BEAM INTENSITY ADJUSTMENT IN THE RIA DRIVER LINAC*

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Abstract

The Rare Isotope Accelerator Facility currently being designed in the U.S. will use both heavy ion and light ion beams to produce radionuclides via the fragmentation and spallation reactions, respectively. Driver beam power of up to 400 kW will be available so that beam sharing between target stations is a viable option to increase the number of simultaneous users. Using a combination of rf-sweepers and DC magnets the driver beams can be delivered to up to four targets simultaneously. With simultaneous beam delivery to more than one target independent adjustment of the relative beam intensities is essential. To enable such intensity adjustment we propose to use a fast chopper in the Medium Energy Beam Transport (MEBT) section. Several design options for the fast chopper are discussed. The MEBT beam optics is being designed to accommodate and match the chopper technical specifications.

BEAM SWITCHYARD

A preliminary design for a driver linac switchyard has been discussed in the recent RIA Facility Workshop [1]. The proposed switchyard will deliver beams to four production targets. The design of the switchyard for the driver beams of RIA is a complex problem due to the following features: 1) Sharing beams of various ion species accelerated over a wide range of energies; 2) Delivery of beams to four target stations simultaneously; 3) Providing high quality beam optics with higher order corrections for multiple charge state beams. The accelerated beam in the RIA driver can be distributed to four targets simultaneously using rf sweepers. A low frequency rf sweeper is appropriate for the deflection of heavy ion beams and the delivery to two or more targets simultaneously. The deflector design is based on an H-type rf cavity. The fundamental frequency of the bunch sequence is determined by the multiharmonic buncher at the front-end of the driver linac. In the two-charge state injector mode all four harmonics are applied and the bunch repetition rate will be 57.5 MHz. In the single charge state injector mode only three harmonics of the multi-harmonic buncher will be used and the bunch repetition rate is still 57.5 MHz. Therefore the rf sweeper can operate at 86.25 MHz to split the beam intensity 50/50 to two directions. The length of the rf sweeper's electrode is chosen to provide a phase slippage of 180° inside the cavity for uranium beams. This condition eliminates any effect of fringing fields on uranium beams but produces negligible momentum spread for lighter ions because of their higher velocity and shorter time-of-flight. A room temperature rf cavity operating at 86.25 MHz can provide a maximum electric field on the surface of ~18 MV/m in cw mode. We have conservatively designed for a maximum electric field of ~7.2 MV/m between the electrodes. The main parameters of the rf sweeper are shown in Table 1. Two such sweepers are used in series. The rf sweeper is followed by two DC septum magnets.

Table 1: Basic parameters of the rf deflector for the RIA switchyard

Maximum electric field between the plates	7.2 MV/m
Effective length	1.2 m
Deflecting angle	± 3 mrad
Aperture	3.0 cm
Tank diameter	68 cm
Required rf power according to the MWS Studio	25 kW

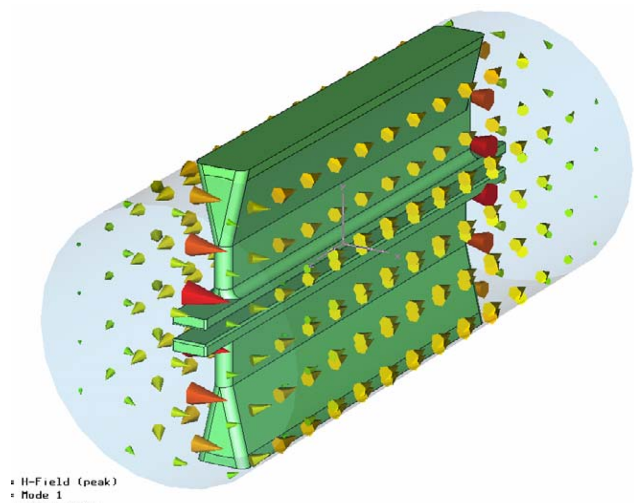

Figure 1: MWS design of the 86 MHz rf sweeper.

BEAM INTENSITY ADJUSTMENT

The switchyard will deliver beams to 4 targets simultaneously. Using rf sweepers beam microbunches will be alternatively sent to different targets. In this mode, all targets will receive equally distributed beam power. For most experiments it is desirable to have adjustable level of beam intensity on the targets. This problem can be solved by using a chopper which could remove any fraction of the beam. The chopper can be made as a device with a deflecting electric field and should be located in the MEBT to minimize the required voltage as well as to reduce the power on the beam dump. The

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MEBT will transport 200 keV/u beams of any ion with charge-to-mass ratio in the range 28/238≤q/A≤1. Due to the low energy of ions in the MEBT, the utilization of the deflected beam power is straightforward. The total beam power does not exceed 100 kW. In the most extreme case, about 75% of this power should be dumped. To absorb and remove this power, water-cooled slits must be provided.

