BEAM DYNAMICS STUDIES FOR THE LOW ENERGY SECTION AT MAFF*

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Abstract

For the LINAC of the Munich Accelerator for Fission Fragments (MAFF) a new scheme for the low energy section has been proposed in order to fulfill new experimental requirements, such as time spacing between bunches and low longitudinal emittance. The proposed solution consists in a combination of an external multi-harmonic buncher with a traditional RFQ with a shaper and an adiabatic bunching section included where the employment of the external buncher is upon request from the experiment. The matching section downstream the RFQ has been redesigned in order to allow room for the installation of a beam cleaning section for a proper injection into the following DTL. Details about the optics and the beam dynamics studies of the low energy section are presented in this paper.

INTRODUCTION

By the use of the new FRM-II reactor as a source of neutrons for production of radioactive isotopes, the MAFF project aims to be one of the most intense accelerated radioactive ion beam facility in the world. The isotopes produced are first ionized [1], then cooled [2], separated, injected into a charge breeder source [3] and finally they will be injected into the accelerator. In Fig. 1 is shown a part of the layout foreseen for MAFF. The first stage of the acceleration chain for MAFF consists on a multi-harmonics buncher and a 101.28 MHz IH-RFQ. The injection energy of the machine is 3 keV/u and the final energy is 300 keV/u. The maximum mass to charge ratio is A/q=6.3, and the duty cycle is 10%. The maximum transverse emittance considered for beam dynamics is $\beta\epsilon_t = 0.2\pi$mm mrad, a value that in case of a cooled beam is 20 times larger. For the low energy transport, the optics has been calculated with a geometrical emittance of $\epsilon_t = 100\pi$mm mrad, and the same value has been used for the initial transverse emittance of the RFQ. Downstream the RFQ a chopping section has been integrated together with the matching to the following accelerating stage. A strong re-bunching will be needed in order to inject the beam longitudinally with a very low phase spread into the IH-DTL.

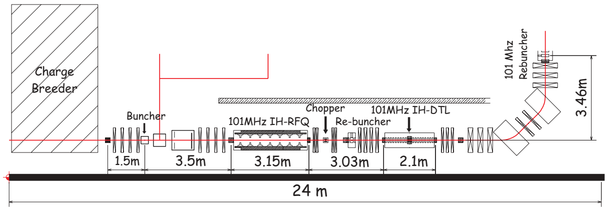

Figure 1: MAFF layout - low energy area.

LEBT

Since the request of the installation of a separate multi-harmonics buncher upstream the RFQ, the Low Energy Beam Line has been modified. The concept of the new LEBT is based on 3 modules. The backbone of the transport is a FODO cell with a phase advance of 90° degrees per cell. The other modules are insertions made out with triplets for creating waists e.g. for the buncher, and lastly a single RFQ matching section consisting in 4 quadrupoles. The envelopes shown in Fig. 2 considers only the transport in a straight line which should connect the mass separator of a charge breeder source or of an off line ion source to the RFQ. The advantage of having such modules is that is possible to transport the beam by means of very few knobs, being all the symmetric quadrupoles lenses designed to have the same voltage. This has also an impact on the cost of the beam line, since in principle is possible to connect several lenses in parallel with the same power supply. In order to allow some corrections, steering plates will be used at front-ends of every modules. As for the optional case of a transport to a low energy experiment area, then the switchyard should be positioned just upstream this straight line.

The optics has been calculated at the 1st order, higher order calculation will follow as soon as a definite layout will be established. For the quadrupoles we have considered only elements with a bore radius of 50 mm and with a length of 100 mm. The maximum voltage never exceeds the 6 kV limit which is due mainly to the cost of the power supply. As the only exception, the last quadrupole before the RFQ has a radial aperture of 25 mm and a length of 50 mm. This is because the beam required by the RFQ is highly convergent (100 mrad for an emittance $\epsilon_t = 100\pi$mm mrad) and a short final quad avoids the beam to become too large in the second-to last quadrupole. The matching section is actually the most critical part of the transport channel, since a bigger emittance would definitely cause distortion and beam loss.

THE MULTI-HARMONICS BUNCHER

The aim of the multi-harmonics buncher is to produce a time spacing between bunches of around 80 ns. Since the frequency of the RFQ is fixed to $f_0 = 101.28$ MHz, the choice of the fundamental frequency for the buncher has to be one of the sub-harmonics. We have chosen the 8th sub-harmonics of f_0 corresponding to a frequency of 12.66

