IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

INJECTED BEAM CHOPPER SYSTEM FOR THE INTENSE PULSED NEUTRON SOURCE ACCELERATOR SYSTEM*

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Summary

A new chopper system has been designed and built to allow versatile manipulation of the H^- beam for the Intense Pulsed Neutron Source (IPNS) accelerator system. The beam is chopped at an energy of 750 keV, just before injection into the 50 MeV linear accelerator. The system consists of a high speed logic control system, a high power pulse amplifier and a travelling wave beam deflection electrode. The control system allows for up to four concurrently operable functions. The first mode is dedicated to personnel and equipment protection interlocking. The second is for low frequency pulse shaping. The third is a high frequency chop mode for RF synchronized injection of the 50 MeV beam into the Rapid Cycling Synchrotron (RCS). The fourth mode allows width and/or time modulation of the RF synchronized chopping to control the loading of the RF bucket area in the RCS.

Introduction

Until recently, a duoplasmatron H^- source had been in use for the RCS. Considering it was designed to operate at 1 Hz, it operated very reliably at a repetition rate of 30 Hz, but was limited in the amount of beam current delivered to the RCS, a 50 μs pulse of approximately 6.5 mA. In addition, a prototype beam chopper system had been installed to study RF synchronous injection into the RCS. However, the low brightness of the source prevented extensive study since the RCS was efficiently accelerating nearly all of the beam the source could supply.[1] Early this year, a new magnetron type H^- source was installed and at present can deliver a 60 μs, 15 mA beam pulse at 30 Hz to the RCS.[2] The increased intensity of the new source would allow study of RF synchronous injection so the existing chopper system was resurrected together with a new set of control electronics. Since the steady state operation of the source could not be easily altered or inhibited without source contamination or temperature changes, the chopper system was also required for several other reasons: 1) to control the width of the injected pulse into the RCS, and 2) to provide safety interlocking for personnel and equipment protection.

* Work supported by the U. S. Department of Energy.

Chopper System Description

Electrode

The beam chopper deflection electrode is a 1 m long travelling wave structure. It is constructed of 12 mil copper wire wound on G-10 insulators, spaced 7 cm apart, with a wire spacing of 7 mm. The ground plane is a 0.8 mm thick copper cover which is tapered in the vertical direction to conform to the vertically converging beam profile. The vertical aperture is 4.60 cm at the upstream end and 3.65 cm at the downstream end. Cooling for this cover plate is provided by a single loop of copper water line at the upper corners of the cover. This electrode configuration provided a reasonable impedance match of the load to the pulse amplifier as well as the best match of the electric field propagation time to the β of the 750 keV H^- ions through the electrode. The rise time is limited only by the pulse amplifier. The electrode is shown in Figs. 1(a) and (b).

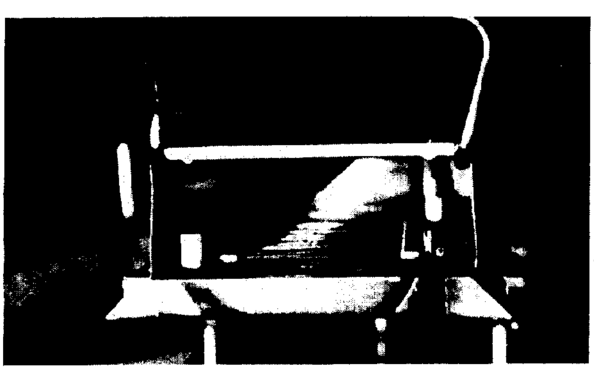
Pulse Amplifier

The pulse amplifier used in the chopper system is a commercially available model 350 high power pulse generator made by the Velonex Division of Pulse Engineering, Inc. It is capable of driving a 200 Ω resistive load to −2.1 kV peak with rise and fall times of <50 ns at a duty factor of 5%.[3] The chopper system requirements are 2 kV peak with a duty factor of less than 1%. Although the rise and fall times are not ideal, this pulse amplifier was used because the "price was right," since several were readily available.