BEAM INTENSITY ADJUSTMENT OF DUAL CHARGE STATE BEAMS

The baseline design of the RIA driver linac calls for the extraction and the acceleration of dual charge state beams with masses from 180 to 238 to the location of the first stripper [2]. The intensity adjustment of two-charge state heavy-ion beams extracted from the ion source does not require any additional equipment. The LEBT section between the ECR source and multi-harmonic buncher is designed as an achromatic system. The horizontal position of the beam depends on the charge state at high dispersion area which reaches its maximum in the mid-plane between the magnets [2]. At this location, beams of different charge state are completely separated in space and the intensity of each beam can be adjusted by the slits. The front-end of the driver is designed such that the same ion species with different charge states are accelerated in alternative buckets of the RFQ [2], therefore the rf sweeper will automatically produce two beams of different intensities.

CHOPPER CHOICE

Two basic options have been considered for the intensity adjustment in the RIA driver linac: 1) A fast chopper with high repetition rate (57.5/2 MHz) of deflecting voltage pulses; 2) A combination of low repetition rate fast chopper and rf chopper.

Fast Chopper

The arbitrary adjustment of the intensity of three beams delivered to 3 of the 4 targets can be performed in the MEBT using the fast chopper, similar to the ATLAS chopper [3]. In this mode of operation, one of the targets will receive 25% of maximum available intensity while the other three will receive any fraction between 0 and 25% of the full intensity. The available space for the chopper location in the MEBT is restricted to ~50 cm and it is defined by the beam matching requirements in the 6D phase space. The most challenging chopper parameters are those for the uranium beam (see Table 2, Regime A). As is seen, the voltage requirement is similar to the SNS chopper [4], however, the repetition rate is significantly higher. Therefore the SNS-type voltage switcher is not directly suitable for our application. Higher repetition rate of 12 MHz is provided in the ATLAS chopper [3] but the voltage ~0.8 kV is too low for the RIA application.

A traditional solution for the fast chopper includes two main devices: a) a voltage modulator with nanosecond rise- and fall-time and b) a traveling wave structure to synchronize the voltage pulse propagation to the beam velocity. The modulator power is determined by the required deflecting voltage and impedance of the traveling wave structure. To minimize the power requirements of the voltage modulator, high shunt impedance (~300 Ω or higher) is required. Even if the high impedance is provided, the frequency of the modulator is still high and not available commercially. In addition, high shunt impedance reduces effective deflecting voltage.

To reduce the required power significantly, we are considering series of solid-state or vacuum tube switchers operating at an individual capacitance of ~10 pF instead of a traveling wave structure. About 15 modulators can be triggered with appropriate delay to match the beam velocity. Further detailed engineering studies and prototyping are under-way.

If it is proven, the fast chopper operating at 28.75 MHz repetition rate can be easily implemented into the MEBT and simplifies the overall MEBT equipment compared to the option described below.

Table 2: Basic parameters of the chopper

	Regime A	Regime B
Beam velocity	0.02c	0.02c
q/A	28/238	28/238
Length	60 cm	60 cm
Voltage	±1.8 kV	±1.8 kV
Pulse rise/fall time	12 nsec	12 nsec
Pulse length	5-40 nsec	2 μsec
Repetition rate	28.75 MHz	0.25 MHz
Duty cycle	Up to 75 %	25 %

Beam Intensity Adjustment using a Combination of a Fast and an RF Chopper

Both ISOL and fragmentation targets tolerate ~0.25 MHz beam intensity modulation. An rf chopper can be used to adjust number of bunches within ~2 μsec length of beam burst that will reduce the beam intensity. However, to avoid not fully deflected bunches during the rise- and fall-time of the rf chopper, ~2 μsec "gaps" in the beam structure are required. These "gaps" can be produced by a fast chopper which will operate at 0.25 MHz repetition rate (see Regime B in Table 2). Such a chopper is entirely technically feasible. The beam structure downstream of the fast chopper is shown in Fig. 2.

For the actual beam intensity reduction within every ~2 μsec beam burst a dual frequency rf chopper, similar to the device developed at TRIUMF [5] can be used. In this chopper an rf voltage is applied to the deflecting plates. One of the plates have to be biased by a dc voltage $V_{dc}=V_{rf}$, where V_{rf} is the amplitude of the rf voltage. To transport the beam through the chopper without any deflection, the rf chopper should operate at 57.5 MHz in order to compensate for the dc voltage (see Fig. 3a).

