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PERFORMANCE OF THE INTENSE PULSED NEUTRON SOURCE ACCELERATOR SYSTEM*

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Introduction

The Intense Pulsed Neutron Source (IPNS) Accelerator System has had a banner year since the last ICANS meeting. Average beam current increased by 12% to 13.4 μA and our already excellent reliability increased by 2.1% to 93.2%. The reliability improvement came not from equipment improvement as much as from prudent operating practice. In the prior year, we had 66 hours of lost operation waiting for radiation cooldown before we could repair beam induced damage to our rf shielding liners. This year, thank the synchrotron gods, the liners stayed undamaged and no cooldown time was required.

Table I.

Accelerator Operating Summary

	Nov. 81- July 82	Oct. 82- July 83	Oct. 83- July 84	Oct. 84- June 85	Oct. 85- July 86
Average Current (μA)	8.02	9.21	11.46	11.94	13.39
Operating Efficiency (%)	88.9	90.2	90.4	91.6	93.2
Scheduled Hours	3358	3833	4750	2946	3892
Available Hours	2985	3458	4294	2699	3628
Pulses on Target x 10^8	2.94	3.33	4.23	2.81	3.80
Proton on Target x 10^{20}	4.44	6.39	10.12	7.00	10.63

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Operating Summary

Several completed modifications were discussed in last year's status report and the indications were clear that they had helped to increase beam on target without a concurrent increase in beam lost. These devices were primarily equipment feedback loops that helped correct for the power line phase slip that occurred when the neutron choppers[1] controlled the start time of the synchrotron operating cycle. Just before the summer shutdown in July of 1985, a new type chopper-accelerator-synchronization system[2] was brought into test operation. This unit drastically reduced the rate of phase slip as well as limiting the slip to ±15°. The effect of this new equipment was twofold. First, there was an immediate increase in beam current of about 1 µA and second, with the increased phase stability, it was easier to identify other equipment that should be improved.

It was clear that the main culprit was the stability of the power supplies that power the main ring guide magnets. This instability was in effect making about 14% of the vacuum aperture unusable. An immediate assault on the regulator circuitry of these supplies was begun. This regulator improvement is described in some detail later in this paper. The problem with the regulator was a stubborn one. At first the "improved" regulator was worse than the previous unit and we ran six weeks averaging only about 11.5 µA. But the designer's persistence paid off and by the end of December we had our first weekly average current of 15 µA and had pushed the short-term best up to 16.7 µA. In fact, since the completion of the regulator improvements the current is almost 14 µA averaged over 280 million pulses. The target current graph (Fig. 1) shows the dramatic increase just before the beginning of 1986.

The viewer of Fig. 1 will note that beam current improvement leveled off for most of 1986. Two new factors had entered the equation of IPNS operation. All attempts at increasing beam current stopped and we just ran the machine with little if any accelerator research. The last five months the accelerator research was less than 1% of the scheduled running time--not a very healthy long-term situation.

The first of these new factors was IPNS accelerator personnel participation in preparation of the proposal for the X-ray source proposed

