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RECENT PERFORMANCE OF THE INTENSE PULSED NEUTRON SOURCE ACCELERATOR SYSTEM*

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Summary

The Intense Pulsed Neutron Source (IPNS) accelerator system has now been in operation as part of a national user program for over five years. During that period steady progress has been made in both beam intensity and reliability. Almost 1.8 billion pulses totaling 4 x 10^{21} protons have now been delivered to the spallation neutron target. Recent weekly average currents have reached 15 μA (3.2 x 10^{12} protons per pulse, 30 pulses per second) and short-term peaks of almost 17 μA have been reached. In fact, the average current for the last two years is up 31% over the average for the first three years of operation. See Table I. Figure 1 shows the pattern of beam current increase over the 5 year operating period.

Table I.

	Nov. 1981–July 1984	Oct. 1984–Dec. 1986
Average beam current	9.78 μA	12.77 μA
Availability factor	89.9%	92.3%
Scheduled hours	11,941	7,259
Available hours	10,737	6,701
Pulses on target x 10^8	10.5	7.0
Protons on target x 10^{21}	2.10	1.87

A little over a year ago IPNS was approached by the Argonne National Laboratory (ANL) Strategic Defense Initiative Office (SDI) about use of our H^- linac beam for Neutral Particle Beam (NPB) studies. This program became operational five months after its construction start and continues to grow. Details are provided in later paragraphs.

Introduction

The IPNS accelerator system consists of a 750 keV Cockcroft-Walton preaccelerator containing an H^- ion source, a 50 MeV proton linac and a 450 MeV 30 Hz Rapid Cycling Synchrotron (RCS). The intense extracted proton beam (3.2 x 10^{12} protons in 80 ns) strikes a U-238 target. A 1 μs burst of moderated neutrons is produced. The neutrons are directed to 12 neutron instruments each of which is optimized for a particular type of material science measurement.

Initial expectations were that the facility would operate only 2 or 3 years. Performance of IPNS, both accelerator and neutron instruments, have been far above expectations. Competing, potentially superior facilities both in this country and abroad, have experienced slower than anticipated turn ons. These two facts have left IPNS with a factor of 2.5 more experiments than operating budgets permit. IPNS plans to cope with this problem with the installation this summer of an enriched uranium target which will increase the neutron flux by a factor of 3, minimizing the eventual superiority of the competing facilities. The hope at ANL is that our reliable operation and relatively inexpensive operating costs will then make us fully competitive both in the eyes of scientific users and the sponsoring agency.

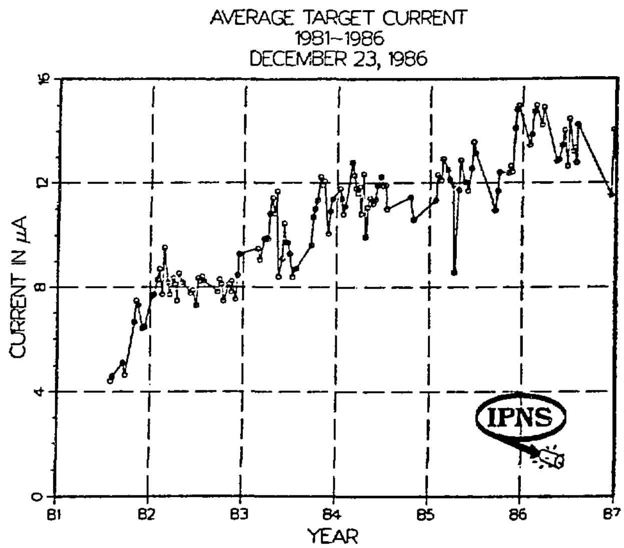

Fig. 1. Average Target Current

Neutron Chopper Synchronization

The IPNS synchrotron was originally designed to operate at 30 Hz synchronized to the 60 Hz power line frequency. The synchrotron ring magnets are powered by a dc biased 30 Hz resonant circuit which is driven by a 24 phase power source made up of two solid state power supplies.[2] The timing of the other accelerator components is synchronized to the magnetic field in the ring magnets by monitoring the zero crossings of the $\dot{B}$ signal from a pickup loop in one of the magnets.

The neutron beam chopper is a cylinder made from a neutron absorbing material with a curved slot which permits neutrons to pass through. The revolution frequency and the width and curvature of the slot determine the range of neutron energies that are transmitted through the chopper to the scattering experiment. The chopper is rotated at a frequency multiple of 30 Hz (typically 270 Hz) by a fractional horsepower synchronous motor. The chopper drive system has provisions for a slow (5 μs/s) phase correction. To maintain adequate energy resolution, the position of the neutron chopper must be synchronized to the time of extraction of the protons from the synchrotron to better than two microseconds.

The synchrotron and the neutron choppers could not be synchronized to the 60 Hz power line frequency.

