UPGRADE OF THE BROOKHAVEN 200 MEV LINAC*

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Abstract

The Brookhaven 200 MeV linac serves as the injector for the AGS Booster, as well as delivering beam to the Biomedical Isotope Resource Center. During the past year, many linac systems have been upgraded to allow operation at 2.5 times higher average current (150 μA). This was achieved by an increase in rep-rate from 5 to 7.5 Hz, an increase in beam current from 25 mA to 37 mA, and a slight increase in pulse width to ~530 μs. Additional upgrades were made to improve reliability and modernize old systems. This paper describes improvements made in the 35 keV and 750 keV beam transport, 200 MeV beam transport, rf transmission line, rf power supplies, control systems, and instrumentation.

Introduction

The AGS 200 MeV linac accelerates H^- ions for injection into the AGS Booster. The linac operates at a 7.5 Hz rep-rate, and since the Booster takes only 4 pulses every ~3 seconds, all remaining pulses are sent to the Biomedical Medical Resource Center (BIRC). This facility produces radioisotopes for the pharmaceutical and medical community, as well as supporting a medical research program. In order to meet increased demand for isotopes, we have nearly completed all phases of a program to upgrade the average current out of the linac. The AGS has also benefited from the improvements, since higher peak current out of the linac improves Booster injection, and the reliability of the linac was improved through modernization of systems. Most of the improvements were funded as part of the BIRC project, through DOE OHER, but parts have also been supported through AGS Department Accelerator Improvement Projects. As a result of these improvements, the average current out of the linac has increased by a factor of 2.5, to 146 μA. Table 1 shows the linac performance before and after the upgrade. The improvements made to the various subsystems are described in the following sections.

Table 1

	Before Upgrade	After Upgrade
H^- Beam Current	25 mA	37 mA
Repetition Rate	5 Hz	7.5 Hz
Beam Width	500 μs	530 μs
Average Current	62 μA	146 μA

35 keV Beam Transport Line

The beam from the magnetron surface-plasma H^- source is matched in to the RFQ by two pulsed magnetic solenoid lenses. Until this year, the distance between source and RFQ was 2.1 m. This line also included an emittance measuring device and a fast beam chopper. Because fast beam chopping is now done much more effectively in the transport line after the RFQ, this 35 keV chopper box was removed to improve the matching in to the RFQ. In addition, calculations showed that matching could be further improved if the first solenoid were moved closer to the source, and the second solenoid closer to the RFQ. With the new distance of 1.4 m, the first solenoid moved 4 cm upstream and the second solenoid moved 4 cm downstream, the transmission through the RFQ improved by ~10%, from the 70-80% range to 80-90%, depending on source operating conditions. The emittance of the beam in front of the RFQ was reduced by about ~20%. Typical current out of the RFQ is now 65 mA, and the maximum current through the RFQ was 80 mA, 82% transmission. (In our case, the "transmission" is the ratio of output current, measured 61 cm after the RFQ, to input current measured 55 cm before the RFQ).

750 keV Beam Transport Line

There is a 6 m transport line from the RFQ to linac, to accommodate a pulsed dipole where polarized H^- comes from a second beamline, and a fast beam chopper. There are three bunchers and 13 quadrupoles in this line. Transmission in this line was only ~75%, with losses early in the line caused by the fact that the first quadrupole after the RFQ was not close enough to catch the beam before it got too large. In order to reduce the beam divergence quickly coming out of the RFQ, a 1.1 cm aperture, 3.5 cm long permanent magnet quadrupole was placed in the endflange of the RFQ, only 2.1 cm from the RFQ vane tip. In addition, this quadrupole can be moved transversely while running beam, via micrometer adjustment outside vacuum, in order to steer the beam. A picture of the RFQ endflange with PMQ is shown in figure 1.