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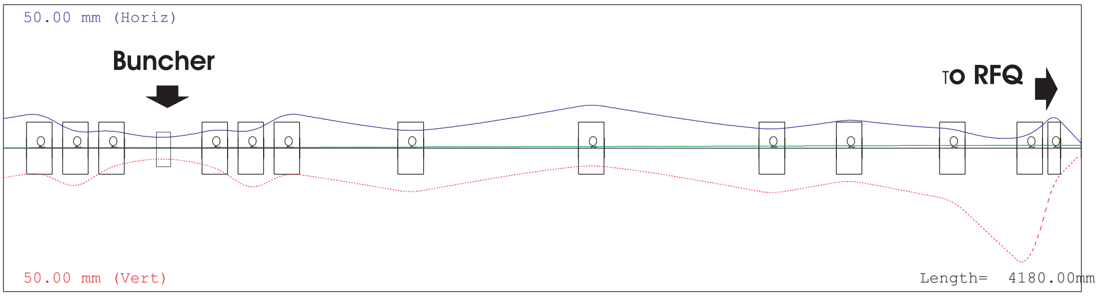

Figure 2: Beam envelopes in mm for $\epsilon = 100\pi\mu m$ through the straight line of the LEBT. The upper trace is for the horizontal plane, the lower one is for the vertical plane.

MHz. Since the low energy of the ions and the low energy spread acceptance of the RFQ, the voltages requirements are very low, in the range of few hundreds of volts, the buncher can be made out with a very simple structure using two circular plates with a beam aperture in the center and superimposing the harmonics connecting directly the plates to a broad band amplifier.

Electrostatic fields have been calculated for the simple structure described above by mean of `EM Studio` and then a simple 3D integration routine has been written within `EXCEL` visual basic macro for solving the motion equation for the case of oscillating fields with 3 harmonics. The single gap structure optimized has a full gap distance of 8 mm and a radial aperture of 7 mm. This choice it's a trade-off between sufficient large aperture and good efficiency in term of transit time factor. The numerical analysis of the fields shows that the linear region is within 4 mm of the radial aperture [4].

Simulation and numerical integration of the longitudinal motion equation has been performed and the results has been used for input the `PARMTEQ` program for the dynamics of the RFQ. Fig. 3 shows a final longitudinal phase space portrait after the multi-harmonics buncher for a initial DC beam.

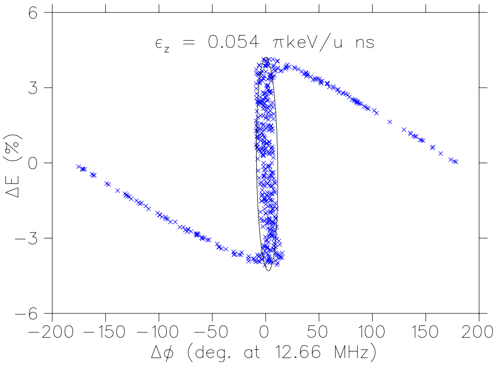

Figure 3: Longitudinal phase space portrait of a DC beam after the multi-harmonics buncher. The energy spread ΔE shown in the figure is for a case where the time focus is 1m downstream the buncher. In general $\Delta E \propto 1/d$ where d is the focus distance.

RFQ BEAM DYNAMICS

The guiding lines for the design of the RFQ were a very high transmission keeping as low as possible the final longitudinal emittance, which is really helpful for the following accelerating stage, an IH-structure working at $0°$ deg synchronous phase. In Tab. 1 are listed the main parameter of the machine.

Table 1: RFQ parameters.

Frequency (f_0)	101.28	MHz
Inter-Vane Voltage (V)	64.52	kV
Max A/q ratio	6.3	
Aperture (a)	2.64-3.71	mm
r_0 value	3.65-4.91	mm
modulation factor (m)	1-2.4	
Initial Energy E_i	3	keV/u
Final Energy E_f	300	keV/u
N. of cells	295	#
Total Length (L)	2810	mm

Fig. 5 shows the machine parameters chosen for the RFQ. The general design philosophy was to use a higher focusing parameter then, for example, of the REX-ISOLDE RFQ [5], so that the transverse phase advance per cell was $\sigma_t = 40°$ deg. This setting has the advantage that the beam is smaller in between the electrodes and in general even in the case of large emittance the transmission is always close to 100%. Another aspect of the design is that the bunching section was kept a little longer than what is required and the acceleration stage is split into two parts, one with the synchronous phase ramping from $\phi_s = -22°$ deg to $\phi_s = -18°$ deg. The reasons for the choice of these settings of the RFQ was for the first to have a high longitudinal capture/acceptance and hence to be able to accelerate already a bunched beam and to form a low longitudinal emittance, and for the second to short the RFQ as much as possible without compromising the longitudinal beam quality also for a reduced transverse focusing strength. Lastly, the combination of a initial strong transverse focusing with a delayed acceleration section avoids the crossing of the longitudinal and transverse phase advances, and hence the risk

