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COMMISSIONING OF THE ARGONNE INTENSE PULSED NEUTRON SOURCE (IPNS-I) ACCELERATOR

by

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COMMISSIONING OF THE ARGONNE INTENSE PULSED NEUTRON SOURCE (IPNS-I) ACCELERATOR*

Antanas V. Rauchas, Franklin R. Brumwell, and Gerald J. Volk†

Abstract

The IPNS-I 500 MeV Rapid Cycling Synchrotron (RCS) was commissioned during March of 1977. It was originally designed as an injection energy booster for the Zero Gradient Synchrotron (ZGS), as well as a source of high intensity proton beams for neutron production. With the termination of the high intensity operation of the ZGS, the accelerator became a dedicated machine for neutron physics. After a period of tuning and improving accelerator components, the accelerator officially began neutron physics experiments on July 1, 1978. The accelerator has achieved a repetition rate of 15 Hz with beams of 1 x 10^{12} protons delivered on target. Operation at 30 Hz is expected soon. A description of the accelerator is presented. Turn on procedures, operating experience and initial performance problems are also discussed.

Description

The RCS is a strong focusing, combined function synchrotron. The magnet lattice is described in detail elsewhere,[1] so only a brief description will be presented. The RCS is a six period machine with a magnet structure of DOOFDFO and a circumference of 42.95 m. The ring magnets, part of a biased 30 Hz resonant circuit driven from twin solid state power supplies,[2] generates a magnetic field from 0.28-1.0 T for the acceleration from 50-500 MeV. Two pairs of quadrupole magnets and two pairs of sextupole magnets, powered by 30 Hz sine wave power supplies, provide betatron tune correction and manipulation. The accelerator layout is shown in Fig. 1.

Two ferrite loaded coaxial cavities are used to provide the accelerating RF potential. The frequency swing for the first harmonic acceleration cycle is 2.20 to 5.29 MHz. A detailed description of the RF accelerating system is provided in Ref. 3.

The successful use of H^- stripping injection in Booster-I[4] and the ZGS[5] prompted the use of the same method for the RCS. The poly-paraxylene stripping foil is located on the inside radius of a long straight section (L1) outside the limit of circulating beam. The equilibrium orbit is deformed in the injection region into the foil by a series of three small, pulsed "bumper" magnets.[6] The H^- beam is injected through a singlet ring magnet so that at the stripper, its path matches the deformed orbit (Fig. 2). During injection, the bumper magnet current decays at a controlled exponential rate, moving the closed orbit away from the stripper foil and uniformly filling the horizontal aperture.

The RCS beam is extracted in a single turn by two ferrite kicker magnets and one septum magnet. The rise time of each kicker magnet is ∿ 100 ns with a 100 ns flat field region.[7] The septum magnet is pulsed by a half sine wave current with a period of 3 ms to a peak of 12 kA and a magnetic flux density of 1 T.[8]

Turn On and Operating Experience

Studies of the 50 MeV transport line to the RCS began in January 1977. Final checkout of the accelerator components was completed in March; and on

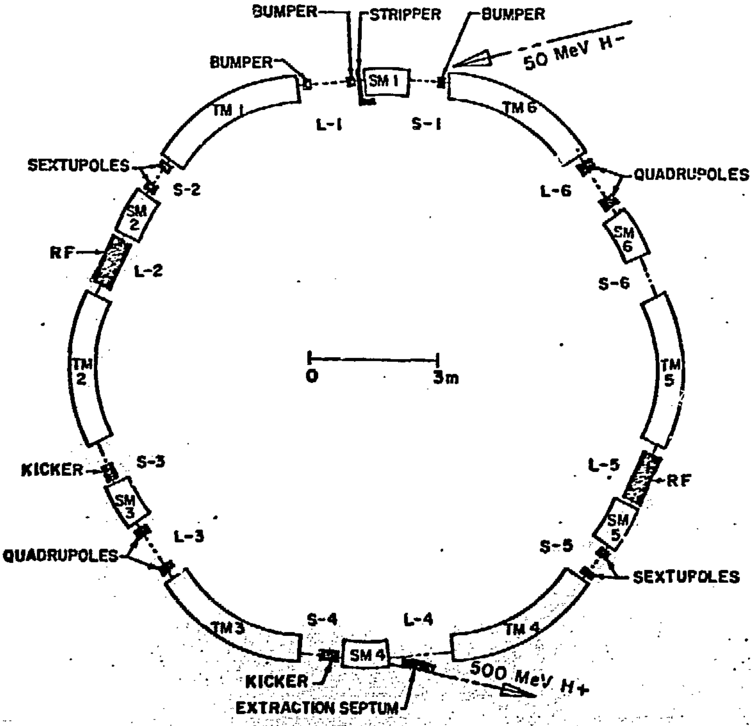

Fig. 1. Accelerator Layout

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April 13, 1977, the final injection line Faraday cup was removed from the beam path and the RCS was christened by beam. With the injection bumper magnets off, the L1 segmented Faraday cup was used to set the angle and position of the incoming beam as well as the position of the stripper foil. The bumper magnets were then energized and beam was detected on horizontal and vertical segmented Faraday cups located in L3 and L4. The bumper magnet current and the ring magnet field were trimmed to center the beam horizontally at both locations.

