PERFORMANCE OF BEAM CHOPPER AT SARAF VIA RF DEFLECTOR BEFORE THE RFQ

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Abstract

We describe performance of a beam chopper at the SARAF accelerator consisting of a HV deflector preceding the RFQ. The deflector and electronics, developed at LNS Catania, was designed to provide slow beam chopping for beam testing and diagnostics where low beam power is necessary. The HV deflector sweeps away the low energy beam onto a water-cooled beam catcher, while a fast HV switch momentarily switches off the HV whenever a transmitted beam to the RFQ is desired. We report on measurements with this chopping system, where minimum transmitted beam pulse of 180 ns duration is attained and where individual nano-bunches of the RFQ are visible. Comparisons are made with beam dynamics calculations that simulate the LEBT and the RFQ. The simulations suggest that single RFQ bunch selection can be attained with appropriate alternating positive-negative deflecting HV waveform, where single bunch transmission occurs during the positive-negative crossover.

THE SARAF ACCELERATOR: PHASE I

The SARAF accelerator complex [1] is designed to provide CW proton or deuteron beams of up to 5 mA and 40 MeV. Currently, phase I of SARAF has been installed and has undergone commissioning, and is currently operational for experimental work. SARAF phase I consists of an ECR ion source (EIS), a 176 MHz radio-frequency quadrupole (RFQ), and a prototype superconducting module (PSM). The PSM contains 6 superconducting half-wave resonators (HWR) and 3 superconducting solenoids, and provides acceleration up to about 5 MeV. Figure 1 shows the layout for SARAF phase I, including the EIS ion source and LEBT, the RFQ, MEBT, the PSM and D-plate, and the magnetic beam line transporting the beam either to the beam dump or to target station for experimentation.

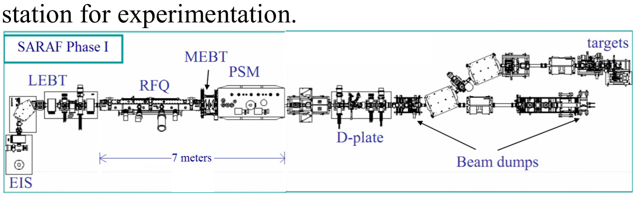

Figure 1: Layout of SARAF phase I showing EIS source, LEBT, RFQ, MEBT, PSM, D- plate, and beam lines.

SLOW CHOPPER AT SARAF

The slow chopper at SARAF consists of deflection plates and electronics developed at LNS Catania within the SPIRAL II program [2] and mounted in SARAF for tests and evaluation. The slow chopper consists of a set of parallel plates on which HV is applied for deflecting a low energy beam at an angle of 20°. For a transmitted beam, a fast switch shuts off the HV for the required beam on-time. The slow chopper was provided to SARAF along with electronics that enable applying a potential of up to 10 kV, and controls for varying the duration, frequency and phase for the off-time. The electronics provided allows for minimum off-time of about 180 ns and maximum switching repetition rate of up to 800 Hz. The slow chopper was installed in the SARAF LEBT between the second and third solenoids. The slow chopper provides a simple mechanism for lowering beam current and/or duty factor without having to pulse the ion source. Pulsing of the beam is especially required in order to tune the high intensity beam when using the downstream beam-destructive diagnostics. Figure 2 shows a schematic diagram of the LEBT and placement of the slow chopper, including the water cooled beam catcher at 20°, and also the RFQ and MEBT.

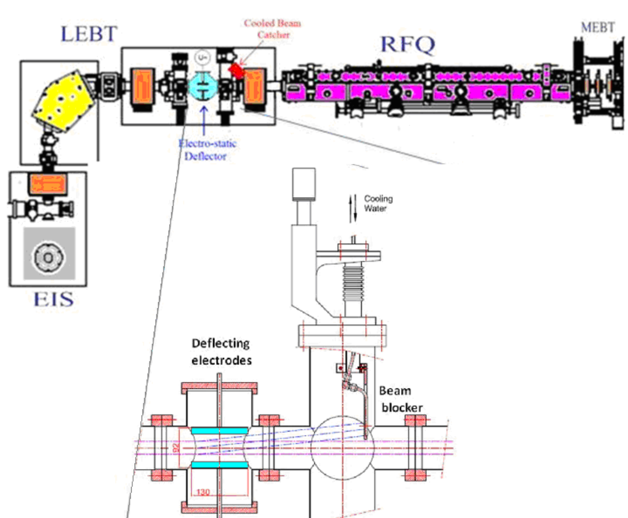

Figure 2: Schematic diagram of the EIS source, LEBT, RFQ and MEBT, with placement of slow chopper and beam catcher in the LEBT. A detailed drawing of the LEBT section containing the chopper and beam blocker is shown in the inset.

