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STATUS REPORT ON THE RAPID CYCLING SYNCHROTRON*

Charles W. Potts, Franklin R. Brumwell, Yanglai Cho, Antanas V. Rauchas, and Gerald J. Volk
Argonne National Laboratory
Argonne, Illinois 60439

Abstract

The Rapid Cycling Synchrotron[1] (RCS), originally designed as an injection energy booster for the Zero Gradient Synchrotron (ZGS), operated under constraints imposed by ZGS operation until December 1979. Once these restraints were removed, the RCS made rapid strides toward its near term goals of 8 μA of protons for Argonne National Laboratory's Intense Pulsed Neutron Source program. Reliable 30 Hz operation was achieved in the spring of 1980 with beams as high as 2 x 10^{12} protons per pulse and weekly average intensities of over 6 μA on target. These gains resulted from better injection matching, more efficient RF turn-on and dynamic chromaticity control. A high intensity small diameter synchrotron, such as the RCS, has special problems with loss control which dictate prudence during intensity improvement activities. The studies and equipment leading to the intensity gains are discussed.

Introduction

Figure 1 shows the configuration of Argonne National Laboratory's (ANL) Intense Pulsed Neutron Source-I (IPNS-I) spallation neutron facility.[2] It will come into operation in May of 1981 as a national user-oriented facility intended to be used for neutron scattering studies 75% of the time and radiation damage studies 25% of the time. A high energy physics test beam is also provided. In this facility, a fast burst (90 ns) of 500 MeV protons from the RCS will be slammed into a uranium or tantalum target 30 times per second. Resulting spallation and fission neutrons travel down 12 neutron beam lines to users' instruments. A prototype target (ZING P'), Fig. 1, was the recipient of the protons in 1979 and 1980. The neutrons from ZING P' were used for target yield studies, moderator material and arrangement studies as well as neutron science. Some 55 publishable neutron scattering measurements were made after the RCS came into a production mode in the summer of 1980.

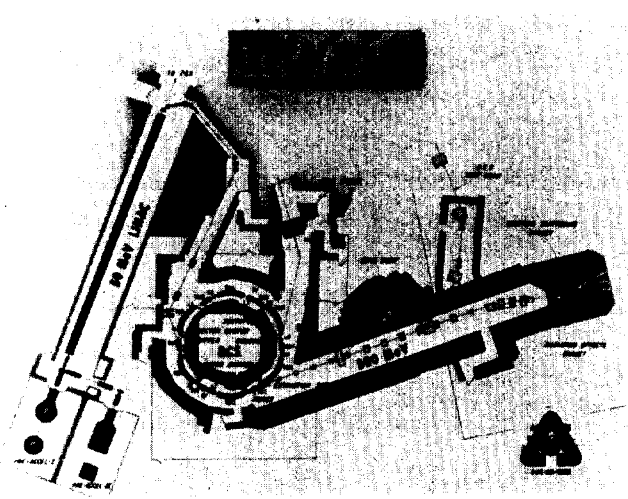

Fig. 1.

The trials of turning on and improving a new machine with scientific users waiting with high expectations is old hat to most of the readers. Normally, however, the users have some previous accelerator user experience and are, therefore, somewhat tolerant of the foibles of synchrotrons. In the case of the RCS, however, the users are reactor oriented and become somewhat irate when the published intensity, energy, and reliability are not available within a few months after startup. Fortunately, the accelerator made dramatic progress in intensity and reliability during the summer 1980 run and the needed rapport was developed between users and operators, and a viable scientific program seems to be on the horizon.

The goals of the RCS have long been to deliver 20 μA of 500 MeV protons to a target with 90% operating reliability. Numerous review panels have not seriously questioned the ability of the RCS to meet the 20 μA goal. Neutron science reviews have, however, questioned whether the national neutron science budget can support a dedicated facility like IPNS-I. This is a complicated, many-faceted question which may take quite awhile to answer. Lower goals are compatible with a lower budget, and the goals have now been changed to 8 to 10 μA. As Table I indicates, the RCS has made tremendous progress since 1978 and the new lower goals will be achieved in 1981. In the meantime, the 20 μA plans are being kept alive as well as possible, given the budget realities of the IPNS program.

The remainder of this paper will present, in chronological order, what improvements were made to achieve these results. It is of great importance to realize that in some of 1979 and most of 1980, the beam intensity was limited somewhat by fears concerning heating and thermal cycling of the uranium target. One certainly must not be fooled into thinking that was the only limit. The operators of a small radius fast cycling machine without extensively prepared remote handling apparatus must always consider beam loss control as a prime goal if the machine is to be kept repairable. The gentle positive slope of the beam current in Fig. 2 was planned as accelerator problems and uranium target worries were slowly worked out in unison. Some of the peak numbers such as 10 μA and 2 x 10^{12} protons per pulse were short-term accomplishments that could not be sustained over long periods because of beam losses, but they do provide input as to the machine's overall capability.