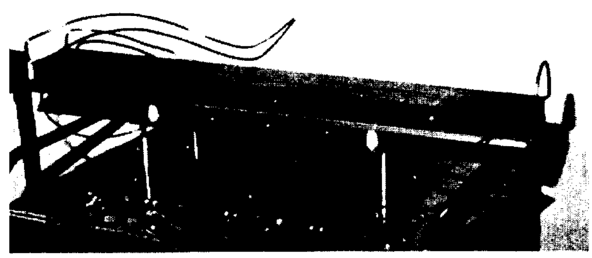
Chopper Control Electronics

The chopper control electronics was designed to allow versatile beam manipulation as well as reliable interlocking for personnel and equipment protection. It is constructed of high speed Schottky TTL logic and uses optically isolated current loops for all controlling inputs and outputs. The control system allows for up to four concurrently operable functions:

1. CHOP ALL - The deflection electrode is pulsed on at a time when the linac RF transmitter pulse has reached 50% of the normal operating level and stays on



(a). End view.



(b). Side view.

Fig. 1. Beam chopper electrode.

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until the transmitter pulse is off (approximately 300 μs). In this mode, all of the beam exiting from the source is deflected. This mode is not adjustable by the RCS operators and is automatically selected by the electronics for personnel and equipment protection regardless of the operator selected mode. The chopper operates in this mode at a 30 Hz rate and during normal operation, this mode is modified at operator selected rates by any or all of the following modes.

2. SHAPE - This mode allows the operators to "chop out" the leading and/or trailing edges of the source pulse and thereby control the injected pulse width. The chopper starts in the CHOP ALL mode, but at an operator selected time, the chopper is shut off. The chopper remains off for an operator determined period and then reverts back to the CHOP ALL mode (Fig. 2). The chopper off period can be based on time (with 1 μs resolution) or on the number of turns injected into the RCS.

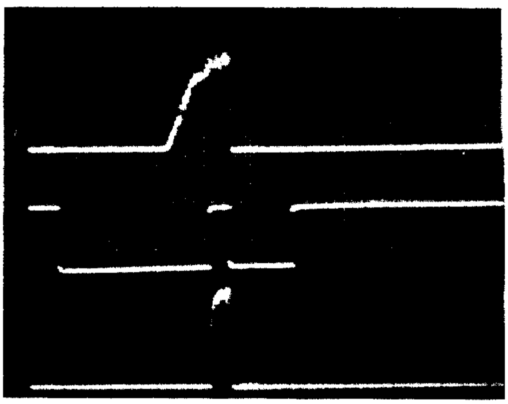

Fig. 2. Beam chopper operation in shaping mode.
Top: Source output pulse (10 mA/division).
Middle: Chopper pulse (-1.5 kV/division).
Bottom: Beam pulse after chopping (10 mA/division).
Horizontal scale: 50 μs/division.

3. SHAPE/CHOP - This mode will be used for RF synchronous injection. In this mode, the injection pulse is shaped as above, but in addition, the beam is also chopped at the RCS RF rate. The operator is able to control the width of the chopped pulse as well as the phase relationship to the RCS RF in increments of 10 ns. Figure 3 shows the high frequency chopping during the injection pulse. Figure 4 shows the injected chopped beam stacking in the RCS.

4. MODULATION - This mode is for use with RF synchronous injection and allows the width of the chopped beam to be modulated during the injection pulse to control the loading of the RF bucket area in the RCS. As presently set up, the width of the chopper beam can be decreased by 10 ns every N turns in the RCS, where N is an operator controlled variable. An external input is also provided which also reduces the width by 10 ns for every input pulse. This mode can be easily reconfigured in the electronics to provide other types of modulation, for example, injecting every other turn during the first half of the injection pulse and every turn thereafter. Together with the adjustable slope of the injection bumper magnets,[4] various methods of bucket loading can be achieved. Simple width modulation effects on the injected beam stacking is shown in Fig. 5.

