BEAM DYNAMICS DESIGN STUDY AND BEAM COMMISSIONING OF THE ISAC TWO FREQUENCY CHOPPER

R. E. Laxdal, M. Pasini, L. Root, TRIUMF, Vancouver, Canada

Abstract

A chopper comprising two sets of plates driven at two different frequencies has been installed and successfully commissioned with beam. Each plate pair consists of one DC biased plate and a second modulated with rf. Analytical estimates on emittance growth and Monte-Carlo beam simulations are included. Results of the final beam commissioning runs are presented.

1 INTRODUCTION

The ISAC post accelerator consists of a 35.4 MHz RFQ and 106.1 MHz DTL in series[1]. The RFQ accelerates beams to an energy of 0.153 MeV/u for mass to charge ratios up to $A/Q = 30$. The ISAC Medium Energy Beam Transport (MEBT) transports beams from the RFQ and delivers beam to the DTL. The MEBT, shown in Fig. 1, is

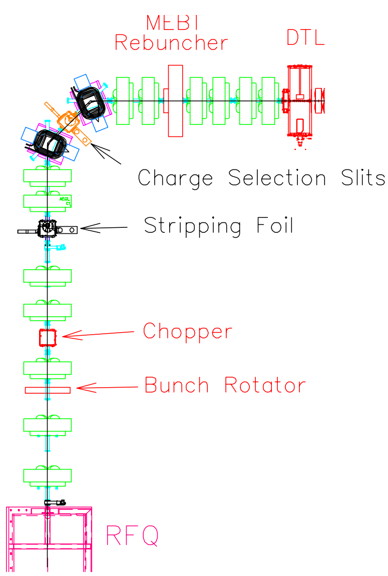

Figure 1: ISAC Medium Energy Beam Transport (MEBT).

composed of three basic sections: an entrance matching section to stripping foil, a charge selection section and an exit matching section to the DTL.

The ISAC accelerated beam is pre-bunched in the low energy beam transport (LEBT) at 11.8 MHz, the third subharmonic of the RFQ frequency. Since bunching only reduces but does not cancel the beam between bunches there is a small quantity of accelerated beam emerging from the RFQ in the two 35 MHz buckets on either side of the main bunch. In order to achieve the design specification of 85 ns between beam bunches it is required that a chopper be installed somewhere in the accelerator chain.

Experimenters requiring a larger bunch separation request the further possibility of removing every second main bunch to give a spacing of 170 ns between bunches at a reduced intensity. It was decided to design a two mode chopper for the ISAC MEBT with Mode A producing 85 ns between bunches and Mode B producing 170 ns between bunches.

2 TRANSVERSE OPTICS

The MEBT is the ideal spot for the chopper since the bunches are now well-formed and so the increase to the emittance is reduced and the beam velocity is moderate. The chopper is installed in the first section of MEBT. This demands higher voltage deflections from the chopper due to the higher A/q but there is little room between the stripping foil and the DTL. The beam optics of the first MEBT section are shown in Fig. 2. The chopper plates are positioned between the third and fourth quadrupoles. The optics are chosen to give a broad low divergence waist at the chopper plates in the selection plane and a double waste at the chopper slits. In this way a small deflection at the chopper plates produces a displacement of the deflected beam at the chopper slits.

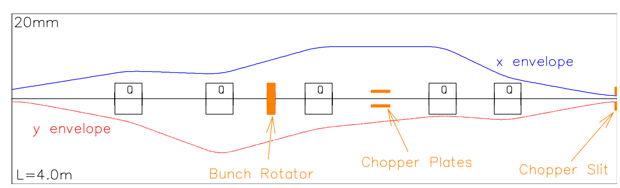

Figure 2: Beam envelopes for the initial MEBT section. The chopper plates are positioned after the third quadrupole where the 'x' divergence is very small. The chopper slits are positioned close to the stripping foil where the beam is focussed to a double waist.

Based on a given beam emittance of $\beta\epsilon_{x,y} = 0.15\pi$mm-mrad a chopper plate gap of 4 cm is sufficient. A chopper strength corresponding to a minimum deflection of 2 mrad for the unwanted pulses will ensure a clean separation of the transmitted beam from the chopped beam. This requires a deflection of $VL = 72$ kV-cm for the unwanted particles.

3 CHOPPER CONCEPTS

We consider two basic types of deflecting fields; a Sine-wave deflection and a Cosine-wave deflection. In the Sine-wave deflection an rf frequency of half the bunch frequency is used (5.9 MHz) and phased so that the desired high intensity bunches pass through the plates at the zero-crossing of the waveform giving transmission at a frequency of 11.8 MHz. The Sine-wave chopper may be excited symmetrically with peak voltages of $V_o/2$ on each plate in antiphase or asymmetrically with one plate at a peak voltage of V_o and the other grounded. In the Cosine-wave deflection the rf period is identical to the bunch period and phased so that the passage of the desired high intensity bunches coincides with the base of the waveform. Only one plate is fed rf, the other is fed a DC bias, V_{dc}, at the rf amplitude so that the generated voltage difference oscillates from 0 to $2V_{dc}$.

