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THE BNL 200 MEV H^- LINAC – PERFORMANCE AND UPGRADES*

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Abstract

For the past two years the linac has had reliable operation from the new RFQ preinjector. The performance of this preinjector is described. There is a fast beam chopper in the transport line between the ion source and RFQ. By injecting narrow pulses into the AGS we can obtain an accurate linac energy measurement, or the detailed shape of the linac beam energy distribution, on a single pulse. Some general comment on the linac operation are also presented.

Introduction

The BNL 200 MeV linac began operating as the proton injector for the AGS in 1971. In 1982, the linac was switched to H^- operation. In 1983 a polarized H^- source and 750 keV RFQ were added to the preinjector area, and polarized protons were accelerated in the AGS. In 1988, a second 750 keV RFQ was installed in place of the Cockcroft-Walton preinjector, for high intensity H^- operation, so we now have only the two RFQ's as preinjectors. The linac presently delivers ≈ 25 mA of H^- in 500 µs pulses, at a 5 Hz repetition rate. In this paper, we will first describe some features of the new RFQ preinjector, and discuss its performance. As part of this new beamline, a fast beam chopper was added. This chopper has allowed us to do several interesting linac studies, and we will describe accurate measurements of the linac energy and energy distribution, both obtained on a single pulse basis using the fast chopper. Finally, some general comments will be made on the linac reliability, and improvements being made.

RFQ Preinjector

We have now been operating for two years (approximately 7 months continuous per year) with the RFQ preinjector. Details of the beamline have been given previously.[1] Briefly, the line is as follows. H^- is produced in a magnetron surface-plasma source, with a circular extraction aperture. The beam is extracted at 35 keV, and transported 2 m to the RFQ. Focusing in the 35 keV line is provided by two pulsed solenoids, with a fast beam chopper located between the two solenoids. The 4-vane RFQ, designed and built at Lawrence Berkeley Laboratory,[2] accelerates the beam to 750 keV. There is then a 6 m transport line from the RFQ to the linac. (The line is long to allow room for the polarized H^- beam from the other RFQ to also be injected into the linac). Transverse focusing in the line is provided by three quadrupole triplets and a quadruplet. The bunch structure of the beam out of the RFQ is maintained by three buncher cavities in the transport line.

The operation of the RFQ has been trouble free, with only an occasional problem with its rf power supply. (An RCA 4616 tetrode is used as the final stage, delivering approximately 160 kW). Both maintenance requirements and downtime are much improved over previous operation with the Cockcroft-Walton. Under typical operation, we measure 50-60 mA on a current transformer 60 cm before the RFQ entrance, and get ≈ 80% transmission to the exit of the RFQ. Better transmission was observed in early tests in which the source extractor design was different, but the present extractor was chosen for its improved reliability. With ≈ 45 mA out of the RFQ, we lose 25-30% of this current in the 6 m transport to the linac. The exact source of this loss is not well understood, and discrepancies still exist as well between measured emittances and computer modelling of the optics in this 750 keV transport. Transmission through the linac is typically 80%, with ≈ 25 mA measured at 200 MeV. In comparisons of the emittance measured 76 cm upstream of the RFQ, and the emittance measured 173 cm downstream of the RFQ, there is an ≈ 50% emittance growth. Previous measurements on a test stand, taken closer to the RFQ entrance and exit, had shown only an ≈ 10% emittance growth.

Based on the design calculations, the proper voltages are obtained in the RFQ cavity at 121 kW. This is the power level maintained under normal operation. We observe, however, that the RFQ output drops off only slightly down to 80 kW. The transverse emittance of the beam at 80 kW is also essentially the same as at 121 kW. We have not measured the bunch structure of the beam at this lower power, but with no retuning of the bunchers from their normal values, we still accelerate ≈ 66% of the normal current to 200 MeV at 80 kW. We have also studied the dependence on injection energy. Under normal operation at 35 kV, the source output is space charge limited rather than emission limited. Therefore, as the source extraction voltage is decreased, the current out of the source drops as $V^{3/2}$. However, the fraction of the beam transmitted through the RFQ drops by only ≈ 10% at an energy of 29 keV. At this energy, the output emittance is also still constant. At an injection energy of 23 keV, however, the accelerated beam through the RFQ is essentially zero.

