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PERFORMANCE OF THE NEW AGS RFQ PREINJECTOR*

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Introduction

In the fall of 1988, the 750 keV Cockcroft-Walton (C-W) preinjector for the AGS 200 MeV H^- linac was replaced by an RFQ, in what has proved to be a very successful upgrade. The motivations for the upgrade included improved reliability, simpler maintenance, and the added convenience of having the ion source located at nearly ground potential. At the same time, the controls and instrumentation in the preinjector area were modernized. The linac has been operating full time with this RFQ preinjector since January 1, 1989, and the reliability has been excellent. The source, RFQ, and linac operate at a 5 Hz repetition rate, and the beam pulse width is approximately 450 μs. At this time, the H^- current at 200 MeV is typically 23-25 mA, the same as previous operation with the C-W, although the capability is there to reach higher currents in the future.

The layout of the new preinjector is shown in Figure 1. An important consideration in the layout of this line was the decision to leave the final 2.4 m section before the linac intact, so the optics of a second C-W injector line and polarized H^- injection from another RFQ remained the same. The resulting line has a distance of almost 6 m from the RFQ to the linac, and there are three "rebuncher" cavities to maintain the bunching of the beam from the RFQ. The following sections will describe some details of the preinjector line, and then discuss the installation and performance.

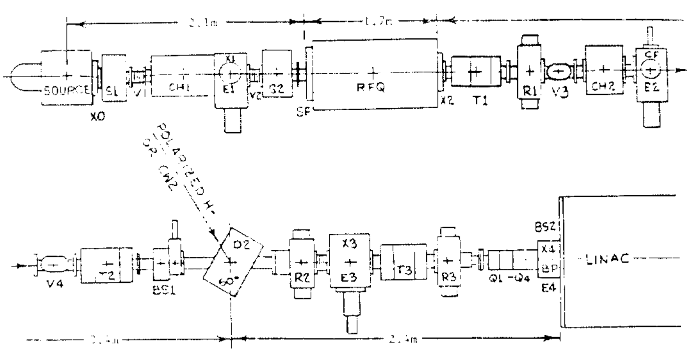

Figure 1. Layout of the new RFQ preinjector beam line: BP-Beam phase probe; BS-Beam stop; CF-Coaxial Faraday cup; CH-Chopper; D2-Bending magnet; E-Emittance analyzer; Q-Quadrupole; R-RF cavity; S-solenoid lens; SF-Segmented Faraday cup; T-Quadrupole triplet; V-Vernier steering magnet; X-Beam current transformer.

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H^- Source

The H^- ion source is a magnetron surface-plasma source, operating with a pulsed extraction voltage of 35 keV. It differs in several respects from that used for H^- injection with the C-W. Rather than extraction from a slit, the anode and extractor apertures are circular in order to produce an emittance symmetric in the x and y planes. The source magnetic field of approximately 700 G is provided by two small SmCo magnets. With the present 4 mm extractor gap, 2.8 mm diameter anode aperture, and 2 mm diameter extractor aperture, 70 mA of H^- is typically extracted from the source. The operating discharge current of only 15-20 A is 2-3 times lower than the operating current required with the slit source for the C-W.

The extracted electron current is 1-1.5 times the H^- current, and most of these electrons strike the extractor electrode. Therefore, in order to reduce the rate of erosion of this electrode, the tip of the electrode is made from tungsten. There is some increase in the beam emittance out of the source as the electrode erodes during the first couple weeks of operation. The rate of erosion then seems to diminish and the source continues to operate stably. We have so far had two months of continuous operation on a single electrode, and the beam output is remaining at 70 mA.

35 keV Transport

The 35 keV transport line from the source to the RFQ is 1.9 m long, and has two pulsed magnetic solenoids (10 cm diameter) for focusing, as well as two sets of steerers. Space charge effects are important in this line, and with the background pressure of 10^{-6} T, it takes about 50 μs for the beam to space charge neutralize. Approximately 85% of the beam is transported from the source to the RFQ entrance.

Another element in this 35 keV transport line is a fast beam chopper.[1] This is a slow-wave electrostatic deflection device, in which ± 700 V is applied to opposing plates at rates up to 2.5 MHz, for bunch-to-bucket injection into the AGS. Rise and fall times of 10 ns have been measured on the chopped beam pulses. The fast chopper affects the space charge neutralization of the 35 keV beam, so some retuning of the transport line is required, and the instantaneous current out of the RFQ is reduced somewhat from that when the chopper is not used.