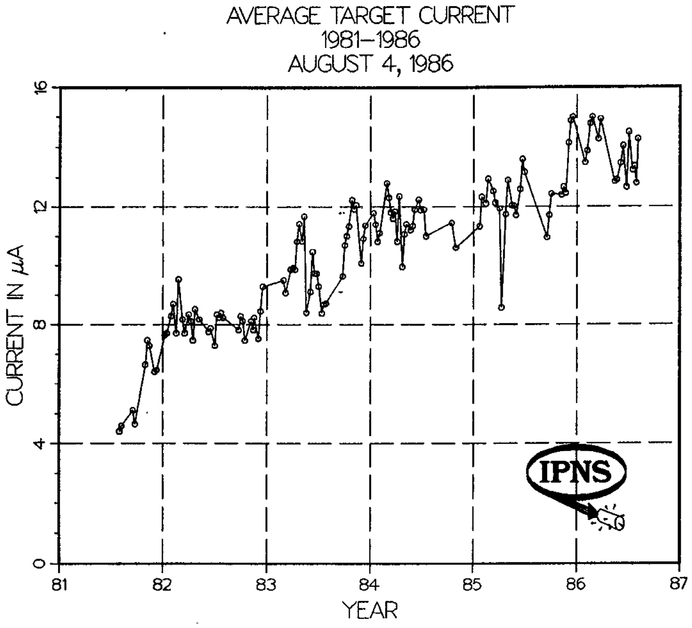

Fig. 1. IPNS Weekly Average Target Current Since Turn-on

for Argonne National Laboratory (ANL). The number of people diverted wasn't large but they were leaders in our beam improvement program. The second factor was IPNS accelerator personnel involvement in the Strategic Defense Initiative (SDI) Program at ANL. The SDI program asked ANL to build two test beams in the old Zero Gradient Synchrotron (ZGS) hall for Neutral Particle Beam (NPB) activities. This beam is derived from the IPNS 50 MeV H^- linac. IPNS accelerator personnel took a leading role in the design and construction of these test beams and are now assisting in the operation of these test beams as well as operating the linac for NPB studies. These studies have consisted primarily of methods of neutralizing H^- beams and sensing the direction, size, divergence, etc., of a neutral beam. In total, more than one-half of the accelerator group's effort has been diverted to other activities this fiscal year. This is great for the financial health of IPNS but there will be long-term consequences if this continues too long. A photograph of one of the NPB test beams is included as Fig. 7.

The point we have been trying to make is that this year's great performance is based on previous year's equipment improvements. However, our very experienced and skilled shift operators deserve a great deal of credit for taking advantage of the opportunities offered by the new equipment. As Fig. 2 shows, the beam losses have been held to about

1.5 μA. There are now 1.72 billion pulses on target and the residual radiation in the accelerator tunnel has not increased over the last year. We feel further increases in target current are possible when our personnel again are able to take a full time interest in the IPNS accelerator.

The reliability graph (Fig. 3) and trouble distribution graph (Fig. 4) document our comfortable feeling about machine reliability. The operation has been very smooth from the user's perspective. Most of the increase in ring magnet power supply (RMPS) trouble came during two long incidents of intermittent ground faults. Obviously, two thirty hour breakdowns are less of a user disturbance than ten three hour breakdowns. Most of the increase in kicker magnet trouble came from pushing the thyratron tubes for very long lifetimes. We got 560 million pulses out of one of the tubes. If our financial situation were improved we could probably decrease this source of trouble somewhat.

