THE ANL 50 MeV H⁻ INJECTOR - 35 YEAR ANNIVERSARY

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Abstract

The H^- Injector at ANL consists of a 750 keV Cockcroft-Walton preaccelerator and a Alverez type 50 MeV Linac. The accelerator was originally constructed as the source of protons for the Zero Gradient Synchrotron (ZGS). The first proton beam was extracted from the preaccelerator in 1961. The accelerator is presently used as the injector for the Intense Pulsed Neutron Source (IPNS), a 500 MeV rapid cycling synchrotron with a spallation-neutron target. During most of the time since turn-on over 15 years ago, the IPNS facility availability has rarely dropped below 90% and has averaged 95% over the last ten years. During the same period, the 50 MeV injector availability has averaged 99%. Performance and improvements over the 35 year period is discussed.

Introduction

The ANL 50 MeV Injector has proven itself to be a very versatile and reliable machine. The linac has been used as a source of protons, H^- ions, polarized protons, polarized deuterons, and neutral particle beams during it's many years of operation. Ground was broken for the injector in June 1959. The first 750 keV proton beam was obtained in December 1961. The first 50 MeV protons were accelerated in the linac ten months later in October 1962. The injector was used as the proton source for the ZGS 12.5 GeV synchrotron until 1976 when the ZGS became the first accelerator to utilize direct injection of H^- ions as a normal mode of operation. The last two years before the ZGS was shut down in October 1979, were dedicated to the acceleration of polarized protons. A Rapid Cycling Synchrotron (RCS)[1] was developed and constructed in the mid 1970's as a proposed booster for the ZGS. Due to the scheduled shutdown of the ZGS the booster concept was abandoned. However, the RCS evolved into the 500 MeV accelerator for injecting protons to the IPNS spallation-neutron target. The linac has now supplied H^- ions at a 30Hz rate to the RCS for over 15 years. We expect to inject the 5 billionth pulse into the RCS in late November of this year.

Injector General Discription

The layout of the IPNS accelerator system including linac, RCS, and the spallation target is shown in Figure 1. The preaccelerator houses the 750 kV Cockcroft-Walton power supply, the H^- ion source, and the high gradient accelerating column. The H^- ion source is a magnetron type[2] in which negative ions are extracted directly from the hydrogen plasma on the surface of the cathode. The extractor electrode and magnet poles are at terminal ground and the source, including the pulsed arc supply, pulsed hydrogen supply, and cesium supply are pulsed to a negative 20 kV potential. After extraction, the beam is bent 90° by a magnetic dipole, focussed by three quadrupole magnets, and injected into the high gradient column. The 750 keV beam is transported 6 m to the linac in a beamline containing two quadrupole triplets for beam focussing, a vertical and horizontal steering magnet, one 200 MHz buncher, and a fast beam chopper for beam shaping. The linac cavity is a copper clad structure 0.94 m in diameter and 33.5 m long operating at 200.070 MHz. It was constructed in eleven sections, which are bolted together. The linac contains 124 drift tubes, each containing a dc quadrupole magnet. Rf power is supplied to the linac via a rectangular waveguide to a single feedloop in the center of the cavity. A 50 MeV beam line transports the H^- beam 38 m to the RCS accelerator. Beam steering and focussing is provided by a total of eight horizontal and two vertical dipole magnets and sixteen quadrupole magnets.

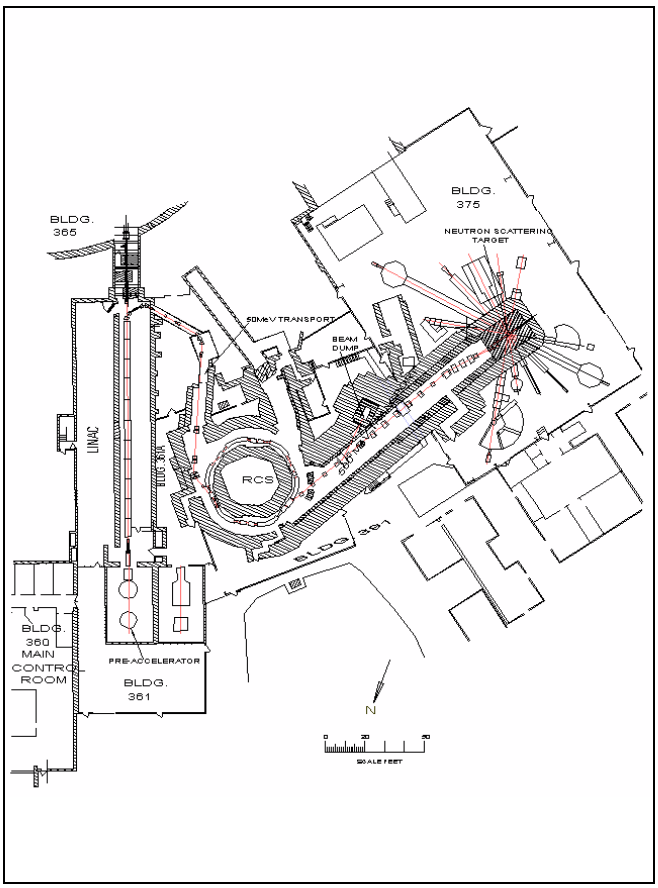

Figure 1. Layout of the IPNS accelerator.

