CONSIDERATIONS ON PARTICLE DYNAMICS IN A HEAVY ION DTL*

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Abstract

In heavy ion inertial fusion scenarios presently discussed, a long linac is proposed for the acceleration of intense beams of singly charged heavy ions, e.g. Bi^+ or Pt^+. A particle dynamics layout of a conventional DTL has been attempted with respect to low emittance growth at high transmission for beam currents up to 400 mA. Design aspects and first results of single particle beam dynamics calculations will be presented.

1 LAYOUT OF THE LINAC

In the HIDIF (Heavy Ion Driven Ignition Facility) scenario [1] the formation and acceleration of an intense $^{209}Bi^+$ ion beam (400 mA current) with a transverse emittance of 1.2 π mm mrad (full, normalized) is required for injection into some following storage rings at an energy of 50 MeV/u. The beams from 8 or 16 identical ion sources have to be captured, accelerated and merged together in successive funnelling steps, to produce such a high current.

The beam behaviour has been investigated in a 200 MHz Alvarez DTL taking some advantage from a preliminary study performed in Frankfurt in the framework of INTAS 94-1713 [2].

The same focusing scheme of Ref. [3] was adopted: each period is formed by five quadrupoles of the same sign followed by five quadrupoles of the opposite one (FFFFFDDDDD) in order to limit the maximum magnetic gradient required and to get a smoother focusing. The strength of the quadrupoles decreases linearly with the distance, while their length increases, the product being kept constant. The maximum pole tip field is 1.15 Tesla at a bore hole radius of 1.6 cm.

The electrical field amplitude was set to 3.0 MV/m, leading to a calculated shunt impedance of 26 MΩ/m, which is a reasonable value. The input synchronous phase, its slope along the linac and the injection energy have been varied to study their influence on the beam behaviour. The generation of the linac for the particle dynamics calculations was done with the computer programs CLAS and GENLIN; beam dynamics calculations were done with MAPRO.

2 RESULTS

At first, an injection energy of 4.73 MeV/u was chosen (β= 10%), with an injection synchronous phase linearly decreasing from -40^o to -21^o The input emittance was set to 0.5 π mm mrad (full, normalized) in both transverse planes.

The transverse input parameters were chosen in the middle of the third quadrupole of a same sign, for better matching conditions ($\alpha_x = \alpha_y = 0$); betatron amplitudes are $\beta_x = 13.0$ m, $\beta_y = 6.5$ m. The bunch full length is 54^o; the momentum spread is *dp/p*= 0.23%. From the above parameters, input emittances were generated using a waterbag random distribution.

For a first check, due to limited storage capacity, only 1000 particles were tracked on the first 900 cells of the linac. Especially in the longitudinal phase space, filamentation occurred rather soon, resulting in a not acceptable emittance growth. Keeping the beam input parameters, the electrical field strength and phase fixed, only the choice of a higher input energy was possible to enlarge the longitudinal acceptance.

In a next step, the injection energy was increased to 10 MeV/u, and synchronous phase is now decreasing exponentially rather than linearly to gain acceleration rate. The input transverse emittance was raised to 0.75 π mm mrad, giving still some space for emittance increase due to errors and misalignments.

The linac is made of 9260 cells (14.5% < β < 31.4%), corresponding to a length of about 3 km. A first check with 1000 particles, tracked all along the linac, gave less filamentation and better symmetry, with rms emittance growth at the output of $\Delta\varepsilon_x/\varepsilon_x = 4\%$, $\Delta\varepsilon_y/\varepsilon_y = 8\%$, $\Delta\varepsilon_z/\varepsilon_z = 15\%$.

The following table summarizes the linac and the beam parameters.

Table 1

Mass number	209 (Bi^+)
Frequency	200.0 MHz
Mode	2π
Current	400 mA
Injection energy	10.0 MeV/u
Electric field	3.0 MV/m
Initial phase	-40.0^o
Final phase	-21.0^o
Final energy	50.0 MeV/u
Number of cells	9260
Total length	3192 m
Total energy gain	40.0 MeV/u
Shunt impedance	26 MΩ/m

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Then the number of particles was increased to 5000, to improve space charge calculations; unfortunately this is quite time consuming. Figure 1 shows the development of the emittance along the first half of the DTL for 5000 particles (—), compared to the case of 1000 particles (- - -). Figure 2 shows a good emittance shape but also indicates some halo formation.