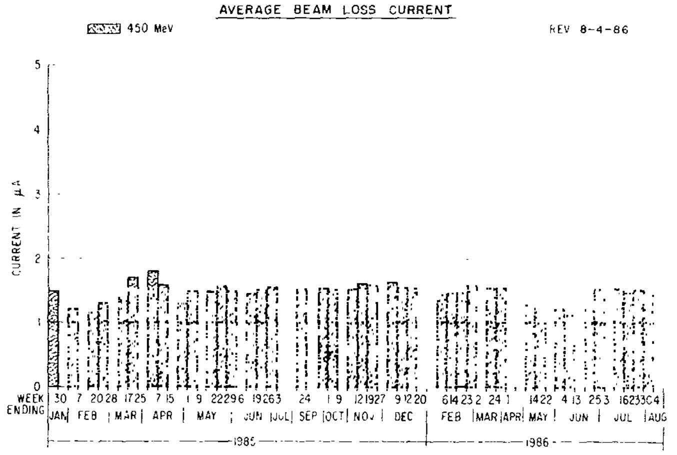

Fig. 2. Average Beam Current Lost in the Synchrotron

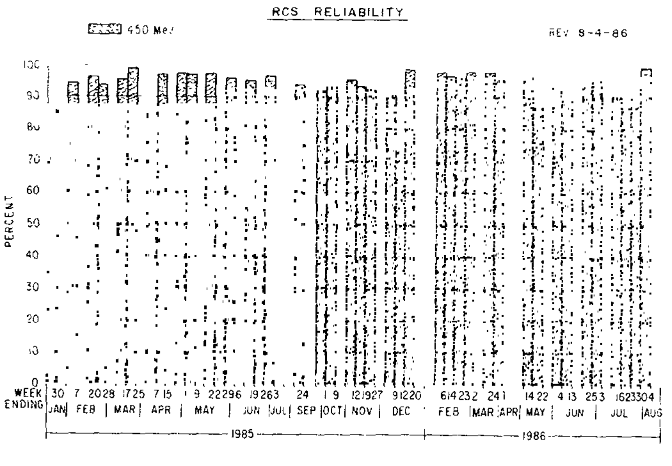

Fig. 3. IPNS Accelerator System Reliability

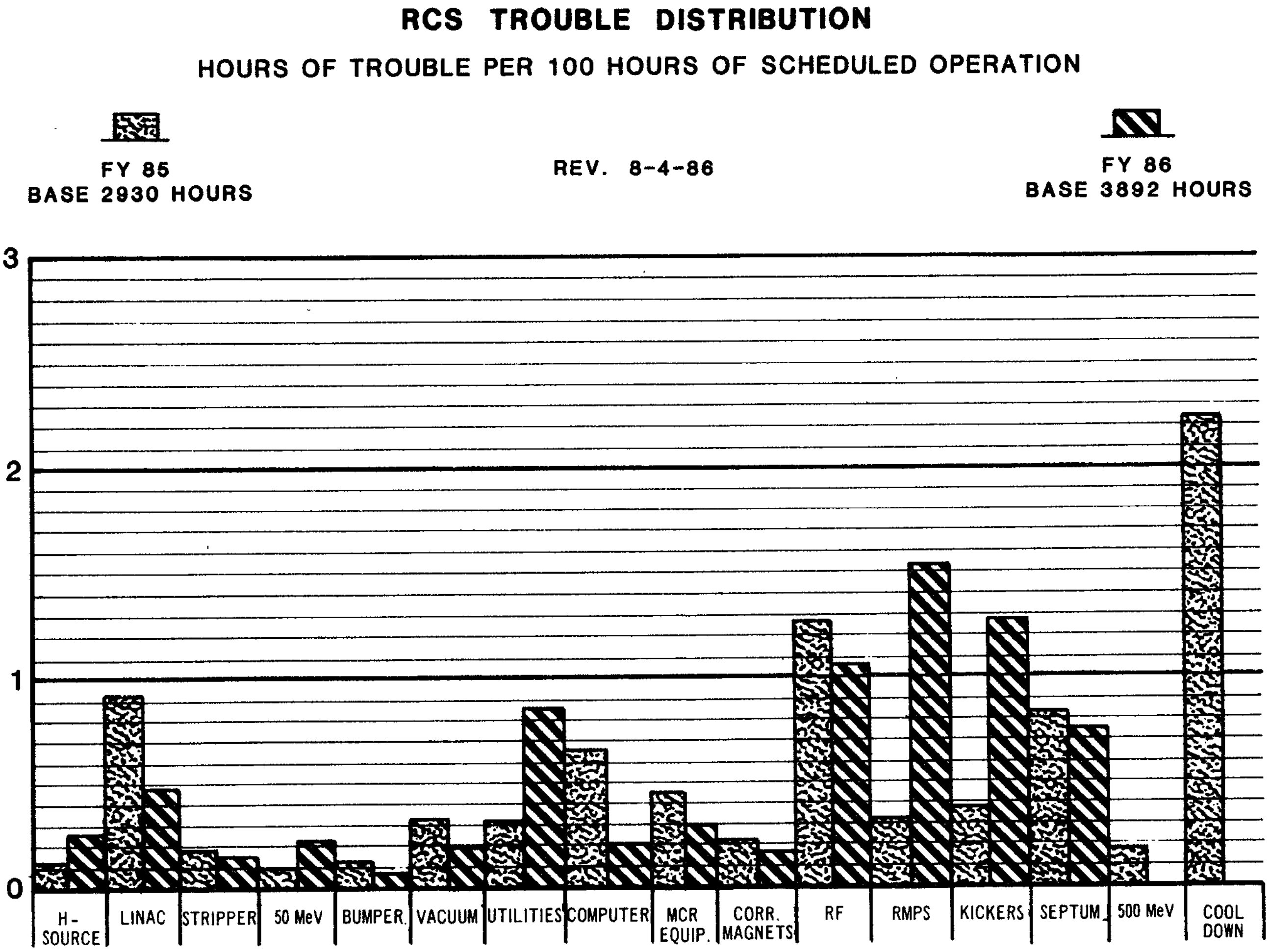

Fig. 4. IPNS Accelerator Subsystem Trouble Distribution

The following sections will provide brief comments on major accelerator subsystems.