The time dependence of the deflecting fields during the passage of the wanted bunch does cause emittance growth dependent on the type of field and the length of the bunch. A summary of analytic estimates of increase in beam divergence due to the chopper fields are given in Table 1 where Q is the charge, A is the mass, V_o the plate voltage, g the plate gap, L the plate length, $k = 2\pi/\beta\lambda$ and ϕ is the half phase width of the beam. The Cosine-wave chopper produces far less emittance growth for well-defined bunches.

Table 1: Summary of analytic estimates of increase in beam divergence through both a Sine-wave (symmetric and asymmetric feed) and a Cosine-wave chopper.

Value	Sine-wave	Cosine-wave
$\Delta p_x/p$	$\frac{Q}{A}\frac{V_o}{g}\frac{L}{\beta^2 E_o}\phi$	$\frac{Q}{A}\frac{V_o}{g}\frac{L}{\beta^2 E_o}(\frac{kL^2}{24}+\frac{\phi^2}{2})$
$\Delta E_{\rm sym}$	$\pm\frac{QV_o x}{g}kL$	$\frac{QV_o x}{g}kL\phi$
$\Delta E_{\rm asym}$	$\pm\frac{QV_o(g/2+x_m)}{g}kL$	$\frac{QV_o x}{g}kL\phi$

We consider various chopper concepts[2] that allow both modes of operation. Concept I comprises a single frequency, single plate option where the chopper operates in classic sine-wave configuration to achieve Mode A (86 ns) timing and with one plate dc biased in a Cosine-wave configuration to achieve Mode B (172 ns) timing. Concept II is a dual frequency single plate option where both Mode A and Mode B use a Cosine-wave approach. Concept III is a dual frequency dual plate approach with each plate pair operating in a Cosine-wave configuration.

Concept I The Concept I Sine-wave configuration even for a well-bunched beam leads to significant transverse and longitudinal emittance growth. It is the latter that experiences the largest relative emittance growth since the longitudinal phase space is not upright at the chopper plates. Reducing the phase width with the the bunch rotator helps to reduce the negative effects of the Sine-wave chopper, however a growth of 75% is still expected. A symmetrical voltage feed reduces the effects on energy spread growth but this is a more complicated hardware solution.

Concept II Concept II greatly reduces problems of emittance growth but demands a second amplifier at a different frequency to achieve the two modes of operation. The voltage required on the plates in the Mode B timing case to achieve sufficient deflection for all satellite bunches is relatively high at 20 kV.

Concept III In Concept III the voltage is reduced dramatically by adding a separate pair of plates downstream of the first to operate in tandem. The first plates produce Mode A timing when excited at 11.7 MHz. For Mode B timing the first plates are left on as before and the second set are powered at 5.8 MHz with a voltage only sufficient to deflect the unwanted main bunch. Two amplifiers at different frequencies are still required but the voltages are now each below 10 kV. The longitudinal space required is twice longer than the single plate solution but this could be reduced at the expense of somewhat higher voltages. Analytic estimates of emittance growth predict broadening of less than a few percent.

Concept III Studies A schematic of the waveforms for the Concept III chopper is given in Fig. 3.

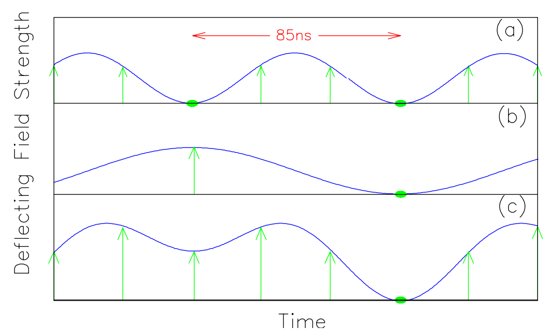

Figure 3: A schematic of the two-mode tandem chopper waveforms. For Mode A the first set of plates is excited with an 11.7 MHz deflecting voltage as is shown in (a). For Mode B the second set of plates is also excited at 5.8 MHz as shown in (b). The total resultant deflection for Mode B is shown in (c).

Care must be taken that both plates kick in the same way so that the second plates don't reduce the deflection from the first set. Note that in the case where the second set of plates are excited the voltage on the first set can be reduced since the two waveforms add.

Electrostatic models of the plate geometry are calculated using `RELAX3D`. To generate the initial distribution for the Monte-Carlo study a particle ensemble consisting initially of 5000 particles at the design emittance of 50πmm-mrad is pre-bunched with three harmonics in a LEBT simulator then accelerated through the RFQ. The resultant ensemble then passes through the MEBT optics including the chopper plates and is analyzed at the chopper slit location. A second set of calculations was performed with a larger emittance of 100πmm-mrad to check if the chopper parameters were sufficient to transfer this larger beam.