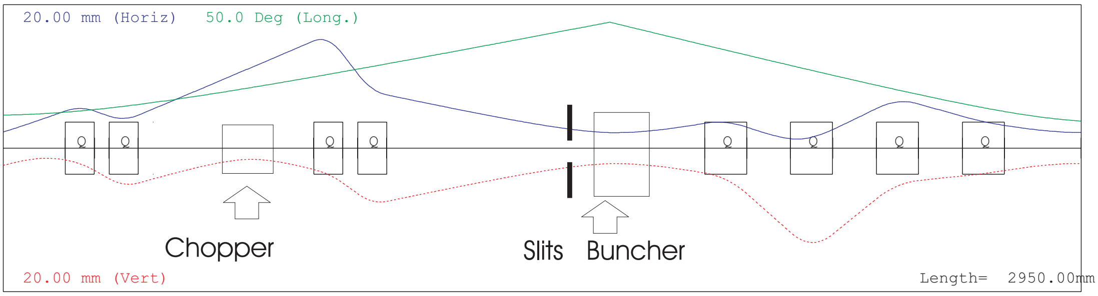

Figure 4: Beam envelopes in mm for $\epsilon_t = 25\pi\mu m$ and for $\epsilon_t = 0.26\pi$ deg MeV in the MEBT. The green trace represents the phase envelope, while the blue and the red one represents respectively the horizontal and the vertical plane.

of the parametric resonances.

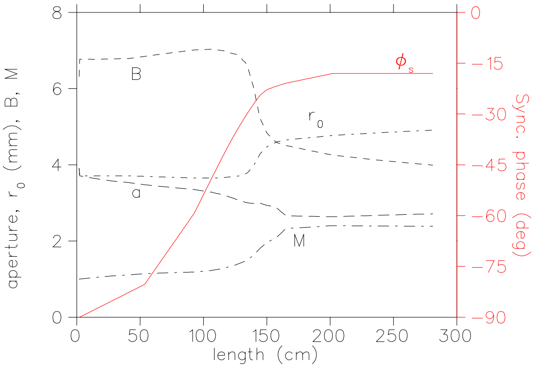

Figure 5: Machine parameters for the MAFF IH-RFQ.

As for the output longitudinal emittance Fig. 6 and Fig. 7 shows the phase and energy distribution in the case of a continuous and pre-bunched injected beam. In the latter case the longitudinal emittance calculated for 90% of the particles is equivalent to $\epsilon_l = 0.2\pi$ deg MeV, while for a c.w. beam $\epsilon_l = 0.4\pi$ deg MeV. The reduction of longitudinal emittance is at expenses of the transmission: only 75 % of the beam if accelerated in the correct bucket, the rest is still transported trough the RFQ, but it will be chopped away in the following cleaning section.

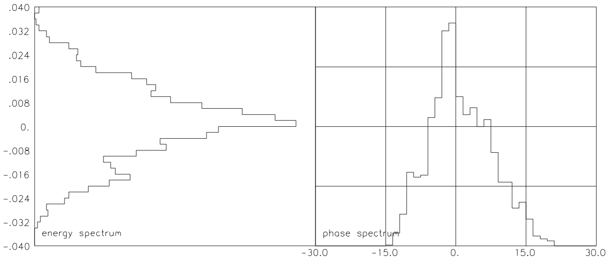

Figure 6: Longitudinal phase and energy distribution of a continuous injected beam.

MEBT

The longitudinal particle distribution (per cycle) outside the RFQ when the low frequency pre-buncher is active will consists in a main bunch with 70% of particles inside, while the remaining 30% will be spread into 7 other bunches, separated in time by nearly 10 ns. In order to have a *clean* time distance between main bunches a chopper is required. Fig. 4 shows an example of a possible MEBT. The diverging beam from the RFQ is focused by means of a doublet, where in correspondence of a vertical waist a chopper will be installed. The chopper will deliver a deflection of a minimum 5 mrad, and the voltage required will be of 15 kV. The slits that intercept the chopped beam are positioned 1 m downstream the line. Another doublet focuses the beam inside a 101.28 MHz re-buncher which will provide the time focus necessary for the next accelerating structure. Lastly four quadrupoles will assure a good transverse matching. The quadrupole considered for the 1st order calculation have length of 80 and 115 mm. The maximum pole field is below 1.2 T.

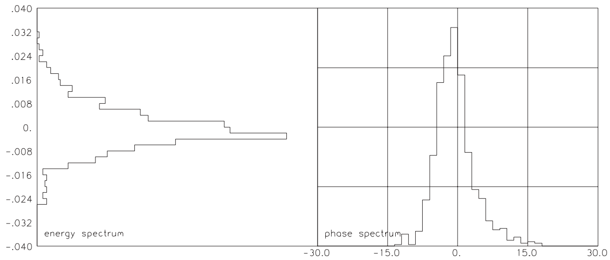

Figure 7: Longitudinal phase and energy distribution of a pre-bunched injected beam.

REFERENCES

[1] O. Kester, *et al.*, **NIM** B 139, (1998) 28.

[2] S. Heinz, *et al.*, “A Radio Frequency ring electrode cooler for low-energy ion beams”, to be published in NIM A

[3] http://www.ha.physik.uni-muenchen.de/okester/eunet

[4] M. Pasini, “Pre-RFQ Buncher Studies” Internal Note, August 2003.

[5] T. Sieber, *et al.*, “Design and Status of the REX-ISOLDE RFQ” Proc. LINAC conf. 1998