Linac Studies With the Fast Chopper

A fast beam chopper is included in the 35 keV transport line between the ion source and RFQ.[3] The purpose of this chopper is to allow bunch-to-bucket injection of beam into the AGS or Booster, in order to throw away at 35 keV those particles which would be lost at injection because they are outside the synchrotron rf bucket. Beam bunches can be produced with the width and delay of each bunch programmable to match the moving rf buckets during multiturn injection. In addition, when this chopper is used in conjunction with a sine wave chopper in the 750 keV transport line, one can accelerate single 200 MHz bunches through the linac, with periods ranging from 50 ns to once per macropulse. The < 1 ns wide pulses can be used for neutron time-of-flight experiments.[4]

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The chopper is a pulsed electrostatic deflector, where voltages of approximately ±700 V are applied to plates above and below the beam to deflect the beam outside the RFQ entrance aperture. The chopper has a total length of 38 cm, and a separation between the upper and lower plates of 8 cm. The chopper is made up of 15 pairs of plates over the 38 cm length, which are connected as a slow-wave structure by coaxial cables, so that the voltage pulse travels plate-to-plate at the beam velocity. The chopper plates are powered by a pair of commercial solid state pulse generators having rise and fall times of less than 10 ns. Rise and fall times of 10 ns are measured on the beam pulses.

Under normal operation, the beam is space charge neutralized in the 35 keV transport line. However, when the chopper is used, the neutralizing ions are partially swept out of the beam by the plate voltage, and even though the voltage is off when the H^- beam passes through, the space charge neutralization does not build back up during the short pulses.[5] The effect of this loss of neutralization is a poorer match of the beam into the RFQ, and even when the line is retuned, approximately 20-60% of the instantaneous beam current is lost (the degree of neutralization depends on the duty factor of the chopper). Because of this loss, the chopper has so far been used only for machine studies, and a new chopper is now being built for the 750 keV line. It is a similar traveling wave structure, and in spite of the higher beam energy it will operate at essentially the same plate voltage. This is possible because the new chopper is approximately twice as long, with half the plate separation, and the rejection slits will be located at a more favorable position.

Several linac studies have been done using the 35 keV chopper, and the AGS as the diagnostic line. There is a momentum recombining bend between the linac and the AGS, and at the point of maximum dispersion are located a position monitor and profile monitor. Using this, and the magnet calibration, we are able to determine the linac energy. However, by injecting a ≈ 100 ns beam pulse into the AGS (with the accelerating voltage off), and watching the signal on a wall current monitor as the beam spirals, we are able to determine the absolute value of the linac energy in a very clean way on a single pulse. The radius of the AGS is accurately known (128.457 meters), so if the time is measured for the beam to spiral for 100 turns, one is doing a time of flight measurement over ≈ 80 km. Using a LeCroy 9400 digital oscilloscope, a 500 μs trace of the spiraling beam can be taken with 20 ns per point, and the center of the bunch on the first and 101 turn can be determined to within ±20 ns. From this, the absolute energy of the beam is known to within ±50 keV. Even a variation in the radius of the AGS by 1.0 cm (a large variation) only changes the determined energy by 41 keV.

We have used this method of energy measurement to periodically check the stability of the linac, and we occasionally noted unexpected changes in the energy. It was finally determined that these energy changes were coming from changes in the phase at which the bunched beam entered the linac. In Fig. 1, a measurement of the linac energy as a function of this phase is shown (the absolute value of the phase shown is arbitrary). Also shown is the linac transmission as a function of this phase. We see from this that the linac energy can change by ≈ 1 MeV without a significant change in transmission (this phase had typically been set by optimizing transmission). The shapes of the two curves could be reproduced fairly well with PARMILA. By optimizing the buncher phases relative to the RFQ, we can get transmission vs. input phase curves such as shown in Fig. 2.

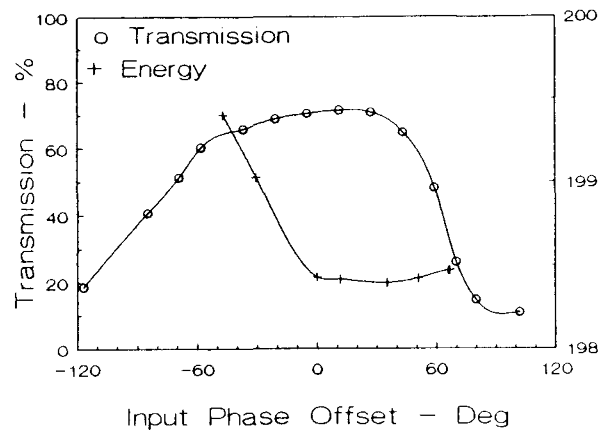

Fig. 1. The output energy of the linac, and linac transmission, as a function of the phase of the injected beam relative to the linac rf. The absolute value of the phase shown is arbitrary.