Additional changes in the line were to move the first quadrupole triplet 9 cm closer to the RFQ, and to convert a final quadruplet (which had been running as a triplet), into a real triplet. We also removed all magnets from the line and

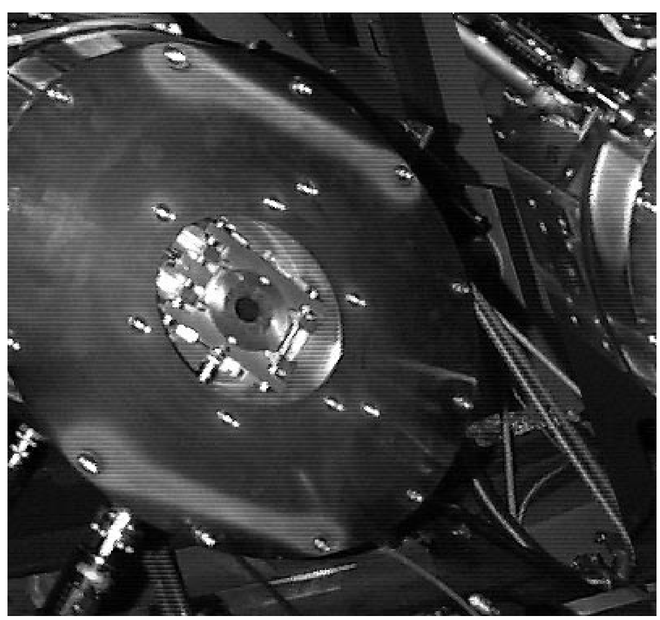

Figure 1: RFQ endflange with permanent magnet quadrupole.

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had the fields precisely measured by the RHIC magnet group. All magnets were carefully surveyed when reinstalled, particularly trying to eliminate quadrupole rotations, which leads to emittance growth of the beam. With these improvements, the transmission from the RFQ to linac was improved to ~85%. We believe that the remaining loss comes from the 12 "grids" (made of thin tungsten strips) in the line, in the three buncher cavities.

With this 50% higher current at the linac entrance, the linac transmission remained the same, with ~70% being captured in the first tank. This agrees with calculations of the line, and comes from the fact that the line is too long to match longitudinally with only three bunchers. The calculations show that with a fourth buncher the capture into the linac could be >95%.

200 MeV Beam Transport Line

There were both vacuum-related and beam optics improvements in the transport line between the end of the linac and the BIRC target. Most of the vacuum components in the line were replaced. O-rings were eliminated, and the line now uses all conflat flanges. Aluminum pipe was used in much of the line to minimize activation. Pumping of the line was increased, with new turbo pumps and ion pumps. Apertures in the line were increased wherever possible, and most of the line has either 6" or 8" diameter beampipe.

Details of the optics of the line are given in another paper at this Conference.[1] Briefly, there are two bends between the linac and BIRC target, and a quadrupole was added to make these bends achromatic. Further downstream, two octupoles and two quadrupoles were added in order to produce a uniform current density on the BIRC targets, to prevent melting of some target materials at this increased beam power. While we have been able to produce flattened beam profiles on an upstream profile monitor, progress on producing a flat distribution on target has been slow, due to the long turnaround time (1 day) on profile measurements at the target location (via activation of foils and counting).

High Power Transmission Line

In order to improve reliability at the increased linac duty factor, all the 12" coaxial transmission line was replaced. Up to 6 MW peak power is fed from each of the nine rf systems, through a 3 db power split, and into two ports on each of the nine accelerating cavities, a total of over 200 m of transmission line for the full linac. Our 25 year old system had disadvantages of having aluminum inner conductor, spring ring rf contacts, and was unpressurized. The new transmission line system was built and installed by Dielectric Corporation. It has a copper inner conductor and an aluminum alloy outer conductor, is pressurized to 15 psi with dry air, and the connectors for the center conductor are EIA-type finger contacts. We replaced the full system, including the 3 db power splitters, waster loads, breakaway and telescoping sections, and reflectometers. A hybrid phase shifter (mechanically variable) was replaced with a transmission line section of optimum length in each system.

