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► To cite this version:

Z. Segalov, I. Ben-Zvi. Subnanosecond Chopper-Buncher for a 14UD pelletron. *Revue de Physique Appliquée*, 1977, 12 (10), pp.1575-1577. 10.1051/rphysap:0197700120100157500 . jpa-00244370

HAL Id: jpa-00244370

<https://hal.science/jpa-00244370>

Submitted on 1 Jan 1977

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SUBNANOSECOND CHOPPER-BUNCHER FOR A 14UD PELLETRON (*)

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Résumé. — Un nouveau système hacheur-groupeur est en construction pour le Pelletron 14UD de Rehovot. On décrit les calculs de dynamique de faisceau pour ce système. L'ultime performance pour des ions Ni est de 100 picosecondes par impulsion, avec un taux de répétition de 4 MHz et une transmission de 15 % de l'intensité en courant continu.

Abstract. — A novel chopper-buncher system is under construction for the Rehovot 14UD Pelletron. Beam dynamics calculations of that system are described. The ultimate performance for nickel ions is 100 picoseconds pulse, at a repetition rate of 4 MHz, and transmission of 15 % of the d.c. beam current.

The beam dynamics of a chopper-buncher system is discussed. This system was designed to operate in the 14UD Pelletron electrostatic accelerator. Its ultimate goal is to bunch ion beams from protons to about nickel to better than 100 picoseconds pulse width. The performance of the system was calculated numerically using a computer code named TLBD.

The pulsing system comprises of three units. A chopper and a prebuncher preceding the low energy tube, and a superconducting cavity buncher at the target area.

The beam dynamics program TLBD simulates the ion optical system from the ion source up to the target area. All the optical components are introduced in the thin lens approximation. The trajectory of a particle crossing an optical element is replaced by a fictitious one, in which the whole change in its path (in longitudinal and both transverse planes) occurs in the median plane. The elements accepted by the program are: drift space, quadrupole singlet, deflection magnet, accelerating tube, gas or foil stripper, aperture, rf-deflector and acceleration gap.

The program generates a set of particles uniformly distributed in a six dimensional phase space volume. This volume is bounded by an ellipse in (x, x') , a rectangle in (E, t) and another ellipse in (y, y') .

The new coordinates of each particle, as it goes through an optical element, are calculated individually. This procedure allows the inclusion of non-linear terms in the description of the various elements, as well as coupling between any two subspaces of phase space.

The set of particles is moved through the machine element by element, and its distribution in phase space can be plotted at any point.

To simulate the beam of the 14UD Pelletron at Rehovot, we ran particles through the structure composed of the elements given in table I.

The first four elements in table I constitute the chopper. This deflector-redeflector chopper [1] corrects to first order energy and deflection modulations of the beam. The two deflectors require the same rf-field strength, and are in phase relative to a standard particle. The thin lens at the chopper's center has a focal length equal to one quarter of the total length of the chopper. Therefore this lens images the beam from the deflector to the redeflector with a negative unity magnification. That is, transverse position and angle of a particle at the deflector, repeat with inverted signs at the redeflector. This together with the phasing of the two deflectors, results in a cancellation of their contribution to the energy and angular deflection of each particle. The energy spread which the beam has in transit between the two deflectors, produces a small phase mismatch, which leads to a residual energy and deflection modulations after the redeflector. However, these residual errors are much smaller than those made by a conventional single deflector chopper.

As can be seen in table I, the prebuncher is located only 50 cm above the low energy tube entrance, since the final pulse width decreases with this distance. The prebuncher is made of two subunits: the main accelerating gap and a third harmonic unit. By a proper choice of the voltages applied to the two gaps, the velocity modulation waveform approaches linearity in a given phase range. It was found that over a range of $\pm 35^\circ$ (at the prebuncher's frequency) the non-linea-

(*) Work supported by the United States-Israel Binational Science Foundation under Grant 926.