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The ring magnet system and the choppers had different moments of inertia and could not maintain synchronization due to line frequency changes, even when the neutron chopper position was used to control the exact time of extraction within a 200 microsecond "extraction window". Methods for synchronization to a fixed frequency clock were developed.[3] These methods improved the neutron chopper experiment data collection, but had severe affects on the accelerator system. Operating the accelerator with the fixed frequency clock caused the acceleration cycle to slip in phase in respect to the power line. This phase slip accentuated the effects on the beam of power supply ripple on numerous accelerator components. Identifying all of the affected components and eliminating the ripple would have been prohibitively expensive and time consuming.

Further synchronization methods were studied until the present synchronization system evolved.[4] The system uses a variable frequency master clock (VFMC) to generate synchronized pulses to both the ring magnet power supply and the neutron chopper drive systems. The VFMC tracks the power line frequency, but its tracking rate is determined by the maximum neutron chopper correction rate. In addition, oscillation damping circuits were added to the chopper drive systems to allow higher chopper correction rates without excessive "hunting." The present system is capable of limiting the phase variation of the accelerator system in respect to the power line to approximately ±15°. This system, in many cases, effectively eliminated the effect of power supply ripple on the beam. Elimination of numerous causes of beam instability allowed the operations team to concentrate their investigations on systems which clearly required additional effort.

Ring Magnet Power Supply

The limiting of the phase variations of the synchrotron in respect to the power line did not significantly affect the variations in the ring magnet power supply. Since the ring magnet power supply operates as a 24 phase dc rectifier, it contains significant ripple at 720 Hz, a frequency beyond the full response of the ring magnet power supply regulator. Again, this ripple did not affect the operation as long as the accelerator was phase locked to the power line. Although the VFMC was able to limit the phase variation to ±15°, this corresponded to a full cycle at 720 Hz and the regulator was not able to correct. These phase variations manifested themselves as ±8 gauss changes in the 2800 gauss injection field. This caused a decrease in the usable synchrotron aperture.

The regulator system was redesigned to improve its frequency response. The basic concept for the old and new designs is the same except for the manner in which the ac and dc components of the current feedback signal are separated. The old design separated these components with a combination of low pass and high pass active filters, which required hand selected components for proper alignment and ovens for stability, and with limited frequency response responded poorly to initial surges and transients. The new design separates the ac and dc components of the current feedback signal with ideal rectifiers and summing amplifiers. This eliminated the need for critical, hand selected components and the ovens. It also permitted tailoring of the frequency response to better match the requirements for stability. The improvements to the ring magnet power supply regulator decreased the variation of the injection field by a factor of 2 to less than ±4 gauss and therefore decreased the beam position variation during injection to less than ±3 mm. A block diagram of the new regulator is show in Fig. 2.

H^- Stripping Foil

After several years of experimenting with stripping foils of various types we have settled on pure carbon of 60 to 80 $\mu g/cm^2$ thickness. These foils are commercially available in the U.S. An entire year's running has been carried out with only nine of these foils. The average life of each foil has been 42 million beam pulses which translates to about 500 hours of operation each. When thought of in terms of the injected protons and recirculations, a good guess is that each foil is struck about 5×10^{21} times. The failure mode is not total breakage but a shredding of the foil edge which affects stripping efficiency. These foils are brought up to essentially full beam current with only two hours of conditioning as opposed to at least eight hours with the old plastic foils. Obviously this improved foil performance has helped create our average current increase. Carbon has always looked like our best choice but mounting

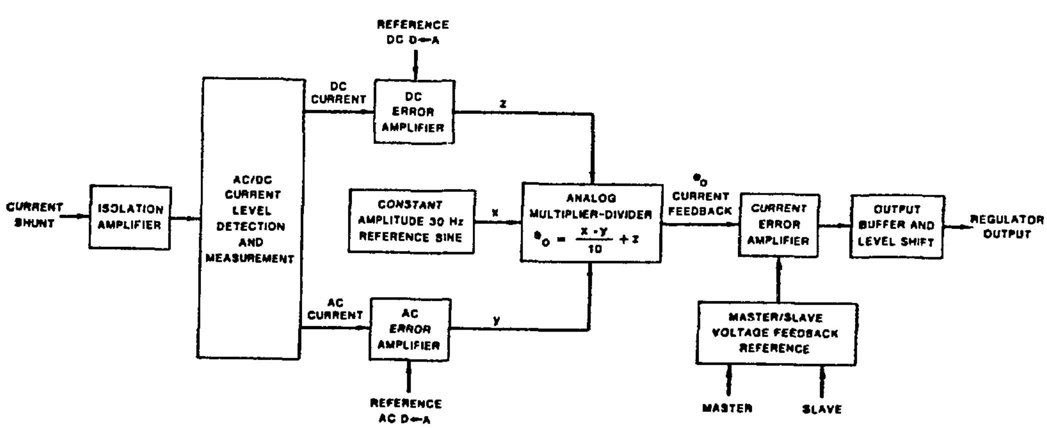

Fig. 2. Block Diagram RMPS Current Regulator

difficulties have precluded its use in past. In late 1985, a small 2 axis manipulator was developed to draw the foil from the water floatation device onto the holder and then draw the mounted foil assembly out of the water. This manipulator avoided the "jerky" motion of the human hand which frequently resulted in foil damage due to water surface tension. Temporarily supporting the free edge with a thin wire until the assembly was in a vertical position has proved helpful. The success rate with these techniques is about 50% when done by our most skillful man.