The removal of the old transmission line took one week, and the actual installation time for the new system was approximately three weeks, although total time to fully complete, test and debug was three months. The new system has operated very reliability, with low insertion loss, very low probability of voltage breakdown, and improved S-parameters.

Linac RF Power Supplies

<u>7835 Anode Power Supply</u>

The 6 MW power amplifiers for the linac use Burle 7835 triodes. At the increased current and duty factor of the linac, some of the 60 kV, 2 A, 7835 anode power supplies would be running at their 2 A limit, a concern for reliability. In addition, these power supplies, constructed in 1968, are oil filled units that are outside the linac building, connected to capacitor banks by a long high voltage transmission system. Servicing the power supplies can be a problem because of weather and the need for a crane. Also, the placement of the power supplies would not meet current code requirements for fire protection or oil containment. It was felt that with the present technology, a dry type power supply could be built, and in order to meet any future requirements, we settled on a 50 kV, 5 A supply.

While several vendors offered high frequency switching supplies, the final selection was a conventional 6 pulse primary phase controlled dry type transformer rectifier (TR) set, built by Universal Voltronics (UVC). To save money, the power supplies were housed in existing linac cabinets that formerly housed the charge control amplifiers. These cabinets are 4x8x8 feet and are fully compatible with the existing lifting fixtures, building crane, and floor space requirements.

The high voltage secondary coil of the transformer presented the greatest technical challenge. In the final design, each of 6 secondary coil assemblies was divided into two individual coils, lowering the layer to layer voltage by a factor of two. The coils were then wound with vertical spacers to allow the epoxy to flow between each of the layers. The final, completed 250 watt transformer assembly is compact, measuring 1.5'x4'x4'. None of the temperatures on the transformer secondary exceeded 60 C after 24 hours running.

The power section is a straightforward six pulse primary phase control. The voltage and current regulating loops are compensated for the capacitive load. The power supply charges the capacitor bank at a constant current (current mode) until the preset voltage is reached (voltage mode).

Seven power supplies have been delivered to BNL and tested, with the remainder due shortly. They will go online in January '97.

<u>4616 Anode Power Supply</u>

The Burle 4616 tetrode is used in the driver stage of the linac rf system. The anode power supply is being upgraded to improve the feedback control, employing both current and voltage feedback, and replace unavailable SCR controllers.

<u>PLC Controls for RF Systems</u>

The linac is made up of 9 identical rf stations. Each station has several subsystems, including the driver, 7835 filament supply and cavity, 50 kV supply, capacitor bank, modulator, and local control station (LCS). Each of the subsystems has individual control buckets for AC and high voltage logic. These buckets were designed and built in 1968 around 7400 TTL series components. Replacing these control buckets with more modern components is a necessity because many of the components are no longer available.

We are beginning to implement a new control system, utilizing programmable logical controllers (PLC's). It is designed for fully independent operation of each rf system, flexibility and reliability. An Allen Bradley 5/40 processor was chosen for each LCS. A 5/50 ethernet processor was selected for the control room. Each of the 5/40's can scan the subsystems of a system (scanner mode), or be scanned by the host in the control room (adaptor mode).

There are 3 networks that make the backbone of the system. The first network is responsible for the data collection and control of each station. The 5/40 in the LCS scans the subsystems of a station. To minimize the wiring, each of the subsystems has a miniature processor (Allen Bradley flex I/O) that multiplexes the data at 230 kbaud for the 5/40. A single twisted pair links all of the subsystems of a mod together. The subsystems are connected together via the Allen Bradley Remote I/O network. The second and third networks are links between each of the systems. The DH+ network runs at 57 kbaud and is responsible for the remote monitoring and control of all 9 systems. The Allen Bradley graphical interface program, Control View, is used to control the supplies. An additional remote I/O network allows the 5/40 E in the control room to monitor each mod at 230 kbaud for fast global control. For example the 5/40 E can turn off all the 50 kV supplies at the same time if needed.