Operation in 1979

The RCS time-shared the 50 MeV linac with the ZGS, usually in a mode of 3 seconds RCS to 1 second ZGS. Programmable bending and focussing magnets made the ZGS H^+ polarized proton operation and the H^- operation linac compatible. The operating frequency of RCS was limited to 15 Hz due to possible damage to the linac when operated at 30 Hz. No one expected major damage, but even two or three weeks of lost operation was considered vital to the high energy polarized beam which was shutting down permanently in October.

This was a very productive period for the machine physicists. Approximately 20 hours per week were dedicated to machine studies. Many of the beam problems uncovered during this period are still being addressed although some were corrected in the spring of 1980 with gratifying results. Studies found that the 500 MeV

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Table I

	1978	1979	1980
Scheduled Operating Time	2681 hours	3976 hours	2569.2 hours
Actual Operating Time	1796 hours	2982 hours	2187.8 hours
Operating Efficiency	67%	73.6%	85.2%
Total Protons on Target	0.294×10^{20}	1.06×10^{20}	2.25×10^{20}
Total Pulses on Target	0.43×10^{8}	1.13×10^{8}	1.98×10^{8}
Average Beam Current	0.73 μA	0.61 μA	4.72 μA

beam was too large for efficient extraction due to "head-tail" instability.[3] Tune measurements disclosed dynamic reversal of the chromaticity at 350 MeV.

Extraction was studied at 200 MeV, and it was noted that 100% of the accelerated beam could be extracted. The extraction kick was insufficient to kick out the wide 500 MeV beam created by the "head-tail" instability. The 500 MeV extraction efficiency was about 65%. A compromise of 300 MeV operation was chosen to get fairly good neutron yield while still providing a radioactively clean extraction efficiency of over 90%.

High radiation levels were detected at 50 MeV end of the linac. This resulted from gas stripped H^o and H^+ particles. Appropriate shielding was added. Quantitative measurements were made later of H^o and H^+ production as a function of linac tank pressure.[4]

This was a beneficial time for the users also as neutron yield measurements were made on tungsten, tantalum, and uranium targets. The results agreed fairly well with computer predictions, and uranium was chosen as the target material in the IPNS-I monolith for neutron scattering and tantalum for radiation damage work. A uranium target was then installed in the ZING-P' monolith for operation until August of 1980. While this target was only a few pounds of uranium, numerous safety reviews, ad hoc committees, and some 30 target interlocks gave the accelerator operations some new concerns.

One of the more ambitious accomplishments was phase locking the accelerator to a crystal controlled neutron chopper. This is fully discussed in a paper in these proceedings.[5] From the accelerator standpoint, this is like the "tail wagging the dog" but it works!

Reliability during this period was not good. The pulsed septum magnet was the real Achilles' heel. It was a 30-inch long conventional 4-turn thin septum magnet. Several different versions of this magnet failed with the best lasting 10^8 pulses. Failure required a lengthy cooldown before repair.

Once the ZGS was shut down in October of 1979 restrictions on linac operating frequency were lifted, but insufficient data existed to begin 30 Hz operation at once. The ZGS authorities graciously allowed use of half the ZGS main ring magnet system and its beam diagnostics as a spectrometer for analysis of behavior in the linac beam running at 30 Hz. At the same time the linac tank was instrumented for temperature measurements at various points. When the linac was run at 30 Hz with RF on for as long as 120 μs, some hot spots were noted on uncooled tuning balls. These had grown leaky over the years and the water was shut off, which was acceptable during low power operation. A very clever design provided cooling for these leaky units, but construction and installation of these cooling adapters took over two months. Thirty-hertz operation was tried again in mid-December, but because of kicker magnet power supply problems it was not successful, although short-term currents of 5 μA were achieved.

1980 Modification and Operation

From January until the third week of March the machine was off for improvement. The most extensive was the installation of a new transformer septum magnet[6] that provided one-half the bend of the old magnet. A more standard dc septum provided the remainder. In addition, two small vertical and one small horizontal trimming magnets were designed and built to better match the machine to the transport line. Significant improvements were made in protecting the low level electronics in the kicker magnet power supplies. These two efforts made great improvements in the operating reliability of these systems, as can be seen from comparing the 1979 and 1980 reliability data in Fig. 3. Several other modifications were added to improve beam output and beam handling efficiency. Programmable linear amplifier power supplies were provided for dynamic chromaticity adjustment. Preamplifier improvements were made in the RF system to improve dynamic range and automatic gain control response. Ninety percent of the complicated 50 MeV transport line from the linac to synchrotron was wire orbitted, and the beam diagnostics were realigned for better injection matching. A 750 keV proton beam chopper was constructed to give the machine synchronous injection capability. One look at Fig. 2 from April through July 1980 should convince the reader that these modifications were, on the whole, quite successful. It is during this running period that 30 Hz operation became routine. The reader should bear in mind that this running was carried out with the ratio of beam on target to beam delivered to the synchrotron at 70% or better.