The simulation studies show that the increase in the transverse and longitudinal emittance due to the chopper is less than 1%. The tolerances on the voltage and phase are not restrictive with $\Delta V/V \leq 2\%$ and $\Delta\phi/\phi \leq 2^\circ$ sufficient to maintain emittance gorwth to less than 1%. The chopper fields produce a small lens effect in the transverse phase space. This can easily be corrected by a slight retune of the quadrupole settings.

Chopper Specifications The final specifications for the chopper are presented in Table 2. The physical length of the plates is chosen to fit into the available space and produces an effective length of 6.6 cm. The length of the entire assembly is about 180 mm. Two lumped circuits drive the rf voltage to the plates. Detailed information on the hardware can be found in a separate paper at this conference[3].

Table 2: Summary of chopper specifications.

Parameter	Mode A	Mode B
Δt (ns)	86	172
Mode	Cosine-wave	Cosine Wave
Frequency (MHz)	11.7 MHz	5.8 MHz
Plate 1A	7.4 kV rf	5.5 kV rf
Plate 1B	−6.8 kV dc	−5.1 kV dc
Plate 2A	0 kV	5.5 kV rf
Plate 2B	0 kV	−5.1 kV dc

4 CHOPPER COMMISSIONING

The chopper is now operational and proves very reliable and easy to tune. A profile monitor at the chopper slit is used to both tune the matching section prior to chopping and, further, to record beam deflection and to optimize the chopper phase. A summary of 'x' profiles taken at the chopper slit during commissioning are shown in Fig. 4. The beam is first brought to a double focus at the chopper slit/stripping foil position and the steering optimized to minimize beam loss (Fig. 4(a)). The Mode A (11.7 MHz) chopper is then turned on and phased to give proper separation between the two satellite bunches and the main bunch. Lastly the dc bias is set to optimize transmission through the chopper slit (Fig. 4(b)). For Mode B the 11.7 MHz plates are first set up as above but with reduced amplitude as in Table 2. Then with the 11.7 MHz plates off the 5.8 MHz plates are powered and phased to give adequate separation of the two main bunches. Lastly the 11.7 MHz buncher is turned back on (Fig. 4(c)).

Final measured beam time distributions for the chopper off case and the the two chopper modes are given in Fig. 5. The chopper produces no measurable increase in the beam emittance as expected.

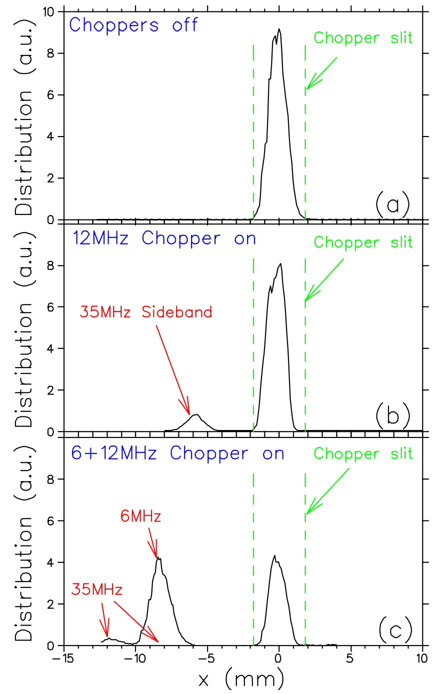

Figure 4: Measured beam profiles at the chopper slit for (a) chopper off (b) chopper Mode A and (c) chopper Mode B.

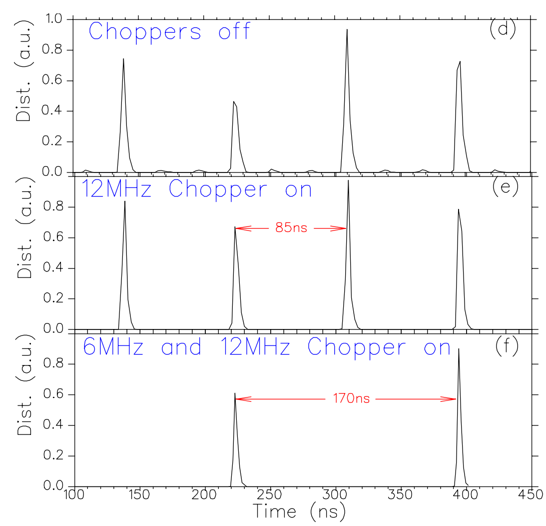

Figure 5: (a) Output time structure from the RFQ is shown in (a). The Mode A 11.8 MHz chopper plate produces a 85 ns time structure shown in (b). In Mode B the 5.9 MHz field is combined with the 11.8 MHz deflection to generate the time structure given in (c).

5 REFERENCES

[1] R.E. Laxdal, "ISAC-I and ISAC-II at TRIUMF: Achieved Performance and New Construction", these proceedings.

[2] R.E Laxdal, L. Root, "A Chopper for MEBT", TRIUMF Design Note TRI-DN-00-02, Nov. 2000.

[3] A. Mitra, *et al*, "Design Test and Commissioning of a Dual Frequency Chopper for the TRIUMF ISAC Facility", these proceedings.