H^- Ion Source and Preaccelerator

A grooved cathode magnetron H^- ion source[3,4,5] has now been supplying negative ions to the RCS since early 1983. As shown in Fig. 4, the H^- 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 Rapid Cycling Synchrotron (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 but a refrigerated baffle is being designed which should allow us greater latitude in cesium flow adjustment.

Linac

The 50 MeV linac was originally designed to run at 10 Hz and for all the years it provided beam to the ZGS the average repetition rate was one pulse per three seconds. While operating at 30 Hz for the RCS, the overall linac reliability has been excellent. Figure 4 shows the total linac downtime in FY 1986 accounted for less than one-half of 1% of the scheduled operating time. The only component that has obviously had an increase in failure rate due to the increased duty cycle is the upper blocking capacitor for the final rf tube (RCA 7835). The manufacturer believes this problem could be eliminated by changing the capacitor dielectric from irrathane to teflon. However, since this would require some redesign of the 7835 cavity and the failure rate is not much more than one per year, there are no plans for any modifications in the near future. The 7835 lifetime is nominally 15,000 hours and if anything, the average has increased with the higher duty factor. The high voltage modulator tube (Machlett 7560) was changed last November due to breakdowns from cathode to grid and it was noted to have accumulated over 43,000 hours.

Synchrotron

Ring Magnet Power Supply

The stability of the injection field is determined by the stability and response of the ring magnet power supply (RMPS) regulator. With the old regulator,[6] injection field variations as a function of the phase of the power main had been over ±8 gauss. Since the ring magnet power supply operates as a 24 phase dc rectifier, the variations had a frequency of the 720 Hz, a frequency beyond the full response of the regulator circuitry. Although the variable frequency master clock[2] was able to limit the variations of the phase of the power main to approximately $\pm 15^{o}$, this corresponds directly to a complete cycle of the 720 Hz injection field variation and therefore did not limit the variation of the minimum field. The improvements to the RMPS regulator system decreased the variation of the injection field by a factor of 2 to less that ±4 gauss and therefore the beam position variation during injection to less than ±3 mm. A block diagram of the new regulator is shown in Fig. 5.

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. A detailed schematic of the process is shown in Fig. 6.

The current feedback signal is a 30 Hz ac sine wave offset by a dc level. This signal is peak rectified and filtered by an ideal rectifier to