TABLE I
A list of the optical elements and their parameters for a mass 60 beam

Element	Length	Strength	Frequency (MHz)	Drift length to next element (cm)
rf-deflector	<i>l</i> 15.5	575 V/cm	2.0	100
slit	<i>D</i> 0.5			
lens	<i>f</i> 50			100
rf-deflector	<i>l</i> 15.5	575 V/cm	2.0	195
quadrupole triplet	<i>l</i> 98			208
buncher		11.65 kV	4.0	
buncher		— 1.06 kV	12.0	50
acceleration tube	<i>l</i> 432	— 7 MV		
quadrupole triplet	<i>l</i> 58			
acceleration tube	<i>l</i> 432	— 7 MV		60
carbon foil stripper	<i>t</i> 2.0			290
acceleration tube	<i>l</i> 864	14 MV		273
quadrupole doublet	<i>l</i> 80			611
90° analyzing magnet	<i>ρ</i> 127			624
quadrupole doublet	<i>l</i> 80			1 123
quadrupole doublet	<i>l</i> 80			825
switching magnet (60° line)	<i>ρ</i> 117			250
quadrupole doublet	<i>l</i> 40			200
buncher		280 kV	420.0	300
target				
<i>l</i> — length, cm				
<i>f</i> — focal length, cm				
<i>D</i> — aperture half width, cm				
<i>t</i> — thickness, μg/cm ²				
<i>ρ</i> — radius of curvature, cm				

rity error of the prebuncher had a negligible contribution to the final pulse width.

The velocity modulation is calculated to achieve a complete bunching at the stripper. Terminal voltage fluctuations may deteriorate the quality of the bunched beam, but due to the Pelletron's excellent stability, this effect was of no importance. At the stripper, energy straggling wipes out the velocity modulation. However, the beam is already fast enough so as to be unaffected by it.

A serious source of pulse temporal spread is the 90° analysing magnet, and to a lesser extent the switching magnet. The effect of the magnet on the pulse width increases with the transverse phase space area. The transverse emittance couples to the longitudinal emit-

tance in a number of other elements, in particular the chopper and the bunchers.

The system was designed to operate satisfactorily for ions of mass 60, at the maximal acceptance of the Pelletron. For lighter ions the performance improves since they can be produced with a smaller emittance.

The superconducting buncher is located near the target in order to prevent pulse spreading due to the intrinsic energy spread of the beam. The high operating frequency dictates an input pulse shorter than 1 nanosecond for a final bunching to about 100 picoseconds.

The performance of the chopper buncher system was tested in two cases, summarized in table II.

The emittance values of table II correspond to two

TABLE II
Beam parameters

	Beam a	Beam b	Units
Particle mass	60	35	amu
Initial energy	120	120	keV
Initial energy spread	0.12	0.12	keV
Transverse emittance	25	8	mm. mrad. MeV ^{1/2}
Charge state after stripping	12	10	

common ion sources: a sputtering ion source in (a) and a duoplasmatron in (b). The pulsed beam average current was required to be 15 percent of the d.c. current at the given emittance.

The chopper slices the beam to 50 ns long pulses. The initial energy spread, and the transverse emittance of the beam were practically not impaired by the chopper.

The pulse width of the bunched beam (at the stripper) was largely due to the initial energy spread while the buncher contributed only a slight temporal spread resulting from non-linearity in its waveform. The nickel ions are bunched at the stripper to a pulse whose standard deviation is 0.155 ns of 0.65 ns. The chlorine beam is bunched to a somewhat shorter pulse of 0.55 ns whose standard deviation is 0.12 ns. The energy spread introduced to the beam by the energy straggling at the stripper converts into time spread through subsequent drift. However, this spread is small compared with the effect of the 90° analyzing magnet which follows. This magnet increases the standard deviation of the nickel pulse from 0.165 ns to 0.235 ns and of the chlorine pulse from 0.14 ns to

0.20 ns. The spread which the magnet causes increases rapidly with the beam transverse emittance. A possible improvement is an isochronous operation of the analyser.

The switching magnet is the last element which increases the pulse width. However, its effect is small (6 % increase for nickel).

All over the target area, the nickel beam is available with a pulse standard deviation of 0.25 ns, and fully contained within 1.6 ns. The chlorine beam is available with a pulse standard deviation of 0.2 ns and total pulse width better than 1 ns. One line of the switching magnet includes a superconducting cavity buncher for the final bunching stage. At the target position the nickel beam has a standard deviation of 45 picoseconds, and the chlorine beam 17 picoseconds. While the chlorine beam pulse is fully contained in 80 picoseconds, the nickel pulse has a long tail. Overbunching the nickel beam will result a pulse, 99 % of which is contained within 100 picoseconds. Otherwise the FWHM is 20 picoseconds, but the pulse tails reach out to ± 0.5 ns.

References

- [1] BEN-ZVI I., to be published in Particle Accelerators.
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