Machine physics studies continued during this running period, more problems noted, some corrections made and some longer range plans formulated. A disturbing coupling between proton beam noise and the ring magnet power supply was discovered and partially corrected. This was particularly troublesome when the accelerator was running in synchronism with a neutron beam chopper. Two-turn extraction, 500 MeV acceleration, and the effects of space charge distribution were among the more common topics. The most troublesome aspect of beam acceleration was, and remains, an instability which occurs at intensities of over 1.5×10^{12} protons per pulse for about the last 2 ms of the acceleration cycle. It seems to be longitudinal in nature since there is a great deal of bucket size modulation. A "head-tail" instability has been noted at this time in the acceleration cycle. This instability, or cross coupling between some of the RF feedback loops is thought to be the cause. Actions are currently underway to try to correct it.

Conversion for Operation into IPNS-I Target Monolith

The accelerator was shut down August 4, 1980 to begin the attachment of a new Proton Transport System

(PTS) to carry the beam to the IPNS-I target monolith. From the accelerator standpoint, additional work is required. The extraction straight section containing the septum magnets must be moved from the L-4 to L-3 straight section. A set of quadrupoles was moved from the L-3 to L-4 straight section. A longer fast kicker magnet will be installed in the S-3 straight section. Extensive shielding additions totaling 450 tons of concrete have been added over the extraction straight section.

Several system modifications and additions are also underway which should improve operating reliability and beam handling ability. The most ambitious of these is a complete reconstruction of the fast kicker magnet power supply system.[7] Programmable octupole magnets and power supplies[8] are being added to help control beam instabilities. More waveform flexibility has been added to the injection bumper power supply. New cavity bias amplifiers for the RF system have been installed. These have a corner frequency of about 10 kHz as compared to 800 Hz for the old ones. It is hoped that better cavity impedance control will improve many aspects of the dynamic RF performance, in particular, better cavity-to-cavity tracking and automatic gain control should result. A major change is also underway on the RCS computer system with an Eclipse AP-130 replacing the present NOVA 210.

The accelerator physics team has been busy wire-orbitting the injection and extraction orbits and has recommended changes which should result in lower beam losses and better stripping foil life.

Linac and Ion Source

One should not expect that a 1 Hz linac and 1 Hz H^- ion source will automatically operate at 30 Hz. The linac, with the beam pulse width restricted to 70 μs or less, has performed flawlessly thus far. Modifications in tank water flow, tuning ball cooling, and oscillator cavity cooling have been necessary. The ion source, with similar power restrictions, has done quite well with grid life being the limiting factor. With pulse widths under 60 μs, grids last about six weeks.

Conclusions

Great strides have been made since the 1978 commissioning paper. Weekly average beam currents have gone from less than 1 μA to over 6 μA, weeks with over 15 million extracted pulses have been recorded, and reliability has jumped from 67 to 85%. Peak intensities of 2×10^{12} protons per pulse and a 24-hour average of 7.6 μA has been attained. Much remains to be done. Five-hundred MeV operation must be reliably demonstrated. Firm control of beam losses must be maintained and stable financing would help.

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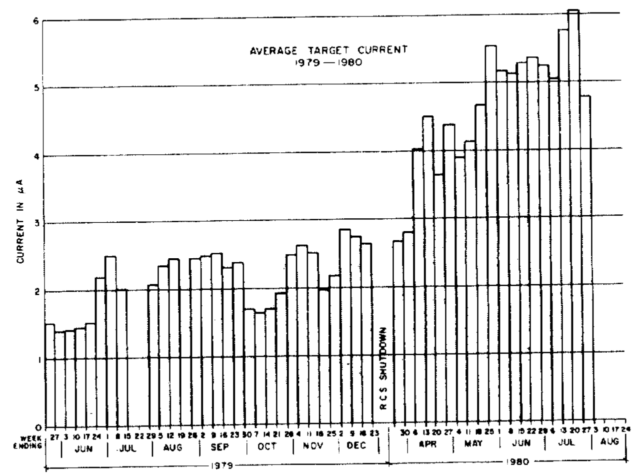

Fig. 2. Weekly Average Beam Current on Target

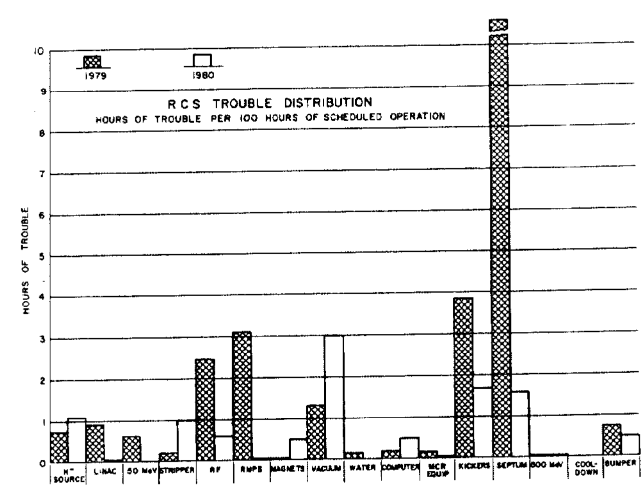

Fig. 3. Comparison of RCS Trouble Distribution for 1979 and 1980