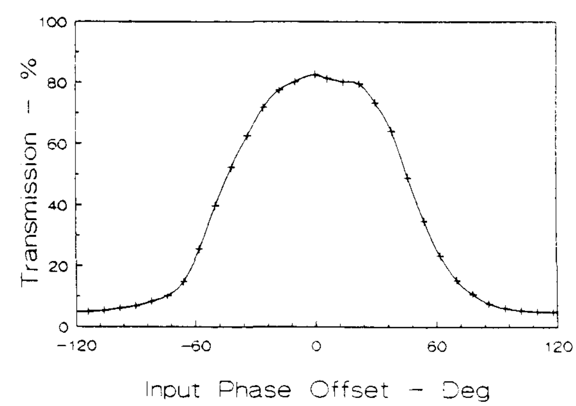

Fig. 2. Linac transmission vs. phase of the injected beam.

At the same time that the linac energy is measured with the spiraling beam, one can also observe the spreading of the pulse over the 100 revolutions, and estimate from that the energy spread of the beam. More interesting, however, is the case in which the single 100 ns bunch is injected into a high voltage bucket of the AGS. In this case, its synchrotron motion will rotate the energy coordinate into the time coordinate in 1/4 of a synchrotron period. If the bunch is ±45° the motion is essentially linear. Figure 3 is a single trace measurement of a bunch taken 1/4 synchrotron period after injection. This plot gives a detailed picture of the linac beam energy distribution. The horizontal axis is equivalent to 0.4 MeV/division, with low energy on the right. It was observed that the detailed shape of the energy distribution can be changed completely by changing the phase at which the bunched beam is injected into the linac, even moving the shoulder from one side to the other. With the relative ease of this measurement, we hope to study further its dependence on various linac and preinjector parameters, and improve the shape of the distribution.

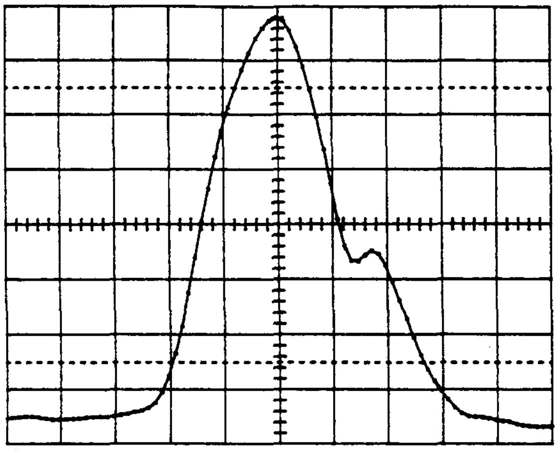

Fig. 3. The linac energy distribution, measured on a single pulse. The horizontal axis is 0.4 MeV/division, with low energy on the right.

Linac Operations

In recent years, the linac has operated ≈ 5000 hrs/yr for the physics program, with ≈ 95% availability. The rf systems are the largest contributor to the downtime, spread among the various components. Vacuum problems come next, followed by ion source downtime. The quadrupole systems typically cause only a few hours of downtime per year. In the past few years, we have begun to experience occasional pinhole leaks developing in the rf windows at several locations. (The feed loops are on the atmospheric side of the window, and ≈ 2 MW peak power is fed through each window). We do not yet understand the sudden occurrence of this problem after many years of trouble free operation.

Many of the 45 ion pumps on the 9 linac tanks have never been rebuilt (20 years old), and were beginning to trip off frequently or develop shorts. Therefore, approximately 20 ion pumps have been rebuilt by the AGS Vacuum Group over the past two years, and this program is continuing. In addition, vacuum valves are being installed on each tank to allow us to do an intermediate stage of pumping, after roughdown, with a cryopump. In tests, this reduced the pumpdown time of a tank from 8-12 hours to only 2-3 hours. In addition, less stress will be put on the ion pumps, since they will be turned on at a much lower pressure than is presently possible.

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