RFQ

The RFQ is a four-vane structure, 1.6 m long, operating at the linac frequency of 201.25 MHz. This was designed and built at Lawrence Berkeley Laboratory, and was delivered to BNL in September, 1987. Power is fed through a single port at the longitudinal center, and it employs vane coupling rings for field stabilization. The required power of approximately 160 kW (121 kW plus beam loading) is provided by a power amplifier using an RCA 4616 tetrode in its final stage, the same as is used as the driver stage for the linac tank rf systems. The cavity is water cooled on the outside. A single rotating tuner loop with automatic frequency tracking and a range of 360 kHz allows the RFQ to be kept on frequency during warmup.

During normal operation, transmission has been 85%, with 45-50 mA at the exit of the RFQ. In earlier tests, essentially 100% transmission was measured at 40 mA, and with a 3.5 mm source extractor gap currents of up to 60 mA have been accelerated in the RFQ. With a normalized, 90% emittance of 0.11 π cm-mrad going into the RFQ, an emittance of 0.12 π cm-mrad was measured at its exit in both planes.[2]

753 keV Transport

As mentioned previously, this transport line is almost 6 m long, in order to keep two other injector lines intact. Transverse matching is via magnetic quadrupoles. The longitudinal bunch structure is maintained from the RFQ and matched to the linac via three rf buncher cavities. This longitudinal matching over such a long line has turned out better than anticipated, with 80-85% of the beam at the linac entrance being captured and accelerated to 200 MeV. (Some of this loss is probably due to transverse mismatch.)

From the exit of the RFQ, only 65% of the beam is transported to the linac entrance, with most of the beam loss occurring in the aperture of the first buncher. In tests before final installation of the line, the first buncher was removed, and 95% of the beam could then be transported past D2 in Figure 1. We plan to increase the aperture in the first buncher this summer (the bunchers have grids for field flattening). This should allow us to exceed 30 mA at the output of the linac, if desired.

There is a 10 MHz sine wave chopper in the 750 keV line, driven by a high Q tank circuit. When used in conjunction with the 35 keV chopper, this allows us to accelerate single microbunches of the 200 MHz linac for high resolution time-of-flight experiments. The repetition period of the microbunches can be varied from every 50 ns to once per linac pulse. Figure 2 shows an oscillograph of a single linac microbunch ($\leq$ 1 ns), measured on a fast gap monitor[3] at 92.6 MeV. The micropulses had a 10 μs spacing.

Instrumentation and Controls

The instrumentation in the new preinjector line includes horizontal and vertical emittance measurements at four locations, five beam current transformers, a five-segment Faraday cup at the RFQ entrance, and a fast Faraday cup (2 GHz bandwidth) near the entrance to the linac. While all hardware is in place, work on the electronics and software is still in the debugging phase. The controls for the new beam lines include the feature of pulse-to-pulse modulation of setpoints for power supplies. This allows the tune of the transport lines to change at 5 Hz, depending on whether the next beam pulse will be delivered to the AGS, the isotope production facility, or the radiation effects facility. The

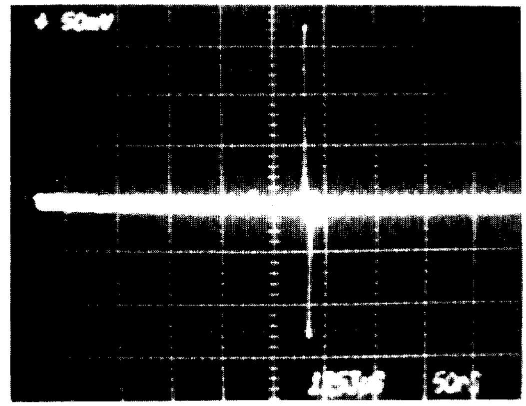

Figure 2. Oscillograph of a single linac micropulse ($\leq$ 1 ns) produced by a combination of beam chopping at 35 and 750 keV (time: 50 ns/ division).

ability to have independent tunes is important when the different users have different intensity or beam chopping requirements.

