FIRST TESTS OF A TRAVELING-WAVE CHOPPER FOR THE ATLAS POSITIVE ION LINAC

R.C. Pardo, J.M. Bogaty, B.E. Clifft
Argonne National Laboratory, Argonne, IL 60439
USA

Abstract

A ten segment traveling-wave chopper has been constructed and successfully tested at 5% of the design 12 MHz repetition rate. The chopper must remove unbunched tails from a partially bunched heavy-ion beam in order to avoid undue emittance growth in the linac and the production of undesirable satellite beam bunches. When poorly bunched beams traverse a chopper, the traditional sine wave chopper produces unacceptable transverse emittance growth and unnecessary beam loss. Emittance growth and unnecessary beam losses are expected to be much reduced in the traveling wave chopper. These first tests have confirmed the validity of these claims, clearly showing much reduced transverse emittance growth as compared to the original sine wave chopper and excellent selectivity for the desired beam. Details of these tests will be presented and compared to calculations. Operation of the new chopper at the full 12 MHz rate is the next goal. Development of a driver power supply capable of full CW operation will also be described.

1 INTRODUCTION

Excellent beam quality is an important feature of heavy-ion beams provided to the research program by the ATLAS superconducting linear accelerator. The measure of beam quality includes relatively low emittance, small spot sizes with little or no halo, small energy spread, and when requested excellent bunch time width (<200 ps FWHM) on target. In order to make use of these properties, a rather larger bunch period of 82.4 ns is provided meaning that only every sixth or eighth RF bucket is filled with beam.

To achieve these beam quality goals, a two stage bunching systems converts the DC beam from the ion source into a beam with a 12.125 MHz bunch structure. The system is able to adequately bunch approximately 70% of the DC beam into acceptable pulses, but the remainder of the DC beam must be removed in order to provide the correct bunch structure and beam quality. This unbunched beam 'tail' is removed with a vertically deflecting electric beam chopper.

The beam chopper which has been used up to now at ATLAS is a resonant 'sine wave' chopper. Bunches are phased so as to arrive at the center of the chopper plates as the sine wave passes through the zero voltage point. The chopper therefore operates at half the frequency of the bunch structure deflecting the unwanted tails both 'up' and 'down'. Since the good beam also sees some voltage due to the finite transit time of the beam bunch through the plate region, portions of the beam pulse are deflected slightly both up and down causing an emittance growth of the transmitted beam. A similar energy gain effect also takes place due to the entrance and exit fringing fields of the chopper. Thus such a device has a significant detrimental effect on beam emittance. The magnitude of the effect depends on the time width of the beam bunch at the chopper. If the chopper can be located in a location with a narrow bunch width these effects can be minimized and acceptable performance is possible. The geometry of a new bunching system in the ion source region of the ATLAS Positive Ion Injector(PII) does not allow the chopper to be located at a location where the beam time width is narrow and the resulting emittance growth from a sine wave chopper will be unacceptable.

Therefore a new non-resonant traveling-wave transmission-line chopping system (TWC) is being developed which can largely eliminate the emittance growth effects described above. The conceptual design and modeled performance has been previously reported [1]. This paper describes the final design and first low duty factor tests of the chopper.

2 CHOPPER DESIGN

The TWC consists of ten shielded plate pair segments arranged transversely to the beam, like rungs on a ladder. The top plates of each section are a portion of one continuous impedance-matched transmission line as are the lower plates. Such a system can propagate a well-formed voltage pulse down the line with a group velocity matched to the velocity of the bunched beam traveling between the plates. The deflector plates have a center-to-center spacing of 4.5 cm which corresponds to a 17.6 ns ion transit time between plates. The deflector plates are isolated from each other by field clamp electrodes which also can be biased with a DC voltage to fine tune any slight beam deflection from incomplete voltage shutoff on the deflector plates. Stripline electrodes are supported by plexiglass plastic strips which provide critical spacing to maintain the proper RF impedance. Three sections of the chopper plate assembly are shown schematically in Figure 1 in relation to the beam direction.

The deflector's characteristic impedance is 125Ω which results from the stripline electrode gap of 3.8 cm and width of 1.5 cm. Each of the stripline electrodes is attached to a pair of 125Ω coaxial connectors. Coaxial cable delay lines are connected in series with the stripline

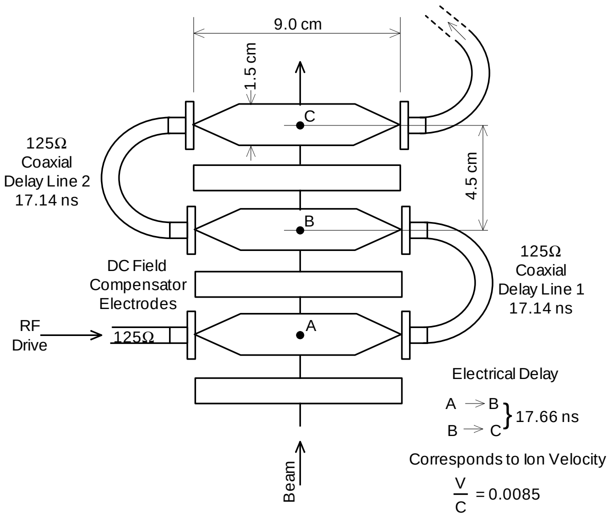

Figure 1: Schematic of TWC deflector plate assembly and its incorporation into the overall transmission line.