After removing the ring segmented Faraday cups, 100% of the injected beam was measured on the L6 Faraday cup. After this cup was removed from the beam path, the beam continued to coast for 1000 turns. With some additional tuning, currents of half an ampere were coasting.

Over the next several weeks, the beam was bunched, beam orbit position and coasting betatron tune measurements were made, and beam was accelerated to 325 MeV. The initial position measurements indicated the presence of orbit warps. Later measurements have substantiated this, and some of the warps have been minimized by repositioning the ring magnets. Future, more intensive, orbit warp studies are planned with improved position electrodes and electronics. The coasting betatron tune measurements confirmed the theoretical tune values of $\nu_x = 2.20$ and $\nu_y = 2.32$ but also indicated the need for sextupole correction. Calibration of the quadrupole and sextupole correction magnet effects also confirmed the design calculations.[9]

Initially, acceleration was limited to 325 MeV due to instabilities in the ring magnet power supply (RMPS) at current levels required above 350 MeV. Even so, this was adequate for studies of accelerator performance. Almost immediately, a problem which had been suspected during bunched beam coasting studies became apparent. Distinct, sharp beam losses occurred throughout the acceleration cycle. Investigation into the loss mechanism revealed noise on the RF system's master oscillator frequency program. The frequency program was generated from $\dot{B}$ information derived from a pick up coil in the ring magnets. A check of this signal disclosed that large RMPS switching transients were coupling into the $\dot{B}$ coils. Shielding efforts were not successful, so an attempt was made to use a less noisy $\dot{B}$ signal from windings in the ring magnet system resonating chokes. This signal provided a satisfactory frequency program, although it was slightly out of phase and did not track the ring magnet field accurately. These problems were solved by phase shifting the frequency and using a beam position feedback system. Since that time, filter improvements in the RMPS have permitted a successful return to the ring magnet $\dot{B}$ signal for a frequency source.

As tuning progressed and beam intensities increased, a new problem developed. When beam intensities over 1×10^{12} were accelerated to 8 ms into the cycle, approximately the maximum $\dot{B}$ point, beam instabilities and losses developed and continued throughout the rest of the cycle. Although beam phase feedback improved the situation, 25% of this beam was still being lost during the second half of the cycle. Tuning of the sextupole magnets further improved acceleration efficiency but affected capture and early acceleration. Tune measurements substantiated these results and showed that the sinusoidally varying currents of the correction magnets were inadequate to maintain constant tunes throughout the acceleration cycle. A satisfactory condition was found, but further studies are planned to redefine the correction magnet current functions. Studies of beam size during acceleration indicated that while damping was occurring during the first half of the cycle, the beam began antidamping during the latter half. In addition, a significant amount of 15 MHz, beam dependent noise was discovered on most cabling terminating in the RCS tunnel. Various attempts were made to improve and decouple ac and dc grounds with little effect on the noise amplitude. Studies are continuing to locate the driving mechanism of this instability. In the meantime, the RF accelerating voltage has been programmed substantially higher during the latter part of the cycle to contain the beam within a larger bucket. The result of all these studies has been that the RCS accelerates 50% of the injected beam to full energy.

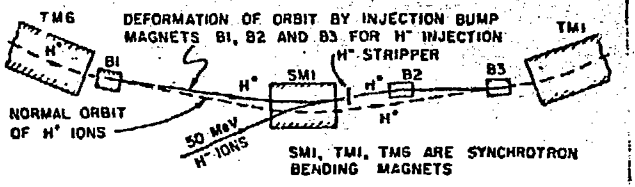

Fig. 2. H^- Injection into the RCS

By the end of June 1977, beams of over 1×10^{12} were being accelerated to the full energy of 500 MeV. Work continued on improving accelerator component reliability and on the completion of the extraction system components. The kicker and septum systems were installed during October and November 1977. By January 1978, peak beams of 8×10^{11} protons/pulse were delivered on target. Problems with the extraction system were also encountered. The high speed, high current pulses of the kicker magnets were radiating noise throughout the RCS. Noise immunity had to be increased in numerous systems.