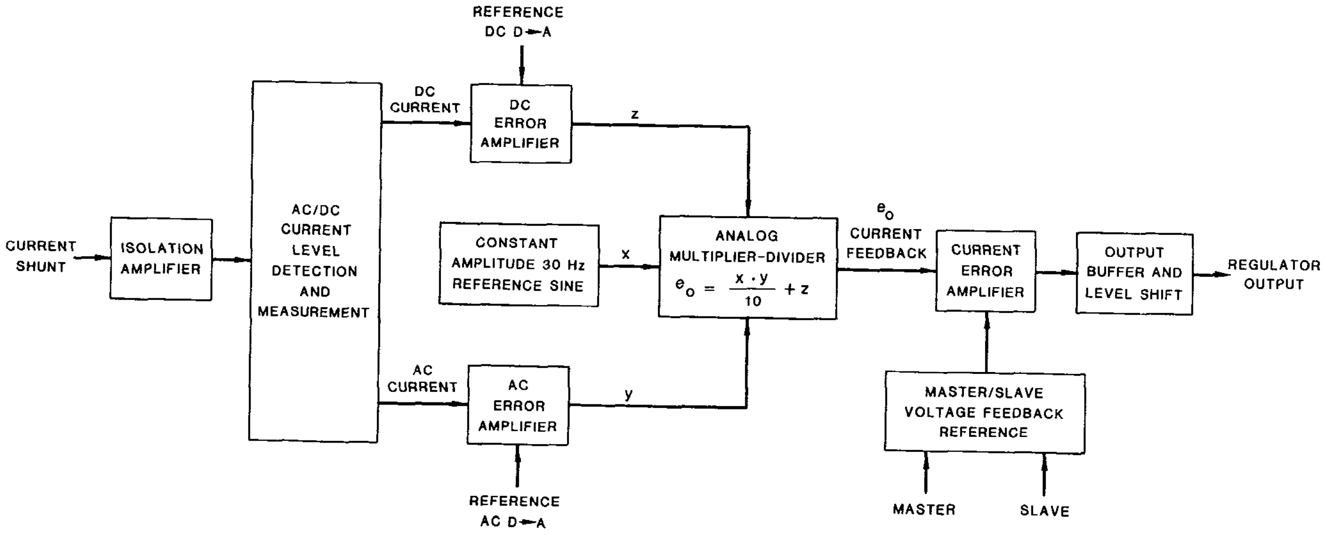

Fig. 5. RMPS Current Regulator Block Diagram

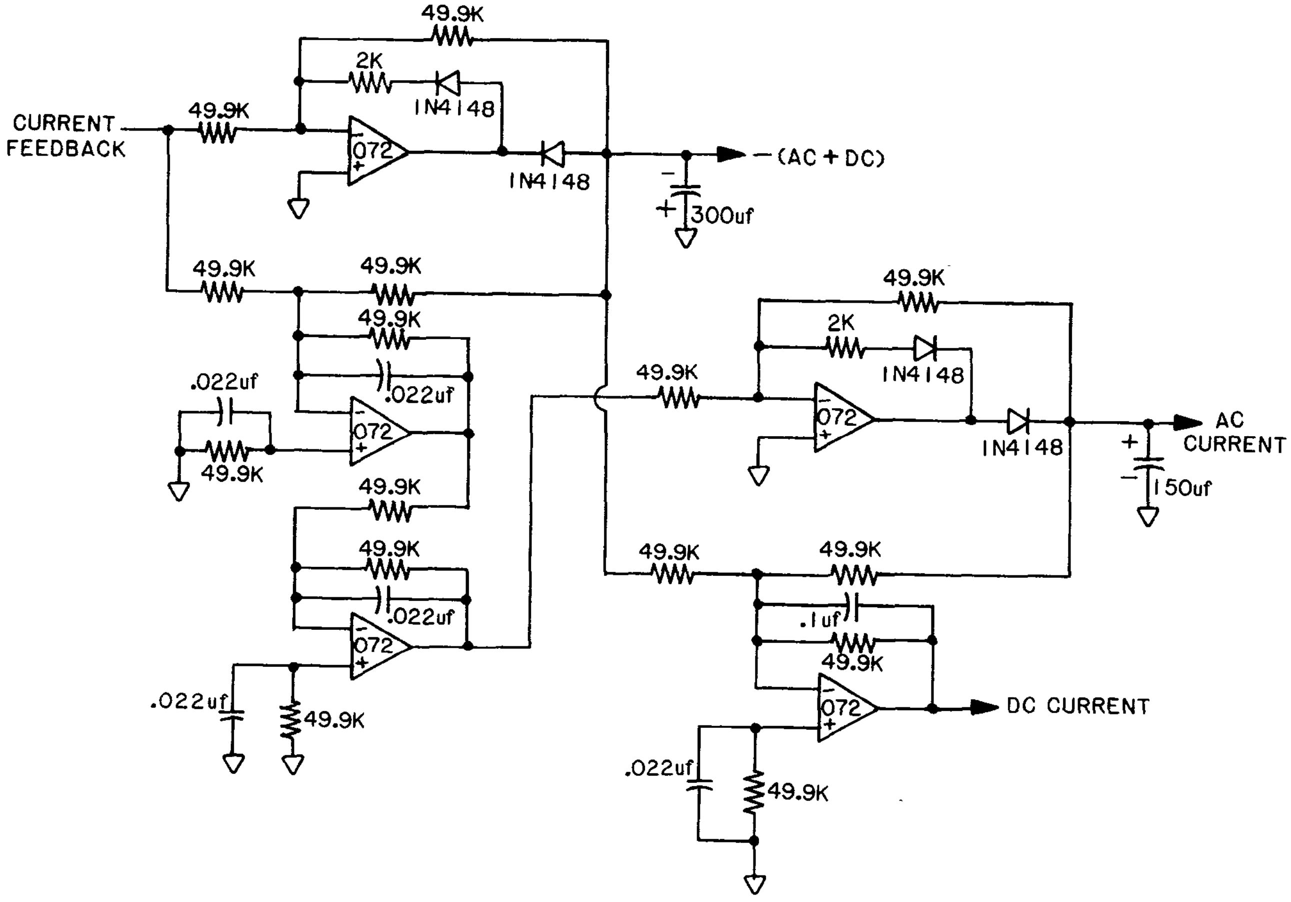

Fig. 6. AC/DC Current Level Detection Schematic Diagram

yield a dc level proportional to the peak of the current feedback (ac and dc). This rectified signal is combined with the original current feedback signal to provide an unbiased ac waveform which is again peak rectified and filtered to yield a dc level proportional to the ac component of the current feedback (ac current). The difference of the two rectified signals provides a dc level proportional to the dc offset of the current feedback (dc current). The dc levels proportional to the ac and dc components of the current feedback are used to generate the error signals for the remaining regulator circuitry which operates in the same manner as the old regulator design.

Master Oscillator Adjustments

The resultant increased injection aperture did not immediately manifest itself in increased accelerated intensities, however, it did provide beam intensity stability. As had occurred many times before, the accelerator operators were able to tune the accelerator under stable conditions and increase the intensity. The injection field stability also allowed other field dependent systems, such as the injection frequency to be optimized. The initial frequency program is derived from the $\dot{B}$ signal by integration. This yields a bipolar sinusoidal waveform which is offset by a stable reference to provide the required injection frequency from the voltage controlled oscillator. Correction of injection frequency for small variations of magnetic field are provided by sampling the field prior to injection, comparing the value to a fixed reference and applying this difference to the function going to the voltage controlled oscillator. Previously, this correction had not been able to be optimized with the relatively large variations of the injection field. After installation of the new ring magnet regulator, this circuitry was optimized, yielding an additonal measure of stability of the injected beam. These improvements contributed to the increase in current shown in Fig. 1.

