. This 3-buncher system gave a theoretical longitudinal transmission efficiency of 88-91.5%, depending on the density model.[14]

Beam Monitoring Equipment

Beam polarization will be measured at 20 keV using an optical polarimeter developed at Yale University, which detects Lyman α-line polarization from decay of exited H° atoms off a carbon foil. The beam Twiss parameters are measured at 20 keV and 760 keV using standard slit and multiple collector emittance heads with low noise amplifiers. Beam current is read at 20 keV and at four locations at 200 MeV using low noise beam toroids. Several Faraday cups are available in LEBT. Profiles are measured at 20 keV and 760 keV by multi-channel probes. In the HEBT line, six single-wire scanners provide profile data. At 200 MeV a polarimeter built by Rice University measures left-right asymmetry in H-carbon scattering at two angles in the horizontal plane using scintillation telescopes. The up-down asymmetry is used to position the beam and for normalization purposes. With a 15-mil Carbon-target, a 2% measurement has been achieved in 2-3 minutes.

Initial Performance

The source and RFQ have performed very well for the several months since they were turned on. A 20 keV beam of 12 μA produces 10 μA at 760 keV from the RFQ, with 6 μA reaching 200 MeV. Approximately 25% of the beam is lost in the transport around the achromatic bend. Measurements with Faraday cups before and after Tank 1 of the Linac indicate over 90% capture.

During a 5-day commissioning run the source reliably provided 8-12 μA of beam at a 300 μsec FWHM every 2 seconds. The 20 keV intensity as measured by a beam toroid, is shown in Fig. 5. The smaller trace, obtained by turning off the atomic beam, is background negative ions. Wider pulses could be obtained but not on a reliable basis. Similarly, higher currents can be obtained at the expense of pulse width. The polarization measured after the 200 MeV Linac was over 60%.

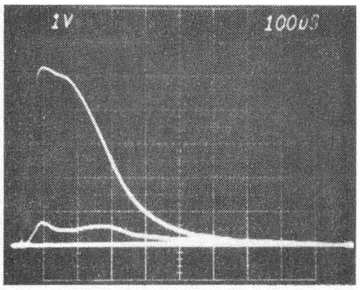

Fig. 5 Polarized source current. Large trace is current thru a beam toroid (2 μA/Div). The small trace is the background remaining when the atomic beam is off.

Although transport to and from the RFQ has not been fully studied, tuning the RF power into the RFQ, resulted in 85% of the 20 keV beam being accelerated to 760 keV with approximately 110kW in the RFQ.

Emittance measurements made at 760 keV yielded normalized values of 0.065 π cm-mrad in both planes at 90% of beam. The emittance did not change appreciably with current. These are consistant with design values for the RFQ, and are comparable to what was calculated for the polarized H^- source.

Future Plans

Much work remains to be done in understanding and documenting the source parameter space and the beam parameters at 20 keV and 760 keV, to properly set up the beam line. While the source and LEBT are now computer controlled, this is available only locally. It will be connected to the AGS main computer system so long-term data logging and analysis can be performed, and so that the AGS operations crew can take over the daily running of the source.

References

1. D. S. Barton and R. L. Witkover, Proc. 1979 Linear Accel. Conf., 47 (1979) BNL 51134.
2. K. M. Terwilliger, et al., IEEE Trans. Nucl. Sci, NS-28, 2031 (1981).
3. C. Hojvat, et al., IEEE Trans. Nucl. Sci., NS-26, 3149 (1979).
4. K. Prelec and Th. Sluyters, IEEE Trans. Nucl. Sci. NS-22, 1662 (1975).
5. C. W. Schmidt and C. D. Curtis, IEEE Trans. Nucl. Sci., NS-26, 4120 (1979).
6. D. S. Barton and R. L. Witkover, IEEE Trans. Nucl. Sci., NS-28, 2681 (1981).
7. J. G. Alessi and Th. Sluyters, Rev. Sci. Instr., 51, 12, 1630 (1980).
8. R. L. Witkover, D. S. Barton and R. K. Reece, IEEE Trans. Nucl. Sci., NS-30, 3010 (1983).
9. R. L. Witkover, Proc. 3rd Int'l. Symp. on the Prod and Neutr. of Neg. Ions and Beams, BNL (Nov. 1982)
10. W. Haeberli, et al., Nucl. Instr. Meth., 196, 319 (1982).
11. J. G. Alessi, Vacuum, 34, Nos. 1-2, 7 (1984).
12. K. Crandall, et al., "Final BNL RFQ Design", AT-1: 82-113, Los Alamos Scientific Laboratory.
13. H. Brown, et al. "Design, Fabrication and Testing of the BNL Radio Frequency Accelerator", Proc. this Conference.
14. H. Brown and Y. Makdisi, "Design of the Beam Transport Line from the 200 MeV Linac, Pol. Proton TN-23, (1982).