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PERFORMANCE OF THE INTENSE PULSED NEUTRON SOURCE ACCELERATOR SYSTEM*

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Summary

The Intense Pulsed Neutron Source (IPNS) facility has now been operating in a routine way for outside users since November 1, 1981. From that date through December of 1982, the accelerator system was scheduled for neutron science for 4500 hours. During this time the accelerator achieved its short-term goals by delivering about 380,000,000 pulses of beam totaling over 6×10^{20} protons. The changes in equipment and operating practices that evolved during this period of intense running are described. The intensity related instability threshold was increased by a factor of two and the accelerator beam current has been ion source limited. Plans to increase the accelerator intensity are also described. Initial operating results with a new H^- ion source are discussed.

Introduction

The IPNS accelerator system has been described in detail previously.[1] Briefly stated, it consists of a 750 keV Cockroft-Walton preaccelerator containing an H^- ion source, a 50 MeV Alvarez type linac and a strong focusing 30 Hz Rapid Cycling Synchrotron (RCS) designed to deliver 90 ns bursts of 500 MeV protons. All the above equipment was originally built for use with the Zero Gradient Synchrotron which was shutdown in 1979. It has been modified extensively since that time to increase the steady state repetition rate to 30 Hz and increase the beam intensity per pulse. After about 1-1/2 years of trial running on a temporary neutron target, the facility was shutdown in August of 1980 to relocate the proton extraction equipment to deliver beam to a new target, the IPNS-I spallation neutron facility.[2] Figure 1 presents a plan view of this facility. This facility has 12 beam lines which intercept neutrons from a depleted uranium target. Of the neutron beams, 3 are set up for fundamental studies which take months (something like High Energy Physics [HEP] experiments), 7 others do material studies which normally take from 1 to 2 weeks, and 2 do materials experiments which sometimes are completed in less than 24 hours. There is also a HEP test beam associated with the facility. This test beam is used for detector development.

Pulsed Neutron Operating Requirements

Since November of 1981, the facility has completed 127 experiments in 187 days of scheduled operation. In fact, the 2 powder diffractometers have averaged less than 3 days per experiment over 79 experiments. This rapid turnover of experiments puts a premium on accelerator reliability and scheduling flexibility. Neutron experiments do not have large supporting groups of people as do HEP experiments so the experimenter must be present on the day his experiment is performed or his experiment is postponed for several weeks. Lengthy (12-24 hours) accelerator failures, which are routinely accepted at HEP facilities, cause great consternation at the IPNS-I neutron facility since the affected short experiments get rescheduled in a later run rather than just one day postponements. Frequently, operating schedules are changed on very short notice to match experimental needs. Since IPNS is a dedicated facility, scheduling flexibility is possible. The IPNS accelerator is not

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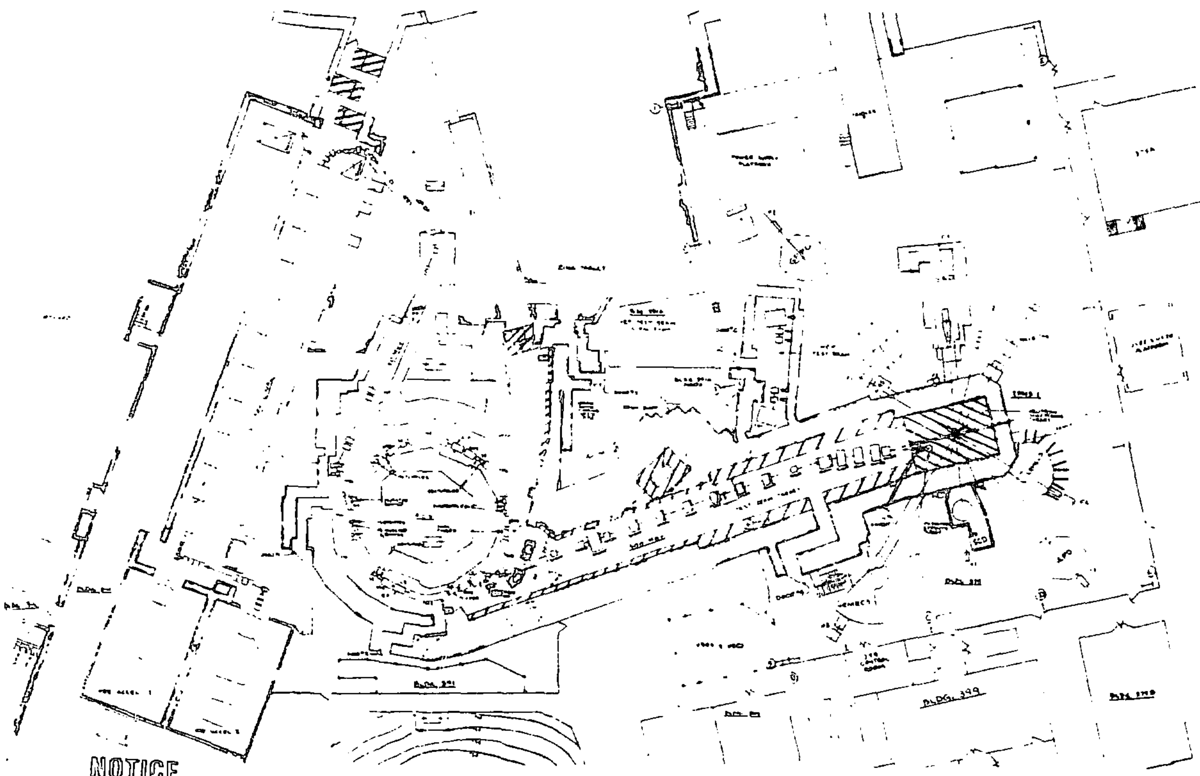