System Evolution

Preaccelerator

The 750 kV power supply for the preaccelerator is a standard four stage Cockcroft-Walton. The input transformers to the four stage multiplier are driven with a 400 Hz motor generator set. There have been no failures of the high voltage transformers, rectifiers, or capacitors since construction. Parts of the regulating system have been updated but some of the amplifiers are still original.

The original ion source used to supply protons to the ZGS was a standard duoplasmatron which produced enough beam current to supply the synchrotron with a 20 mA, 100 µs pulse at a one-pulse-every-four-second rate. When we switched to H^- injection, a modified duoplasmatron with a hydrogen charge exchange cell[3] was used. This source was quite adequate for supplying the ZGS with enough beam current but the RCS was close to being input limited. Also, the hydrogen flow needed in the charge exchange cell required two 30,000 l/s bulk titanium sublimator vacuum pumps in the high voltage terminal. The titanium slugs in these pumps had to be replenished every two or three weeks requiring many man-hours of maintainence. In 1983 the magnetron type H^- ion source was installed. This source produces 45-50 mA, 70 µs beam pulses at a 30 Hz rate, which is more than sufficient to supply the RCS 50 MeV input requirement of 10 mA. The source has been very reliable, requiring only dissassembly and cleaning after several thousand hours of operation.

The original accelerating column was a multi-gapped low gradient structure and required frequent cleaning to enable it to hold the 750 kV. In 1970 a single gap high gradient column was developed and installed, increasing the linac output capability from 20 mA to over 40 mA. A six megohm resister in series between the 750 kV supply and the column results in only a few second trip during a column arc. The column arc rate averages about four per hour. The column hasn’t required dissassembly and cleaning in nearly ten years.

Linac RF System

The rf system was the first linac amplifier built utilizing the 7835 triode. It was the first and only amplifier to transport the rf from the power amplifier to the cavity via a rectangular waveguide. The 7835 cavity is not pressurized, but we have had very few problems with voltage breakdown. We have had continuing problems with blocking capacitor voltage punch-through. These failures seem to come in bunches every several years. Presumably the cause is a void or foreign particle in the irrathene insulation. Besides upgrading most of the power supplies to accomodate the 30 Hz rep-rate, the only major changes in the rf system have been with the plate modulator for the 7835. The modulator has been redesigned and replaced twice due to problems with output switch tube voltage holding capabilities. The tube we have been using for the past 15 years is the ML7560. The tube lifetime has been
excellant, over 25,000 hours, and the arc through rate is maybe one per week.

Linac Cavity

The ANL linac was patterned after the 50 MeV Brookhaven Alternating Gradient Synchrotron (AGS) linac, with the main difference being that the quadrupole magnets in the 124 drift tubes are dc instead of pulsed. Originally each magnet had a transistorized shunt attached for individual control. Presently, transistorized shunts are utilized on only the first 58 magnets. The cavity vacuum system started out with nine 2000 l/s ion pumps and one 20" mercury diffusion pump for pump-down. The present system uses seven ion pumps, two cryo-pumps and a 1500 l/s turbo-pump. The ion pumps in use are the original pumps. We try to overhaul at least one per year which means each pump operates about 7 years before removal and cleaning.

To keep gas stripping of the H^- beam at a minimum, we try to keep the cavity vacuum below 5×10^{-7} Torr. We have an ongoing problem involving water leaks into the linac high vacuum system. There are 57 water cooled tuning balls mounted along the length of the linac. These are 14 cm diameter copper balls both threaded and silver soldered to a 2.54 cm stainless tube which extends through the cavity wall. A smaller diameter water distributor tube runs down the center of the 2.54 cm tube to supply water for cooling the copper ball. Water leaks (apparently through the threaded and silver soldered joints) into the cavity vacuum have developed over the years in 15 of these tuning balls. A method of repairing these leaks without removing the tuning ball or breaking the linac vacuum was developed. A smaller diameter cooling tube is placed inside the original tube making good thermal contact with the inside of the ball to allow for sufficient heat removal. The space between the tubes, which now contains the leak, is evacuated, virtually eliminating what would now be an air leak into the cavity. We presently have a water leak in one of the tuning balls so small that we have yet to locate it.