The slow chopper was tested with a ~0.5 mA and 2.1 MeV proton beam. The beam was deflected onto the movable water cooled beam catcher positioned at ~20°. The chopper HV was switched off at rate of a few Hz for durations of 10 µs down to ~0.2 µs. The accelerated beam was measured with the beam position monitor (BPM) in the MEBT, consisting of 4 button current pick-up devices, and by a fast Farraday cup (FFC) situated in the D-plate [3]. Figure 3 (top panel) shows the signals on a fast digital oscilloscope with 6 GHz bandwidth. The BPM signal is shown in yellow, and the FFC signal in green. The proton TOF and the distance between the BPM in the MEBT and the FFC in the D-plate are reflected by the separation of their waveforms as seen by the scope. The measured transmitted pulse has a pulse width of about 180 ns. Most prominent are the individual RFQ bunches which are resolved very well by the fast scope. Figure 3 (bottom panel) shows a blow-up where the individual bunches are resolved very well by the FFC. Beam dynamics simulations discussed below show the RFQ bunches to have a bunch width of about 0.3 ns FWHM, corresponding to a phase width of $\Delta\phi \sim 20°$, consistent with the measured bunch widths shown in figure 3.

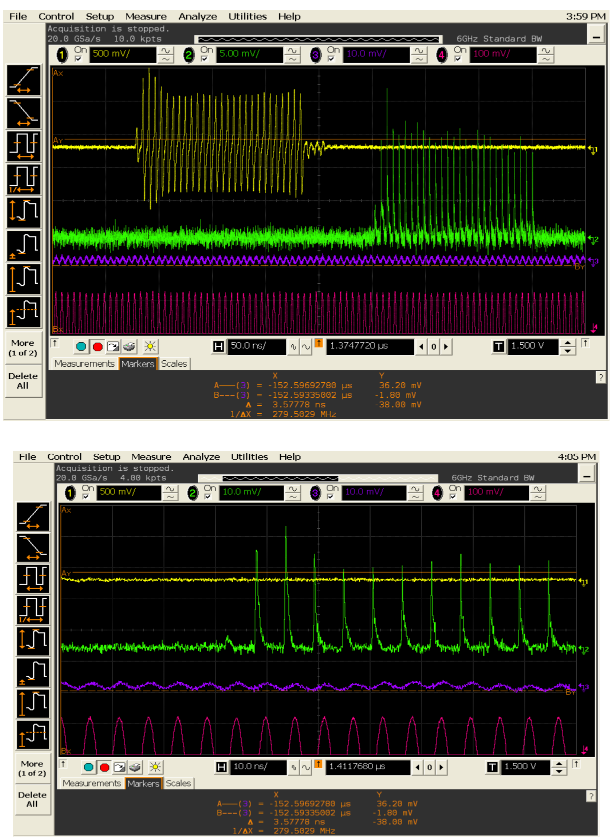

Figure 3: Trace on fast oscilloscope of beam pulse following slow chopper and RFQ. Yellow trace shows BPM (beam position monitor) which is upstream of the FFC (fast Faraday cup) shown in green trace. Red trace is signal from RFQ RF. Beam pulse has width of 180 ns. Individual beam bunches following RFQ are separated by 5.5 ns and have width of about 0.3 ns.

BEAM DYNAMICS SIMULATIONS

Detailed beam dynamics simulations of the SARAF, including the LEBT, RFQ, MEBT, PSM, RF deflector, and beam lines have been preformed to obtain a better understanding of the optics and systematic of SARAF phase I facility. The simulations were performed with the General Particle Tracer (GPT) code from Pulsar Physics, a time-based code includes space charge, an assortment of accelerating and focusing elements, and hooks for providing user supplied elements using c-code based platform. The simulations begin with 20 keV/u proton or deuteron beam from the ion source with normalized transverse emittance of 0.2 π mm-mrad. The RFQ was simulated using a code developed at Soreq [4] and implemented into the GPT simulation package.

Illustration of simulation results are shown in figure 4. To provide a more suitable visualization of the simulations, the SARAF LEBT, RFQ, and MEBT are all displayed along a straight line, where the 90° bend is implied. Figure 4 shows simulated beam entering the RFQ, with the energy development of the beam on the top graph, the transverse development in the bottom graph, and a schematic of the acceleration section in the middle graph for better visualization. Note the transition from DC beam to bunched beam as the beam traverses the RFQ.

