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ACCELERATION OF POLARIZED H^- IN THE BNL 200 MeV LINAC*

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Summary

The AGS Polarized Beam Project was started in 1980. The first beam was accelerated in March 1984, followed by commissioning studies and a high energy physics run at 16.5 GeV at an average 30% polarization. The Linac portion of the project included a new polarized H^- ion source and a Radio-Frequency Quadrupole (RFQ). These will be described as will the design of the new Low Energy Beam Transport (LEBT) line and beam instrumentation for the Linac. Operational results, current status and future plans will be discussed.

Background

In 1982 the AGS Linac was converted to an H^- accelerator,[1] which allowed the overlay of beam in the AGS phase space for higher injection efficiency. This capability was also important for polarized beams due to the low source intensities available.

Since neither of the two Cockcroft-Walton accelerators used for unpolarized operations could accommodate the weight or volume of the polarized source, it was decided to build an RFQ to accelerate the beam to 760 keV. This also allowed the source to be at ground potential, making tuning easier.

The Ion Source

The polarized H^- ion source design, chosen because of its potential for intensity improvement, is based on the colliding beam method of Haeberli.[2] In this source a polarized H° beam is converted to H^- by charge exchange with a Cs° beam. Much of the atomic beam and the interaction region components were supplied by ANAC, Inc. Preliminary work on the pulsing and cooling of the H° and the Cs° beams was done at ANL and Yale University. A new cesium source, and the extensive development required to make the source operational, was done by BNL.

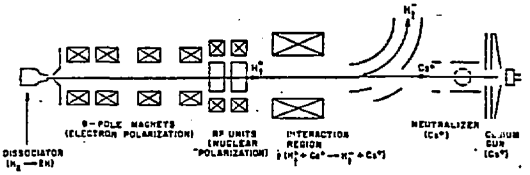

Fig. 1 - H^- polarized ion source schematic.

As shown in Fig. 1, the polarized hydrogen beam is produced in a conventional ground state atomic beam apparatus using an rf dissociator with the nozzle cooled to ~100°K. Both the hydrogen gas and the rf are pulsed. An electron polarized beam results after passing through the four sextupoles. Two rf transition units convert the electron polarization to nuclear polarization, alternating the spin direction on a pulse to pulse basis.

About 15 mA of pulsed Cs^+ beam is produced by surface ionization on a hot porous tungsten button and extracted at 40-50 kV. The low duty cycle allows high currents with low cesium consumption, at a cesium boiler temperature of only 80-90°C, reducing supply loading and surface sputtering due to coating. This beam passes through a pulsed cesium vapor neutralizer which operated reliably with low cesium consumption during the 3-month run.

Aperture limitations allowed only ~ 50% of the Cs° beam to reach the interaction region where it collides with the polarized H° beam. The H^- ions formed by charge exchange are focussed and accelerated to 20 KeV, and deflected to the transport line by a 90° electrostatic mirror. Further details of the source design can be found in Reference 3.

The Radio-Frequency Quadrupole Accelerator

An RFQ accelerates the beam from 20 KeV to 760 KeV. Vanes for the structure were numerically machined at BNL based on a LANL design.[4] The parameters were verified at BNL using the Saclay RFQ codes.[5] The cavity rf and mechanical design and the fabrication were done at BNL.[6]

The RFQ is powered by a 200 KW amplifier chain similar to the rf drive for the Linac final power tubes. Power is fed into the cavity from four loops at each end. Since there is no beam loading at the 10-25 μA beam current, only a phase control loop is used. The vanes are not water cooled, so a change in temperature changes the resonant frequency, requiring retuning. The RFQ conditioned rapidly even though the initial vacuum was in the 10^{-6} Torr range. Beam was immediately detected downstream of the first 60° dipole, confirming the 760 keV energy. The cavity required about 110 KW of rf power rather than the 100 KW design value. A plot of 760 keV beam versus rf power is shown in Figure 2.

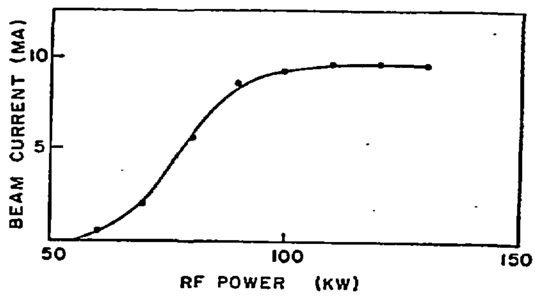

Fig. 2 - 760 keV current Vs RFQ power.

The Polarized LEBT Line

The new Linac LEBT area is shown in Figure 3. Normal AGS operation is from Pit 1. The polarized beam joins the line from Pit 2 to the Linac via a third 60° dipole. When this magnet is off, the beam can be run into an in-line instrument box.