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. The entire year's running described in this paper 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 protons and recirculations, a good guess is that each foil is struck about 5 x 10^{21} times. The failure mode is not total breakage but a shredding of the foil edge which effects stripping efficiency. These foils are brought up to essentially full beam current with only two hours of conditioning as opposed to at least six 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 difficulties have precluded its use in the 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. It was the "jerky" motion which frequently resulted in damage due to water surface tension. Temporarily supporting the free edge with a thin wire until the assembly was in a vertical position has always proved helpful. The success rate with these new techniques is about 50% when done by our most skillful man.

Other Synchrotron Activities

Many of the upgrades mentioned in last year's ICANS report did not get completed because of our SDI involvement but a few things are worth mentioning.

We did, as planned, remove the trim octupoles and replace them with a second set of programmable trim quadrupoles. We had hoped to reduce the β function distortion by applying smaller trim quadrupole correction in more than one location in the ring. The effect of the new apparatus on the beam was not beneficial although the ability of the new quadrupoles to shift the betatron tune was as expected. The new quadrupoles do not have the same beam effect as the old set located 120° around the ring nor are beam effects equivalent when each set operates at one-half current. From this behavior we conclude that the benefit from the old trim quadrupoles is not correction of tune shift but is orbit error correction.

A second set of remotely controlled protective vertical collimators has been installed in the synchrotron. Like the first set, these are adjusted during operation to just touch the beam then backed away about 0.05 inch. Their purpose is to protect the rf liners from beam damage and also localize radiation from the lost beam. Since we had no liner damage this year, they must be working!