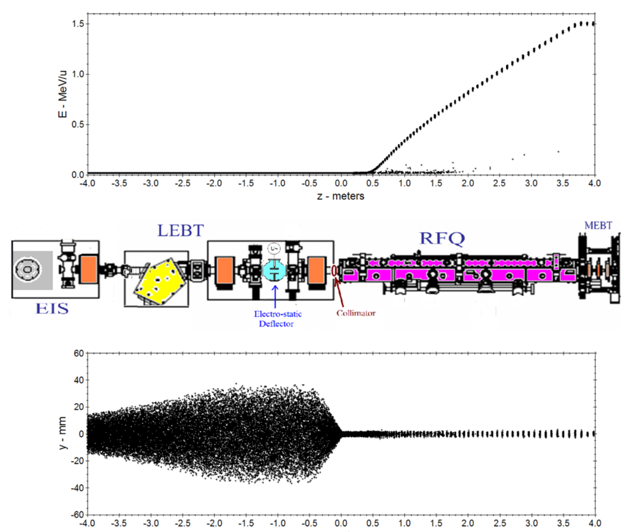

Figure 4: Simulation of CW deuteron beam traversing the LEBT and RFQ. The RFQ bunches and accelerates the beam to 1.5 MeV/u. Top graph shows energy development as a function of longitudinal advance. Bottom graph shows transverse displacement including transverse focusing by solenoids. 90° bend was straightened to facilitate viewing.

SINGLE BUNCH SELECTION

We take advantage of the simulations to investigate possibilities for HV waveforms on the RF deflector that will enable single bunch-selection. RF deflection before the RFQ can be an efficient method for single bunch

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selection since the beam energy is still low and therefore relatively low electric fields and moment arms are required for adequate deflection, and less problematic cooling requirements are foreseen for the beam catcher. Inherent in any pulse selection scheme is proper synchronization with the RFQ RF phase. With the advent of fast high voltage/ high power switching, various deflector pulsing schemes can be possible.

We have found that effective single bunch selection can be achieved by applying an alternating positive-negative HV waveform with a fast switch that can change deflector polarity with a switching time Δt of 80 ns or less. For deuterons at 20 keV/u, a ΔV of ±6kV is required. The switch can be made at any desired repetition rate, provided the HV source and switch can handle the current. In Figure 5, we show again plots and schematic drawing of the LEBT, RFQ, and MEBT, but this time with a positive-negative HV of ± 5 kV applied to the electric-field deflector, and with a switch that changes polarity over a switching time of 40 ns. The electrostatic deflector deflects the unwanted pre-bunches either left or right, with zero net deflection only for the desired pre-bunch, which is focused and transmitted to the RFQ. In the plots, the simulated switching frequency was 3.524 MHz, and so the bunch separation for the transmitted bunches, as shown in figure 5, is 50 βλ.

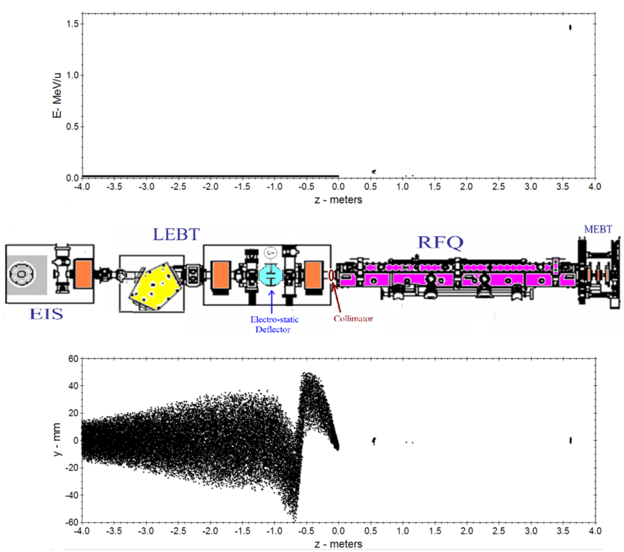

Figure 5: Simulation of a CW beam traversing the LEBT, with alternating positive-negative HV applied on RF deflector, with only non-defleted beam in the HV cross-over surviving to the RFQ. For this simulation, a positive-negative HV of ±5 kV, with a polarity switch of 40 ns at a frequency ot 3.52 MHz. Time snapshot showing beam with two bunches with separation of 50 βλ successfully traverse the RFQ.

DISCUSSION

We report on a slow chopper developed at LNS Catania and installed at the LEBT in SARAF accelerator just before the RFQ. We have shown experimental data taken with a fast faraday cup and peak pickup electrodes using a fast oscilloscope, showing the transmitted non-deflected beam bunch. The data also shows the mico-bunch structure of the beam exiting the RFQ, with 0.3 ns FWHM bunch width consistent with simulations obtained using the GPT particle simulation code.

We have also explored possible HV waveforms on the existing RF deflector which can provide appropriate deflection patterns to enable single bunch selection in the RFQ. We have found that a scheme for alternating positive-negative HV for deflection of the beam, with fast switching between polarities enabling the desired pre-bunch to enter the RFQ at the HV crossover. Detailed simulations show that for applied HV of ±5 kV, with switching speeds of 40 ns or less, efficient single bunch selection can be achieved with more than 60 % transmission for the selected bunch, and less that 3% transmission for the adjacent bunches.

We are now testing electronics that will give us switching speeds of ~10^5 Hz and also with capabilities for alternating positive-negative polarities to allow us to test our ideas for single-bunch selection with the existing HV deflector..

ACKNOWLEDGEMENT

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