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To preserve the bunching from the RFQ, a third buncher was added upstream of the new dipole. The bunchers, the RFQ, and the Linac all run at 201.25 MHz. The new buncher reduces the energy spread by a factor of 3 and reduces the horizontal beam size between the two dipoles. The second buncher retards the phase spread growth at the bunch center. The final one adjusts the energy spread to match the first gap in the Linac. The theoretical capture efficiency of this system is from 88 to 91.5%, depending on the density distribution model.[7]

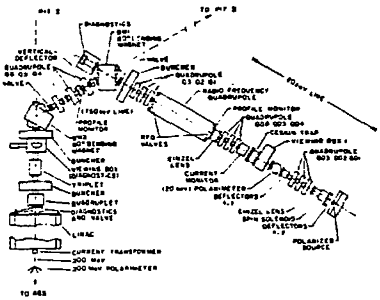

Fig. 3 - LEBT area schematic.

In the absence of measured source emittances, the beam line was designed with a 65% fill factor and considerable focussing flexibility. The 20 KeV section of the line contains a solenoid to precess the spin from horizontal to vertical, Einzel lenses and magnetic quadrupoles for focussing, a cold trap to prevent the diffusion of cesium to the RFQ, an emittance viewing box and a beam transformer. The magnetic quads also act as velocity selectors to keep non H^- ions from reaching the RFQ.

Following the RFQ, magnetic quadrupoles focus the beam into the achromatic section of the Pit 2 beam line. A multichannel profile monitor after the dipole is used to set the RFQ for proper output and to center the beam in the pipe. After the second 60° bend the beam is in the main line to the Linac, where it can be observed with another emittance probe or a Faraday cup to set the second magnet trim. Downstream, two bunchers separated by a triplet and a quadruplet, match the beam into the Linac. Another emittance probe at this location has proved to be the best means of adjusting this match.

Beam Monitoring Equipment

Beam intensity was measured using both conventional Faraday cups and high sensitivity beam transformers. The output of the beam transformer located in the 20 KeV line is shown in Figure 4.

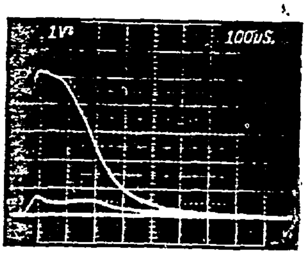

Fig. 4 - 20 keV beam current (transformer) output.

Other transformers were placed at the end of Tank 9 (200 MeV), before and after the first dipole of the achromatic bend in HEBT, and at the start of the injection section to the AGS. Faraday cups were placed in the straight-ahead line after the RFQ, after the second dipole in LEBT and at the entrance and exit of Tank 1.

The beam transformer was based on a LANL design by A. Browman.[8] A high permeability tape-wound core with a 200-turn coil is placed inside a mu-metal shield. This is enclosed in a soft iron outer housing supported by air insulated vibration isolators. (Fig. 5)

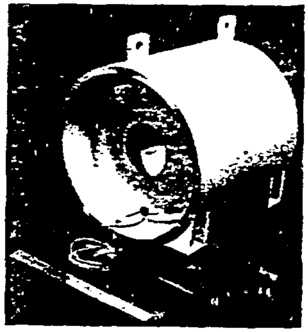

Fig. 5 - High sensitivity beam transformer.

The electronics, located about 1 meter away, consist of a differential amplifier followed by 2 gain stages and a drift control stage. A baseline clamp circuit was located at the receiving end of the cable. The primary noise sources were magnetically coupled 60 Hz and mechanical vibration. The 60 Hz noise was reduced to the equivalent of 100 nA by the baseline clamp circuit. Risetime was observed to be under 20 μsec.

Emittance measuring equipment of the slit and multichannel pickup type, was identical to that for the unpolarized H^- beam but with additional gain and filtering. Difficulty with ground loops limited the initial study of the beam, but the data obtained confirmed the design emittance numbers.

The single wire profile scanners[9] produced poor results. Excessive pickup on the long coax runs and ground loops obscured the signals. New twisted pair cables run in iron conduit have been installed in an effort to allow the the amplifiers to be placed outside the HEBT tunnel.

The beam polarization at 20 KeV was measured using the circular polarization of the Lyman- Alpha line from excited H^0 atoms produced by the H^- scattering off a carbon foil.[10] Signal rates for the low duty factor beam were too low to allow beam tuning. A new polarimeter utilizing the high analyzing power of the $^6Li(P,{}^3He){}^4He$ reaction, is being designed for use at 760 KeV to allow tuning of the source polarization without having to accelerate through the 200 MeV Linac.

A polarimeter, designed and built by Rice University,[11] located in the 200 MeV HEBT line provided the only means of tuning the source for maximum polarization. Left-right asymmetry in H^-Carbon scattering is measured at two angles (12° and 16°) in the horizontal plane using scintillator telescopes. The up-down asymmetry is used for beam positioning and normalization. A 2% measurement was achieved in about 60 Linac pulses with a 15-mil Carbon target. A plot of polarization versus source dipole current in the rf transition units is shown in Fig. 6.