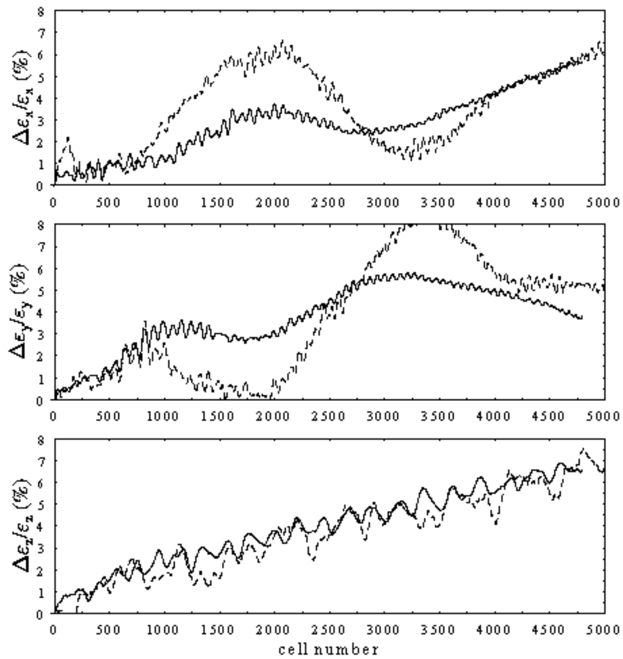

Figure 1: rms emittance along the linac (1000/5000 particles).

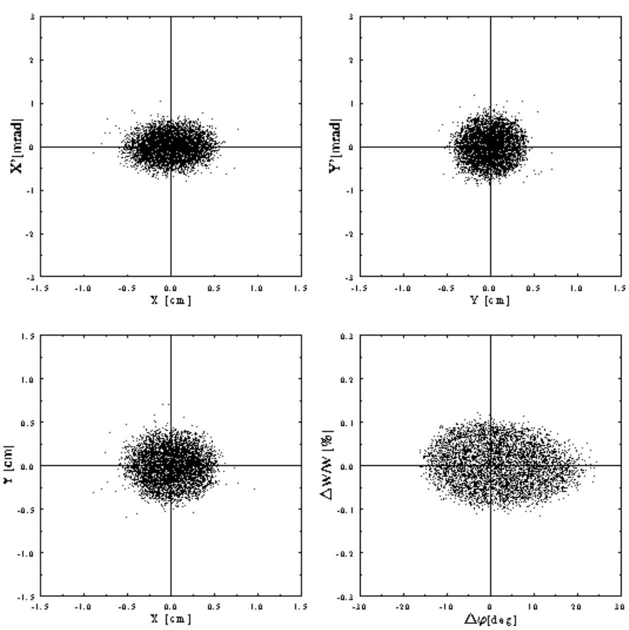

Figure 2: output emittances after 4800 cells (5000 particles)

This can also be seen in Figure 3, in which the total emittance is plotted for 100%, 99.9%, 99% and 95% of the particles, for 5000 particles, for the section from cell number 2000 to cell number 2400, as an example.

Only a few particles contribute to the emittance growth: the emittances for 99% are already rather smooth. A big contribution comes from only a small fraction of the beam. The ratio between full and rms emittance is always smaller than 10.

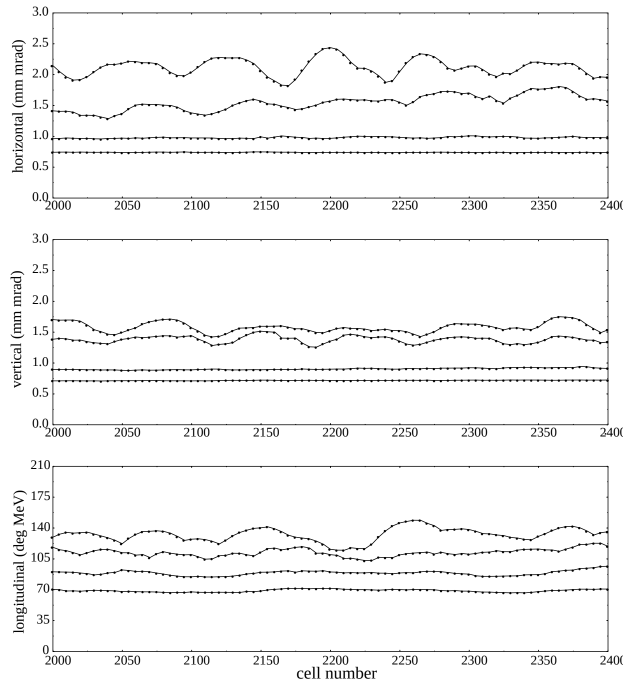

Figure 3: total emittance on a part of linac (5000 particles).

3 CONCLUSIONS

Preliminary results show that a 400 mA DTL, accelerating heavy ions from 10 to 50 MeV/u is feasible, with 100% transmission and a small rms emittance growth. The calculated shunt impedance is 26 MΩ/m; the total length is about 3 km.

These results can be considered as a starting point for further optimization (e.g. fine tuning of the quadrupole gradients) and for the design of a realistic structure.

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