Linac Controls

This past year the original 25-year-old Linac control system was replaced with a modern modular system fully integrated into the existing AGS distributed control system. Unix workstations provide the operator interface, and are networked using ethernet to front-end computers which are implemented using VMEbus components. A front-end computer located in the Linac Control Room sources four high speed serial communication links using the Datacon field bus, a long-standing BNL standard. Although an old system, Datacon is extremely robust and noise immune, can operate over 2000 ft. of coaxial cable, and is relatively inexpensive. Each Datacon link can address up to 256 devices, delivering a 24-bit command and accepting a 32-bit reply. All devices are accessed for each Linac pulse (7.5 Hz), and in particular, device setpoints are rewritten for each pulse; thus any sequence of different Linac clients (Booster, BIRC) requiring possibly different settings can be accommodated - a feature termed pulse-to-pulse modulation (PPM). The individual devices are interfaced to the Datacon link via dual-channel cards housed in crates at 11 locations along the Linac. We are controlling and/or monitoring over 400 devices.

At the heart of the Datacon field bus system is the VME Datacon engine. This device was developed at BNL using modern field programmable gate array (FPGA) and RISC processor technology. The Datacon engine supports multiple Datacon channels with each Datacon channel capable of addressing the full Datacon address space. The Datacon engine has an on board timeline decoder and local memory so that all Datacon transactions can be preloaded into tables, sent on previously programmed timing events, and data returned and stored without intervention by the VME processor. This has resulted in a many fold increase in data throughput compared to older Datacon implementations.

Linac Timing System

There are two aspects of the linac timing system which will be upgraded in FY'97. The "local" timing system provides specialized "fixed" delays, generates sequences of triggers required for rf systems, etc., and checks to make sure that external triggers coming in to the linac are in the proper sequence. It will allow us to time shift the triggering of rf power to individual accelerating cavities, and with downstream cavities time shifted out of beam time we can run at different energies on a pulse-to-pulse basis. This local Linac timing hardware will consist of Altera PLD chips for designing the logic controls. An 8051 microcontroller chip will provide the processing of data to and from the PLD chips. A RAM chip will store the data for each user. The microcontroller will control the data flow. A PC with control software will provide the interface.

A second part of the timing system provides external trigger signals (from downstream accelerators) to the linac local timing, as well as triggers to some specific linac hardware. This new Linac timing system will be an encoded timeline using RHIC generation VME timing system modules. With these modules a Linac timeline can be built without hard wiring or hard coding. The timeline can be changed by command from computers on the accelerator control network and/or by cable changes between modules at the generator. The timeline generator will be located in the Linac control room and the encoded timeline will be distributed along the linac via fiber optic cables. Decoder/delay modules, fully programmable through the VME processor, connect directly to the timeline and provide decoded pulses from events, or can provide delayed outputs from an event.

Instrumentation

A stripline position monitor was added between the bends to the BIRC target, at a high dispersion point, to allow monitoring of the linac energy. As suggested by P. Ostromouv (INR), a diagnostic was added at the end of linac cavities #1 and #4, to aid in the setup of the phase and amplitudes. This is a series of Al plates of appropriate thickness, each electrically isolated and on which the current can be read. Successive plates will stop partially accelerated particles from successive cavities, allowing one to do phase and amplitude scans for coarse setup of the tanks. Finally, a third wire at 45^{o} was added to two SEM units, giving beam profiles in 3 projections by stepping through the beam. With this, we are able to get 3-dimensional tomographic reconstructions of the beam distribution, as described in [2].

Conclusions

With improvements in beam transport through the 35 keV and 750 keV lines, we can now operate at currents 50% higher than previously. The average current out of the linac has reached our goal of 146 μA, and still higher currents should be possible. Most of this past running period was at reduced beam pulse width, due to BIRC target limitations. (They expect to be able to run at full average current next year). Therefore, we can not yet say if reliability will suffer over long periods at 150 μA, but so far indications are that there is an overall improvement in linac reliability.

Acknowledgments

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References

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