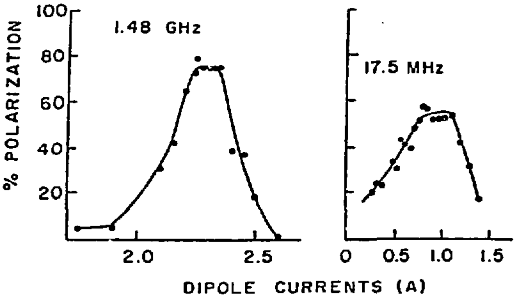

Fig. 6 – Polarization versus source dipole current.

Initial Performance

The performance of the source and RFQ during the 4 month commissioning and HEP operation period was exceptionally good. The beam currents are summarized below:

	Average Beam	
From Source (20 keV)	15.0	μAmp
After RFQ (760 keV)	12.0	"
After Linac (200 MeV)	10.6	"
At AGS	8.0	"

The beam pulse width was typically 300 μsec FWHM at a 2 second rep-rate.

A peak current of 25 μA was achieved, after a new tungsten button was installed, about half of which reached the AGS.

The transmission efficiency through Tank 1 (10 MeV) was observed to be more than 90%. Measurements at 200 MeV showed 75% polarization compared to a theoretical prediction of 82% from the source. The normalized emittances in the 20 keV line at the entrance to the RFQ were measured to be 0.020 π-cm-mrad in each plane for a current of 5 μA. This is about a factor of 3 lower than the design values based on another Haeberli type source.[2] A later measurement in the middle of the 20 keV line gave a vertical emittance of 0.027 π-cm-mrad for a 9 μA beam.

Emittances measured at 760 keV after the RFQ and quad triplet, in the straight-ahead line, were found to be 0.068 π-cm-mrad in both planes at 6 μA. This implies an emittance growth factor of 2.5 through the RFQ. Early studies did not show appreciable growth of emittance as a function of intensity in the RFQ.

Beam transmission through the RFQ averaged 80% to 85%, compared to a design estimate of 95 to 98%. Some beam may have been lost before and after the RFQ since the current measurements were each made about 2 m from the RFQ. The greatest beam loss occurred in the achromatic bend and through the 2 bunchers just upstream of the Linac. The momentum spead after the RFQ has not been measured yet.

Future Plans

There are several development efforts in progress to increase the polarized H^- source intensity. A routine source operation of 25-50 μA is expected from the present design. A longer term project seeks to build a 1 mA source.[12,13] The RFQ pulse width will be lengthened from the present 500 to 700 microseconds, in anticipation of a wider pulse from the ion source. This will leave the 200 MeV Linac as the limiting factor on the beam pulse width.

The emittance measuring system will be updated to improve the reliability of the data acquisition and control in LEBT.

At present it is cumbersome to switch between polarized and unpolarized beam operations, due to the need to manually switch polarities and change the range oo some transport elements. New wide range, switch reversible power supplies will improve the changeover.

The 200 MeV HEBT line requires improved profile measurements to allow proper beam alignment and matching to the 200 MeV polarimeter and higher efficiency transport to the AGS.

The ultimate goal will be to allow the AGS to deliver a polarized beam of comparable intensity to the unpolarized beam.

References

1. R.L. Witkover, D.S. Barton, R.K. Reece, "Conversion of the AGS Linac to H^- Acceleration", IEEE Trans. Nucl. Sci., NS-30, 4, 3010 (1983).
2. W. Haeberli, et al., Nucl Instr and Meth, 196, 319 (1982).
3. A. Kponou, J. Alessi, Th. Sluyters, "The AGS Polarized H^- Source", This Conf.
4. K.R. Crandall, R.S. Mills, R.H. Stokes, T.P. Wangler, "Final Design Study for the BNL RFQ", AT-1:82-113, LANL, June 1, 1982.
5. J-L. LaClare, A. Ropert, "RFQ Generation and Beam Dynamics Calculation Codes at LNS", LNS Group Theorie, LNS.072 Nov. 1982, Saclay, France.
6. H. Brown, T. Clifford, S. Giordano, F. Khiari, R. McKenzie-Wilson, M. Puglisi, "Design, Fabrication and Testing of the BNL Radio Frequency Quadrupole Accelerator", Proc 1984 Linear Accel Conf, 65 (1984) GSI-84-11.
7. H. Brown and Y. Makdisi, "Design of the Beam Transport Line to the 200 MeV Linac", Polarized Proton TN-23 (1982) BNL.
8. A. Browman, LANL, Private communication, June 1982.
9. N. Fewell and R. Witkover, "Beam Diagnostics in the BNL 200 MeV Linac", Proc 1972 Linear Accel Conf, 54 (1972) LA-5115, LANL.
10. C. Liu, F. Pichanick, P. Schuler, private communications.
11. D.G. Crabb, et al., "Polarimeters for the AGS Polarized Proton Beam", IEEE Trans Nucl Sci, NS-30, 4, 2176 (1983).
12. A. Hershcovitch, A. Kponou, B. DeVito, R. Meier, V. Kovarik, Th. Sluyters, "Cooling High Intensity Atomic Hydrogen Beams Down to Liquid Helium Temperatures", Proc. this Conf.
13. J. Alessi, "An Efficient Ionizer for Polarized H^- Formation", Proc. this Conf.

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