Fig. 1. Plan view of IPNS-I facility.

as complicated as most large high and medium energy accelerators and, therefore, can be brought up from a completely shutdown state to 90% of full beam in about eight hours. This characteristic enhances scheduling flexibility and also minimizes wasted standby electrical power, thus providing a good neutron per dollar ratio.

Neutron scattering experimental equipment also makes for unusual accelerator operating conditions. Three of the neutron beams have neutron choppers in them. A neutron chopper is a rotating cylinder with a small slot in it. The cylinder is driven by a small hysteresis synchronous motor. If the slot is properly synchronized to the 90 ns proton pulse, only neutrons with precisely known energies will pass through the moving slot to the experimental sample. The torque to inertia ratio on ANL neutron choppers is so low that they are unable to stay precisely in phase with the power mains. Therefore, means have been devised to synchronize the accelerator operating cycle to the motion of the chopper rotating cylinder.[3]

The synchronizing system described in the referenced paper has worked reasonably well when only one neutron chopper is in operation. In fact, proper energy neutrons are delivered to the sample on 98% of the proton pulses. Having the accelerator track the neutron chopper causes a time variable phase slip between the accelerator power supplies and the power main. This phase slip has a small but noticeable effect on the stability of many power supplies which effectively prevents the beam intensity optimization which is usually achieved during trial and error tuning by the synchrotron operators. The effects are so subtle that none of the 50 or so power supplies involved have so far been identified as the prime culprit. While this phase slip causes only a 5 to 10% loss of protons delivered to the neutron target, it increases beam losses inside the synchrotron tunnel by over 35%.

With this synchronization system, multiple choppers do not fare so well with only one getting good data 98% of the time and the others getting data on only 60% of the beam pulses. A new synchronization system has just been installed which makes the accelerator tracking of the chopper more complicated but has provided data collecting efficiency equal to that achieved on reactors. During the initial weeks of operation of the new synchronization system, all choppers collected data on 98% of the proton pulses. This new scheme, however, does not solve the beam loss problems created by phase slip so accelerator personnel are taking the lead in trying to develop properly damped chopper tracking systems so that the accelerator can again be synchronized to the power main.

Operation in 1981 and 1982

Installation of the IPNS-I target transport line and modifications to the accelerator were completed on schedule and protons were first delivered to the beam dump in early April 1981 and first beam went to the IPNS-I uranium target on May 5, 1981. Operation for outside users commenced in November, 1981. The accelerator ran just enough in the tune-up period between April and November to establish its beam handling ability, but not enough to locate reliability problems that took several million pulses to develop.

Plans in effect at that time called for shutting down IPNS-I in mid-FY83 so effectively only one year was available to evaluate IPNS-I. Since reactor oriented neutron scattering scientists were concerned about accelerator reliability, poor accelerator performance might have affected the scientific attitude toward the United States program in pulsed neutrons sources. The extreme time pressures dictated a compromise that allowed reliable operation immediately. Faulty fast kicker extraction power supply cabling was accounting for over half the reliability troubles and its problems were voltage and, therefore, beam energy dependent. The compromise chosen was lowering the beam energy to 400 MeV. This allowed good operation while the kicker problems were being solved. The machine is currently running at 450 Mev and is scheduled for 500 MeV operation soon.

At the reduced energy, the goal of a reliable 8 μA (1.66 x 10^{12} protons per pulse, 30 Hz) proton beam was met. Table I shows several of the parameters of interest and compares them to operating data obtained in 1980. The benefits of new equipment installed during the 1980-81 shutdown are clearly visible. When proton energy and reliability are taken into account, the 1982 neutron yield per scheduled unit time increased by a factor of 3.25. Short-term peak currents of 11.2 μA and weekly averages of over 9.5 μA have been achieved.