Installation and Performance

The linac went into its normal summer shutdown at the end of June, 1988. It took three weeks for the linac staff to dismantle the C-W and clear the two-story pit area. A concrete floor was then put in at the linac level, taking approximately six weeks. Following this came the installation of electrical and plumbing services, etc. There was then approximately three months to install the RFQ and beam lines, hook up all power supplies and controls, and do testing. Figure 3 shows the new preinjector during installation. Since January 1, 1989, when the AGS proton program began, the linac has been operating with the new RFQ.

The first 2.5 months of operation have been very reliable, with only a few minor problems causing machine downtime. In one instance, the RFQ had to be let up to atmosphere to make a minor repair, and within three hours the repair had been made and the RFQ was again delivering full beam to the linac. The ion source can be shut down, removed, repaired, and be delivering full beam again within six hours. These repair times are quite a contrast to repairs in the C-W, where a full day was usually lost for a source repair which required losing vacuum.

The linac output current has been consistently 23-25 mA. Because the new emittance instrumentation is not yet complete, studies and optimization of the transport from the RFQ to the linac have been minimal. All quadrupoles in the transport lines are essentially operating at very near their calculated values.

It is interesting to note the sensitivity of the linac output beam to several of the parameters in the new preinjector line. One observation is that steering changes made in the 35 keV transport line before the RFQ can cause movements in beam profiles taken at 200 MeV. A second observation is the sensitivity to the RFQ amplitude, and the phases of the RFQ and bunchers. A 5 kW change in the RFQ power (nominally 121 kW), or a 5 degree phase change, while producing no observable effect on the

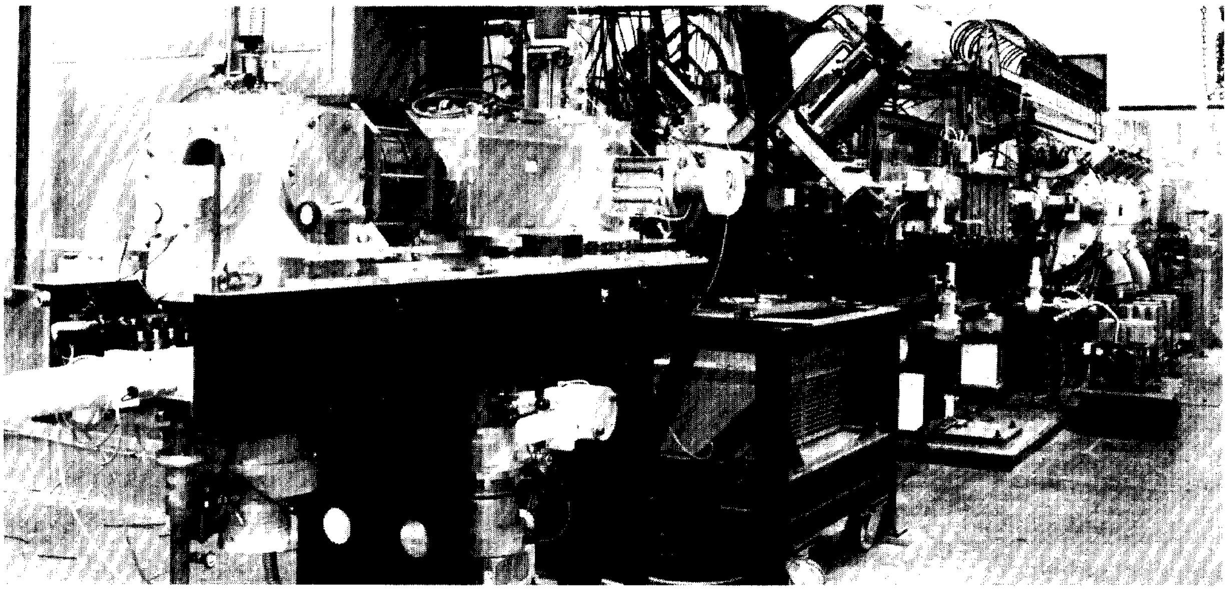

Figure 3. Photo of the new preinjector during installation.

beam in the 750 keV line, causes noticeable changes in the beam at 200 MeV due to changes in the longitudinal match to the linac.

Acknowledgments

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