deflectors. The delay lines are used to match the chopper pulse propagation time to the beam velocity. Transition from stripline geometry to coaxial geometry is facilitated by tapering the stripline electrode ends. The tapered ends are paired with a special ground plane electrode assembly (not shown in figure 1) that maintains the 125Ω impedance. The chopper electrodes and water-cooled delay lines are contained in a 0.56 m long by 0.44 m inner diameter cylindrical vacuum chamber.

Each of the nine 3.35m-long delay lines are made from 122.5Ω semirigid coaxial cable[3]. The coax center conductor diameter is approximately 0.0325 cm. The small cross section results in significant ohmic heating which requires direct cooling. A water cooled stainless steel form is used to support the nine delay lines and provide cooling. The delay lines are coiled on the water cooled form and indium soldered for good thermal contact. About 120 watts will be disipated along the delay line during normal chopper operation. The last stripline deflector is terminated in a 125Ω, 4000 watt air-cooled resistor array.

In the quiescent mode, the plates have a vertically deflecting voltage of up to 1000 volts, effectively blocking the transmission of any beam through the device by deflecting all particles vertically onto a set of slits 2 meters downstream. When a bunched beam pulse arrives at the start of the deflecting plates, a zero voltage pulse of 17 ns width or greater is propagated down the chopper, providing a transmission window with no deflecting voltage as seen by the desired beam pulse. At a repetition rate of 12.125 MHz this generates up to 1648 watts of heat into the termination resisitor.

Three Eimac [4] 4CW2000A tetrode vacuum tubes are used in parallel as an electronic switch. The plates of the tubes connect to the chopper transmission-line assembly as shown in figure 2. When the vacuum tubes are cut off, chopper electrode voltage is maintained at the cutoff value of up to 1000V. Pulsing the tubes into conduction causes 8.0 amperes of plate current to flow for about 20 ns. The pulse of current reduces the deflector electrode voltage to zero just as an ion bunch enters the deflector array. The zero volt window propagates through the transmission line array in phase with the desired beam pulse terminating in the 125Ω resistor load. This occurs at a 12.125 MHz CW rate.

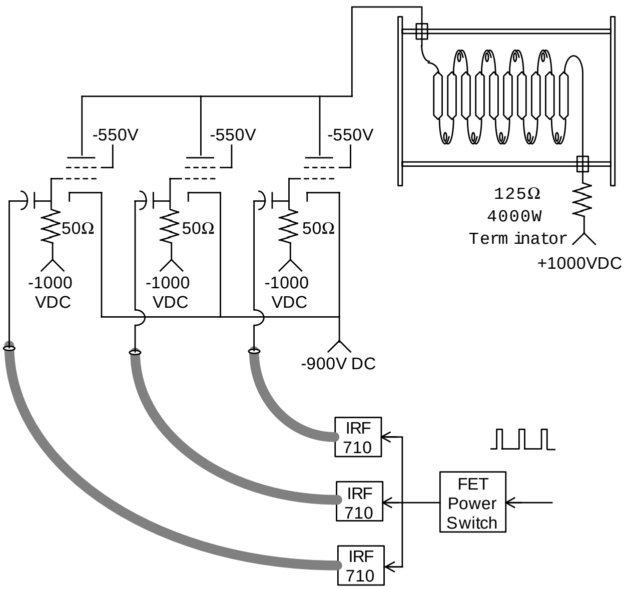

Figure 2: Schematic of the TWC and tetrode final stage with FET grid drivers.

Particles in the timing tails will see some deflection. This is minimized by producing as fast a fall and rise time as possible in the voltage pulse. The effect is weighted by the fraction of transmitted particles in the tail regions. Even this effect is lessened compared to the sine wave chopper since the deflection is always in the same direction for the traveling wave chopper, whereas the leading and trailing beam tails are deflected in opposite directions in a sine wave chopper.

3 FIRST TEST RESULTS

The prototype chopper system was mounted in a vacuum chamber on the PII injection beamline. A photo of the prototype assembly is shown in Figure 3. The delay line for this test was made from RG-63 coaxial cable with the outer insulator removed to improve it vacuum properties. Even so the vacuum obtained was barely adequate for these tests and even at 5% duty cycle, noticeable outgassing of the cable occurred.