H^- Ion Source and Preaccelerator

A grooved cathode magnetron H^- ion source[5] has now been supplying negative ions to the RCS since early 1983. The H^- ion source reliability continues to be excellent with less than 0.3% of unscheduled downtime charged in FY 1986. This number not only reflects the ion source reliability but also includes the Cockcroft-Walton power supply, the high voltage column and all other ancillary equipment required to deliver 750 keV negative ions. The nominal negative ion output as measured in the 750 keV terminal is 40 mA peak at the RCS repetition rate of 30 Hz. There is no forced cooling on the ion source so the arc (beam) pulse width is limited by the source cathode temperature to approximately 80 μs. The source is removed and cleaned after three or four thousand hours of operation. The only component normally requiring replacement after that period of operation is the titanium anode cover plate from which the negative ions are extracted through a 1 cm x 1 mm slit. With about 4000 hours of 30 Hz operation, the focused ions from the cathode groove have eroded the anode cover plate by approximately 50%.

With the somewhat long (>1 m) 20 keV beam line separating the ion source from the high voltage accelerating column, it was decided we could operate without a refrigerated "cold box" to trap the cesium evolving from the source before it could have a chance to migrate into the column. However, after three years of operation it appears that cesium is indeed entering the column at certain times and can cause an increase in the column spark rate up to 3 or 4 times normal. The normal spark rate is 4 per hour. "Normal" sparks do not trip off the Haefly power supply but the beam is inhibited for 1 second each time a "normal" spark occurs. After lowering the cesium flow into the source, the column spark rate will return to normal but it may take up to two days to notice the results. This lower cesium flow condition may result in less than optimum source performance. A source with closer fitting components which allows less cesium to escape was recently installed. This did seem to have a positive effect. A refrigerated baffle has just been installed but it is too early to determine its effectiveness.

Neutral Particle Beams

One of the SDI goals is to put a 50 MeV H^- linac into space in the early 1990s to evaluate the promise of NPB devices. Los Alamos National Laboratory (LANL) will build the ground test version of this linac. Completion is scheduled for 1988-89. The beam intensity and beam quality requirements are far beyond those of any operating linac so a great deal of research is desirable before 1989. This is where ANL has entered the picture. The only operating 50 MeV H^- linac in the U.S. today is the one feeding H^- ions to the RCS. Despite neutron science user over subscriptions, funding is available for at most 6 months of IPNS operation per year, so the linac can easily fill other needs. Many readers will remember that the IPNS accelerator is an orphaned offspring of the old high energy physics accelerator called the Zero Gradient Synchrotron (ZGS). The well shielded, exceptionally stable, ZGS tunnel was also available for SDI use. This tunnel and its associated utilities would cost about $30 million today. SDI got quite a bargain — use of an existing H^- linac about half time and an excellent hall for NPB experiments.

Funding arrived in January 1986 to rebuild the 50 MeV transport line from the linac into the ZGS hall. Once inside the hall, the beam line separates into three beams. The first beam was a rebuilt version of a parasitic beam using H° particles created by residual gas neutralization in the linac. The second beam, totally new but built mostly with surplus IPNS and ZGS equipment, became operational on April 30. It is a fairly complicated, though short, beam line with 8 dipoles, 10 quadrupoles, numerous beam diagnostics and remotely controlled collimators. Over 2000 hours of experiments have been performed on this line, called Test Area A, on such topics as neutralization efficiency, neutralization induced emittance growth, target discrimination, microradian divergence measuring techniques, direction sensing of neutral beams, radiation emitted from neutral beams, etc.

A third beam scheduled to be completed in April 1987 is about 3 times as complex as the Test Area A beam line. Its first purpose is to test the quality of a beam expansion telescope being built at LANL. After completing this task it will be a national user test facility for large diameter neutral beams.

References

1. A. Rauchas, et al., "Intensity Stability Improvements for the Intense Pulsed Neutron Source Accelerator System," IEEE Trans. Nucl. Sci., Vol. NS-32, No. 5, p. 2126, October 1985.

2. W. F. Praeg and D. G. McGhee, "Ring Magnet Power Supply for a 500 MeV Synchrotron," IEEE Industry Applications Society - 1978 Annual Meeting Conference Record, 1118.

3. A. Rauchas, et al., "IPNS Accelerator System and Neutron Chopper Synchronization," Proc. of Intl. Collab. on Advanced Neutron Sources (ICANS-VII), Atomic Energy of Canada Limited, Report AECL-8488, p. 157, September 1983.

4. L. I. Donley, "Phase Locking the IPNS Neutron Choppers to the 60 Hz Power Line," Proc. of the Eighth Meeting of the Intl. Collab. on Advanced Neutron Sources (ICANS-VIII), Rutherford-Appleton Laboratory Report RAL-85-110, Vol. III, p. 689, July 1985.

5. V. Stipp, et al., "A Brighter H^- Source for the Intense Pulsed Neutron Source Accelerator System," IEEE Trans. on Nucl. Sci., Vol. NS-30, No. 4, p. 2743, August 1983.

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