January 1978 was a milestone month for the RCS. During the previous months of operation, the RCS had been running at 1 Hz because of fears that a high repetition rate would damage the H^- source, which the RCS was sharing with the ZGS. But since the ZGS was terminating its final high intensity H^- run, the RCS began 5 Hz operation. Both synchrotrons shared the 50 MeV linear accelerator, so the RCS was operated in a "burst mode" to allow for injection into the ZGS. By April 1978, the RCS was routinely delivering 10^6 pulses, averaging 5×10^{11} protons/pulse, on target per week for calibration of experimental instruments. This operation was limited to nighttime and weekends. Day shifts were spent on machine studies and accelerator component improvements.

During this time, a breakthrough occurred in the stripper foil lifetime problem, which had been plaguing the operation from the start. Foil lifetimes had been as short as a few hundred pulses. Different foil thicknesses, ranging from 1700-14,000 Å, and different foil mounting techniques were tested. Foil lifetimes of millions of pulses were achieved by coating 3000-4500 Å foils with a 400 Å layer of aluminum. These foils were mounted so that the bottom edge was not fixed but weighted by a small weight. An additional improvement was made by trimming the currents of the injection bumper magnets to minimize the number of passes through the foil of the circulating beam during injection. Foils now last well over 10 million pulses.

The official ZING-P' experimental program began in July 1978. During this month, the ZGS was not operating so the RCS went from "burst mode" to continuous "around-the-clock" operation. The rate was also increased from 5 Hz to 10 Hz. The RCS was extracting

4 x 10^6 pulses/week and averaged 8 x 10^{11} protons/pulse. Since October 1978, routine 15 Hz "burst mode" operation with 3 x 10^6 pulses/week and 8 x 10^{11} protons/pulse on target has been achieved. This is equivalent to over 1.0 μA of dc current on target averaged per week (Fig. 3). Operation in a 30 Hz "burst mode" is expected soon; and with the scheduled shutdown of the ZGS on October 1, 1979, continuous 30 Hz operation will begin.

Future Goals

The near term (1979-1980) goal is to achieve a dc current weekly average of 8.5 μA on target. This will be accomplished in part by general reliability improvements. These include a new transformer-style septum magnet[10] which will replace the present septum magnet, which has been failure prone. The kicker magnet vacuum liners, which have been prone to leak due to radiation damage, have been replaced by more radiation resistant vacuum liners. Improvements in RF system feedback controls and in the active control of tune correction magnets, together with the increase of the repetition rate from 15-30 Hz, complete the near term goals.

Long term (1980-1982) improvement goals include plans for 45 Hz and/or 600 MeV operation. Also, improved beam injection and easier accelerator component replacement techniques are planned. With these improvements, dc current weekly averages of 20 μA on target can be achieved.

Acknowledgments

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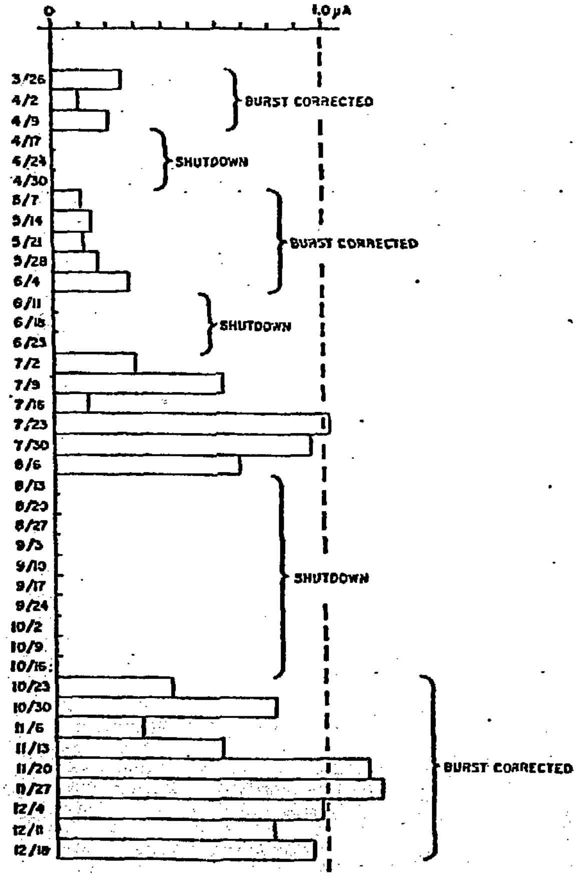

Fig. 3. Weekly Averages of DC Current on Target