A beam of 538 keV $^{16}O^{5+}$ with a velocity of 0.0085c was provided by the ATLAS ECR ion source and bunched by a 4-harmonic buncher operating at 12.125 MHz. For this beam, a voltage of 500 V was adequate for complete beam cutoff using only the upper delay line. The lower delay line was used as a DC ground plane. A DC offset voltage of -150 volts was applied to the lower ground

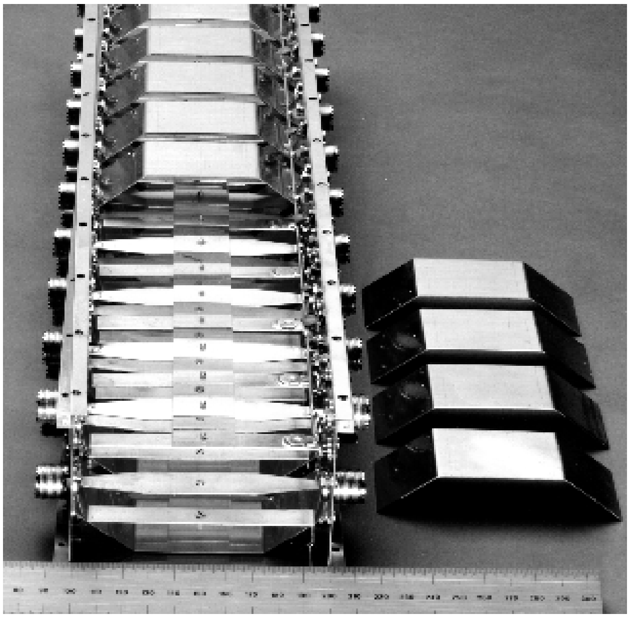

Figure 3: Photo of travelling wave chopper transmission line deflection plate assembly with clamp electrodes in place. A portion of the ground plane electrodes are shown to the side.

plane electrodes to minimize beam steering arising from the inability to completely achieve 0 volts on the transmission-line electrodes. For these tests, a power supply with the required power and rise time was not available and a smaller supply was used, limiting the tests to a 5% duty cycle.

At 500 volts applied deflection, excellent pulse definition was achieved. The achieved voltage pulse waveform is shown in Figure 4. No beam leakage between pulses was observed. 100% cutoff was achieved. These results are in agreement with the calculated voltage and indicated the system was working as expected.

The transverse beam emittance was also measured using the quadrupole method [2]. The original, and still used, sine wave chopper was also immediately upstream of the new chopper and so it was possible to measure the transverse beam emittance with both devices and obtain a direct comparison. Emittance measurements were obtained using both choppers for beam bunch widths of 3 ns and 18 ns FWHM as the beam traversed the chopper plates. Table 1 shows the results of those measurements. The emittance degradation in the chopping plane caused by the sine wave chopper is dramatically demonstrated, especially for the poorly bunched beam. In contrast the TWC shows no emittance growth for narrow pulses and less than a 25% increase in emittance for an 18 ns wide beam. Completion of a full power version of the TWC is expected by the end of the year.

This work was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract W-31-109-ENG-38.

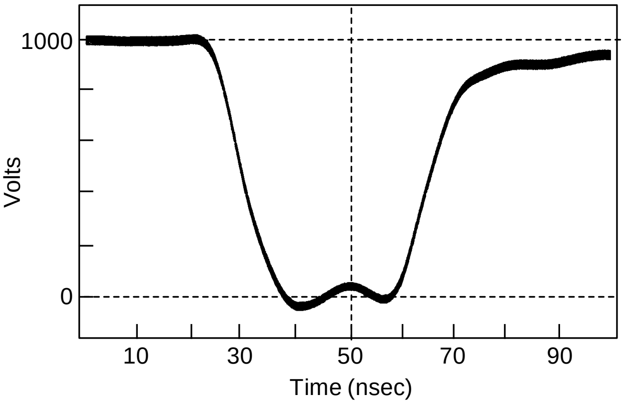

Figure 4: Actual pulse shape waveform achieved in prototype tests of the TWC. Total voltage fall time is approximately 15 ns.

Table 1: Measured growth of the beam emittance of) 538 keV $^{16}O^{5+}$ beam due to the effects of a sine wave and traveling-wave chopper (TWC).

Bunch Width (ns)	Chopper Type	ε^x_n (πmm•mr)	ε^y_n (π mm•mr)
3.0	none	0.09	0.09
3.0	sine		0.13
18	sine		0.17
3	TWC		0.10
18	TWC		0.12

REFERENCES

[1] R. C. Pardo, et al., ‘A Study of Beam Chopping Options for the ATLAS Positive-Ion Linac’, Proc. Of LINAC96, CERN, August 1-5, 1996, 65-67(1996).

[2] Y. Qian, et al., ‘Beam Parameter Measurements for the APS Linac System’, Proc. 1994 Int. Linac Conf., Japan, Aug. 21-26, 1995, 899-901(1994).

[3] Micro-Coax Inc., Pottstown, PA 19464

[4] Eimac, Varian Associates, San Carlos, CA