Operating at 28.75 MHz the rf chopper will deflect and remove every other bunch (see Fig. 3b). As was indicated

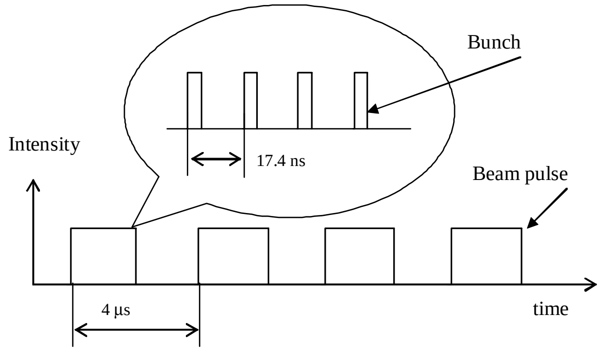

Figure 2: Beam structure downstream of the fast chopper.

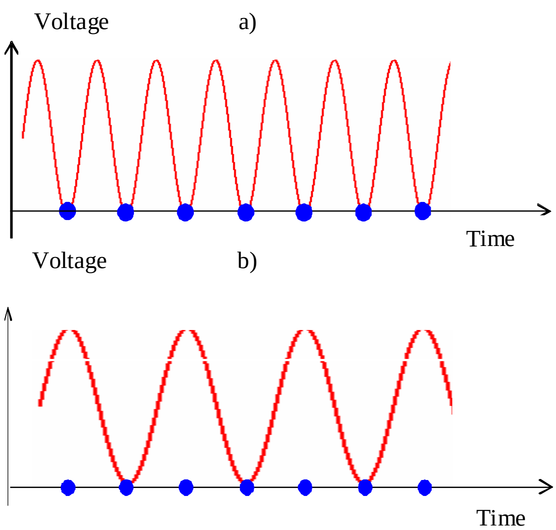

Figure 3: Dual frequency rf chopper with biased plates.

in ref [5], the cosine-wave rf chopper introduces negligible distortion to the beam emittances. To provide beam intensity adjustment to 4 targets an additional dual frequency chopper operating at 28.75 and 14.375 MHz is needed. Two rf choppers and one fast chopper will require ~50 cm space each. Although this design is technically feasible, it significantly complicates the MEBT. Each 50 cm space for the chopper should be supplied by a focusing triplet or a SC solenoid and an rf rebuncher.

MEBT DESIGN

The MEBT matches two-charge state beam to the 6D acceptance of the SRF linac. The MEBT must contain: 1) focusing elements; 2) rebunchers; 3) beam diagnostics tools; 4) steering magnets for simultaneous correction of gravity centers of the two-charge state beams; 5) One or more choppers.

Several options of the MEBT have been studied: focusing by doublets, triplets and solenoids. It was shown that the focusing by SC solenoids is the best system for the transport of two-charge state beams. The solenoidal channel is less sensitive to the charge state and does not introduce additional mismatch of the two-charge state beam. The beam exiting the RFQ is matched to the axial-symmetric channel by three strong electromagnet quadrupoles. The MEBT has been designed by the code TRACE-3D and verified by the code TRACK. Fig. 4 shows transverse envelopes of the deflected and undeflected dual charge-state uranium beam along the MEBT for the case of a single fast chopper.

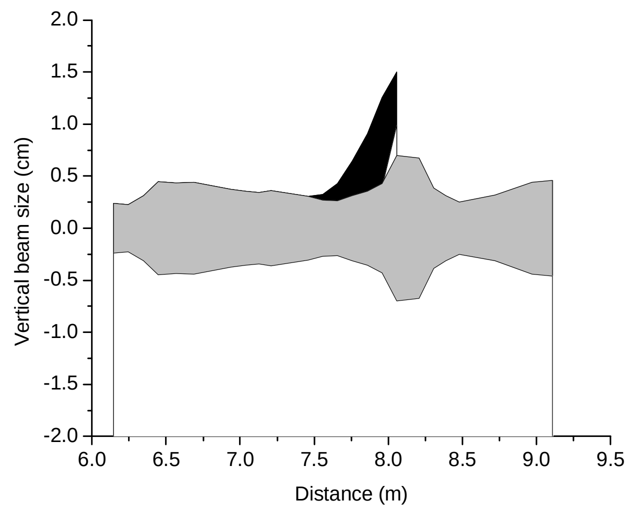

Figure 4: Envelopes of undeflected (gray area) and deflected (black area) beams in the vertical plane along the MEBT. The elements of the MEBT include triplet, SC solenoid, rebuncher, SC solenoid, fast chopper, triplet with slits, rebuncher, and SC solenoid.

CONCLUSION

Several possible solutions for the independent beam power adjustment on four RIA targets are discussed. The most technically feasible solution is a combination of a fast chopper and an rf choppers. However, this solution complicates and increases the MEBT cost by adding more rebunchers and focusing elements. If tested, the fast chopper operating at 28.75 MHz repetition rate can be easily implemented into the MEBT and will keep the overall MEBT equipment simple. However, a significant effort for R&D and prototyping of the fast chopper is required.

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