The RCS shielded tunnel has a mean diameter of 50 ft, a width of 7.5 ft and a mean height of 8 ft. Delivery of 6 x 10^{20} protons in seven months from such a compact machine and retaining hands-on maintainability implies very efficient handling of the beam. An average of 85% of the 50 MeV protons delivered to the RCS are extracted to the target at 450 MeV. Judicious operation and many automatic protective devices have kept residual radiation levels moderate. Maintenance personnel were exposed to a total of only 7.55 man-rem of radiation in 1982.

Table I.

	1980	1981-82
Scheduled Operating Time	2569 hours	4506 hours
Available Operating Time	2188 hours	3991 hours
Operating Efficiency	85.2%	88.6%
Total Protons on Target	2.25 x 10^{20}	6.42 x 10^{20}
Total Pulses on Target	1.98 x 10^{8}	3.86 x 10^{8}
Average Beam Current on Target	4.72 μA	8.03 μA
Beam Energy	300 MeV	400-450 Mev

Beam Intensity Improvement

During the shutdown, improvements were made in the synchrotron RF system, injection bumper power supply and septum magnet power supply. While these changes surely enhanced the beam intensity, the resulting improvement is difficult to quantify. A new single stage kicker magnet and power supply[4] was installed. The increased kick along with a widened extraction aperture provided a 5% increase in protons to the target. Changes in the noise rejection circuits of the ring magnet power supply improved its stability which made the machine more "tunable".

The most significant and readily identifiable beam increase resulted from improved impedance matching to eliminate high frequency reflections in the beam phase feedback system. A previously described intensity dependent high energy instability had plagued the RCS since its turnon. The causes of this instability were unclear, but there was some evidence that it was longitudinal in nature since chromaticity adjustments did not effect it. The beam phase feedback improvement raised the threshold of beam loss due to this instability from 1.3 x 10^{12} to about 2.4 x 10^{12} protons per pulse and has made the chromaticity adjustment much less critical.

Reliability and Operating Cost Improvement

Doubling the current capacity of the driver and predriver RF power supplies allowed more flexibility in adjusting the operating point of the RF power and driver tubes. Cavity bias amplifiers with frequency response increased from 800 Hz to 10 kHz have provided much better dynamic control of cavity impedance during frequency sweeping as fast as 325 kHz per millisecond. These changes have reduced unnecessary RF power excursions. As a result, operating trouble originating in the RF system has reduced from 2.5% of the scheduled time to less than 1% and tube life has improved.

The extraction kicker magnet has 4 quarter turn coils each originally designed to be driven by and terminated in 7 Ω. The planned operating voltage of 68 kV proved difficult to handle because of cable breakdowns and corona discharge at connections. Judicious impedance mismatching has reduced the operating voltage to 49 kV without effecting the current pulse rise time, creating harmful reflections, or loss of beam extraction efficiency. The driving point impedance is now 4.67 Ω and the terminating resistors are 6 Ω. The power supply contains four $14,000 CX1192 deuterium thyratrons. Originally estimated for a life of 10^8 pulses, the tube life has, in fact, averaged over 3 x 10^8 pulses with these improvements in place. One hundred million pulses is only 7 weeks operation.

Immediate Plans

For the last several months the average beam intensity has been limited to about 8 μA by the available current out of the original charge exchange type H^- source. Installation is now complete on a magnetron type H^- ion source similar to that used at Fermi National Accelerator Laboratory and Brookhaven National Laboratory.. This ion source has been modified[5] to operate at 30 Hz. A number of other changes[6] are being implemented to the accelerator system to compliment the operating characteristics of the new ion source. Expectations were that the H^- current delivered through the linac to the synchrotron would increase by a factor of 2.5 to 15 mA. Actually 16 mA has been achieved. The synchrotron is not expected to be able to handle all the 50 MeV beam available, but an increase in the average current to 10 μA (25%) had been expected within 3 operating months. In fact, during the first two weeks of operation, the average current is up to 9.3 μA and short-term peak currents of 11.4 μA have been recorded, so the new ion source is quite a success. During the only accelerator study period prior to writing this paper, it was possible to efficiently capture and accelerate 3 x 10^{12} to an energy of 350 MeV before the particles were lost due to the high energy instability. A change in working point at injection was required to handle over 2.4 x 10^{12} efficiently.

The increased current available from the ion source offers great opportunity to increase the beam intensity, but the 30 Hz repetition rate and small accelerator tunnel require that beam losses be rigidly controlled as beam to the target is increased.

Long-range Plans

The excellent neutron science produced in the initial year of operation of IPNS-I has lengthened the life expectancy of the facility considerably. Operation is planned at least through 1985.

A paper[7] presented to this conference describes the unique characteristics of and benefits expected from the installation of a third RF system. When this additional RF equipment is installed in mid-1985, 16 μA proton beams are expected. More ambitious plans are also being considered which, if implemented, will bring the proton current up over 20 μA.

Acknowledgments

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