Polarized Beams

In 1973, the first high energy polarized proton beam[4] was developed at the ZGS. It operated very successfully until 1979 when the ZGS was shut down permanently. The source was installed in a new preaccelerator located just west of the original as shown in Figure 1. To house the large polarized proton source, a high voltage terminal 2.5 m x 3.5m x 4.5 m in size was required. The terminal was built by a company that manufactures campers. The source weighed over 4,500 kg and consumed over 35 kW of electrical power. It contained three rf systems; six magnets; six beam line elements; and nine vacuum pumps including diffusion, ion, turbo-molecular, sublimator, and mechanical. A pulsed bending magnet at the high energy end of the linac allowed both a polarized proton pulse to be injected to the ZGS, and a burst of H^- beam pulses to be injected to the RCS.

In 1978 the first ever high energy polarized deuteron beam[5] was accelerated. The deuterons were accelerated to 375 keV in the preaccelerator and to 25 MeV by the 50 MeV linac. The rf level and quadrupole magnet currents used for accelerating deuterons in the $2\beta\lambda$ mode were essentially the same as normally used for protons. Normal tuneup resulted in a deuteron transmission through the linac of about 25%.

Neutral Particle Beams

Proton Therapy

In 1983 the H^o beam resulting from gas stripping at the high energy end of the linac was studied as a possible proton therapy facility at Argonne[6]. The H^- beam was separated from the H^o beam by a bending magnet and the H^o beam drifted through the beamline to the previous ZGS area. An intensity collimator and halo foil reduced the lower energy components produced by gas stripping earlier in the linac. The beam was then converted to H^+ by passing through a thin foil. It then passed through a spectrometer magnet into the experimental enclosure.

Strategic Defense Initiative

One of the objectives of the Strategic Defense Initiative (SDI) was to put a medium energy (50-200 MeV) H^- linac into space to evaluate the promise of Neutral Particle Beam (NPB) devices. The beam intensity and quality requirements were far beyond those of any operating linac so a great deal of research was required. The only operating H^- linac in this energy range was at IPNS, so the Neutral Particle Beam Test Stand (NPBST)[7] was developed in 1986. Two beam lines were constructed in the old ZGS tunnel. The first line provided basic physics information on beam diagnostics and high energy neutralization devices. The second line was used to study the magnetic optics required to produce large diameter beams with low divergence.

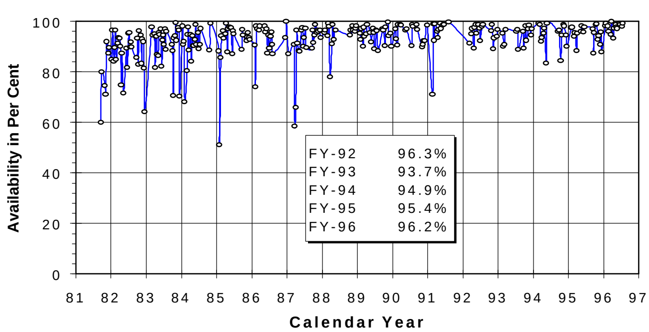

Figure 2. Accelerator Availability.

Accelerator Operations

Figure 2 shows the availability ratio (ratio of beam hours available to beam hours scheduled) for the entire RCS accelerator system. As can be seen the yearly average is around 95%. The availability of the linac alone averages above 99%. Scheduled and operating time are shown in Figure 3. For several years budget constraints have limited operation to less than 20 weeks per year. The Scientific Facilities Initiative (SFI) funding included in the FY 1996 budget provides for an increase in operating time in 1996 to 25 weeks and should eventually result in an operating schedule of up to 32 weeks per year.

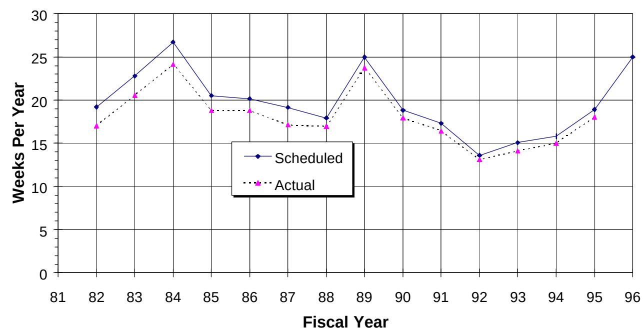

Figure 3. Scheduled and actual operating times.

Acknowledgements

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