Conclusion

This year we harvested the fruits of previous years' improvements and continued attention to reliability. Beam intensity continues to improve gradually which is about all that can be expected without major capital investments. Once the enriched target system becomes operational, perhaps the IPNS future will be more defined and significant accelerator upgrades can be considered.

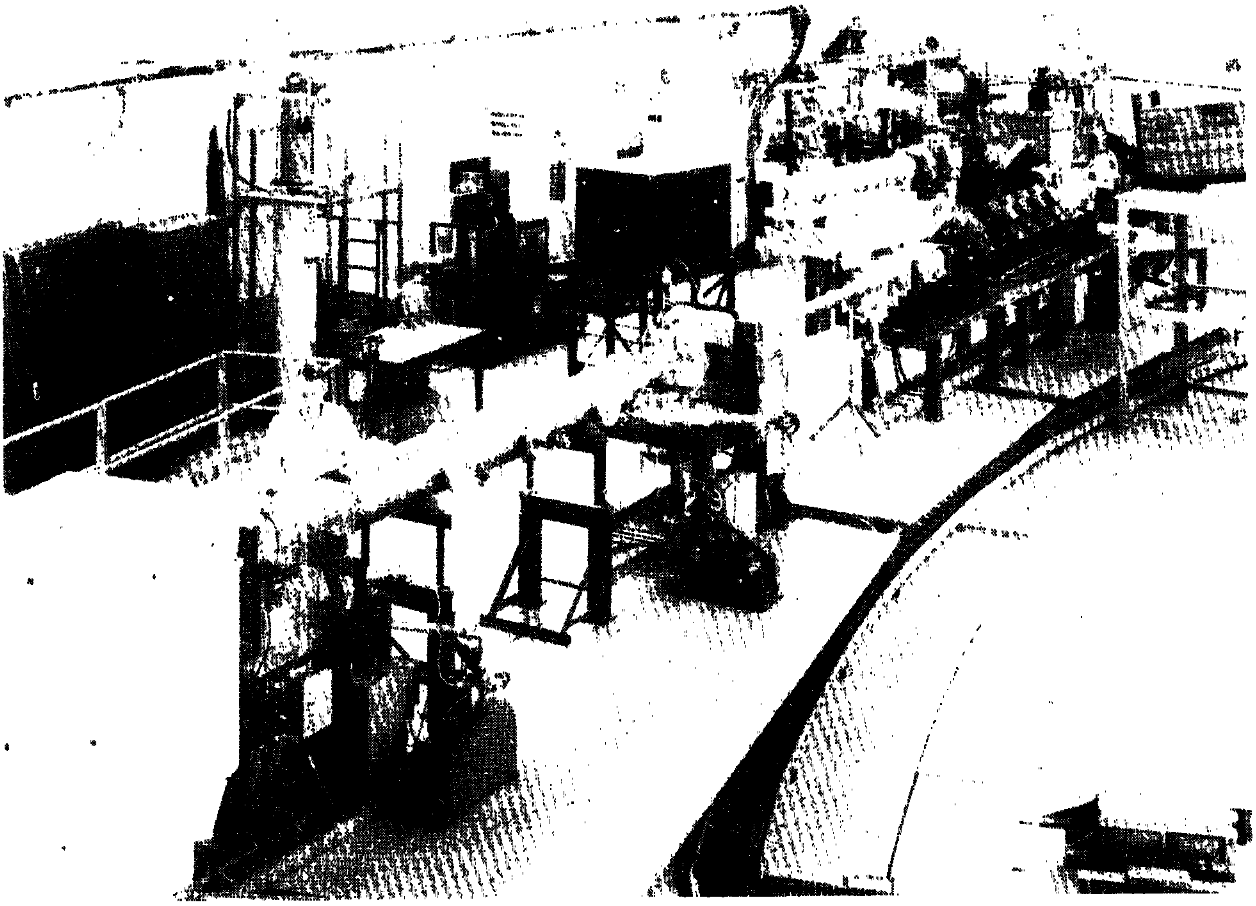

Fig. 7. Neutral Particle Test Beam A

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