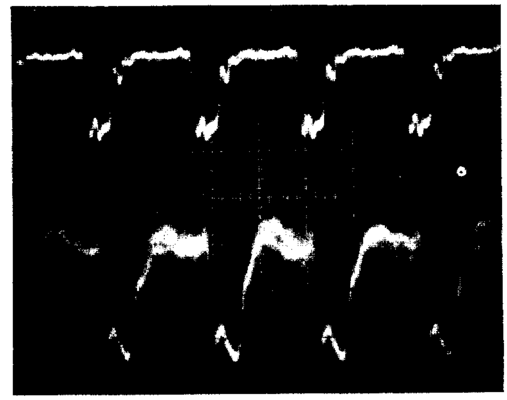

Fig. 3. High frequency beam chopping.
Top: Chopper pulse (-1.5 kV/division).
Bottom: Chopped beam (10 mA/division).
Horizontal scale: 200 ns/division.

Safety Considerations

With the previous duoplasmatron source, the beam was inhibited for personnel and equipment protection by interrupting the source extractor trigger pulse by means of a coaxial relay. This method was in keeping with the long standing philosophy of local safety protection interlocking. In addition, a second level of redundancy was provided by a remotely controlled, automatically insertable faraday cup located upstream of the linear accelerator.

The pulsing of the arc and extractor on the new magnetron H^- source cannot be interrupted for long periods of time without source contamination and temperature changes. Therefore, the source could no longer be used as part of the safety interlocking. This duty was assumed by the chopper system, again with the faraday cup as a redundant safety measure. However, the transport line configuration from the source to the linac precluded situating the deflection electrode in a fail-safe condition, that is, loss of power to the electrode would prevent beam injection into the linac. A biased electrode was also not considered due to manpower and cost limitations. Therefore, the chopper control system had to be able to detect its own faults, and ensure that a safe condition exists. The electronics prevents the acceleration of any beam beyond 750 keV by controlling the insertion of the faraday cup and delaying the linac RF transmitter pulse in respect to the output beam pulse from the source in addition to operating in the CHOP ALL mode. As a further interlock, loss of power to the chopper control electronics interrupts

Fig. 4. Mountain range display showing the injected chopped beam stacking in the RCS.

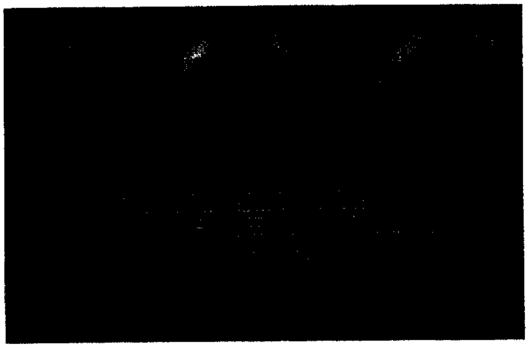

Fig. 5. Mountain range display showing width modulation effects on the injected beam in the RCS.

source operation without regard to the possibility of source contamination. The system was reviewed by local safety committees and is considered adequate for personnel and equipment protection.

Conclusion

The system is presently operating reliably in the SHAPE mode. The more than adequate intensity of the new source will allow machine studies of RF synchronous injection in the near future. Since the RCS now operates with an injection to extraction efficiency of nearly 90%, the expectations of large improvements in efficiency are not great. However, with the RCS accelerating over 6 x 10^{13} protons per second, increasing the efficiency by only a few percent will have significant effect on the beam loss induced activation in the accelerator.

Acknowledgments

The authors wish to acknowledge the efforts of F. Bacci (currently of Fusion Materials Irradiation Test Facility) in developing and constructing the deflection electrode, and the work of J. Madsen in the design of the support structures and actual installation.

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