

180 DEGREE BENDING SYSTEMS FOR HIGH CURRENT HEAVY ION LINACS

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Abstract

Recirculated linacs allow to reduce significantly the space and cost requirements. In this paper the possibilities of 180° bending arcs at 5 MeV/u with a ion mass to charge ratio of 100 are studied for a heavy ion linear accelerator and at high beam load. The arc is placed between two linear accelerator sections and, hence, should maintain the microbunch structure of the beam, i.e. a 1:1 imaging is requested both in transversal and longitudinal plane. Space charge and dispersion effects must be considered carefully. Simulations with beam currents up to 100 mA resulted in modest emittance growths. The 95% transverse beam dimensions are up to 15 mm horizontally and vertically. The beam dynamics calculations based on a modified version of LORASR (particle tracking code for KONUS heavy ion beam dynamics, including dipoles) are presented and discussed here.

1 INTRODUCTION

High intensity heavy ion beams in the few hundred mA range and with normalized transverse emittance areas around 0.5π mmrad are on the horizon now for lowly charged ions, from ion sources like CHORDIS or MEVVA. Funneling along the low energy linac part will be included. Projects like "heavy ion inertial fusion", "secondary beam generators", etc. need linac voltage gains in the range between 3 GV and 10 GV. In these cases especially 180° bending arcs are of interest to get a compact linac design. Fig.1 shows schematically two cases. The improved geometric array of the installations on a facility site is obvious and should offer possibilities for a considerable cost reduction with respect to investment and maintenance.

Additionally, linac upgrades at existing facilities could in some cases be done in a cost effective way by recirculating the beam back into the existing linac tunnel (Fig.1, bottom). A characteristic feature of heavy ion machines is the low beam energy, where processes like funneling and beam bending have to be performed. This paper investigates a 180° arc at a beam energy of 5 MeV/u. A medium-term application could be the recirculation of the GSI-Unilac beam at that energy, namely if a post acceleration of beams from the 1.4 MeV/u High Current Injector [1] would be requested. This would allow for a injection of lowly charged, intense

heavy ion beams into a future GSI 200 Tm synchrotron which is considered as a serious option for a facility extension.

At present, the U^{4+} beam is stripped at 1.4 MeV/u into U^{28+} with an efficiency of 12% only before injection into the Alvarez section of Unilac. Besides on improvement of one order of magnitude in beam intensity, also the space charge limit of stored ions in a synchrotron increases proportionally to A/q^2 , if stripping processes can be given up. Assuming a constant synchrotron injection energy, the linac has to provide a rather high voltage gain. This gives the motivation to study 180° bending arcs for low energetic, intense heavy ion beams in detail.

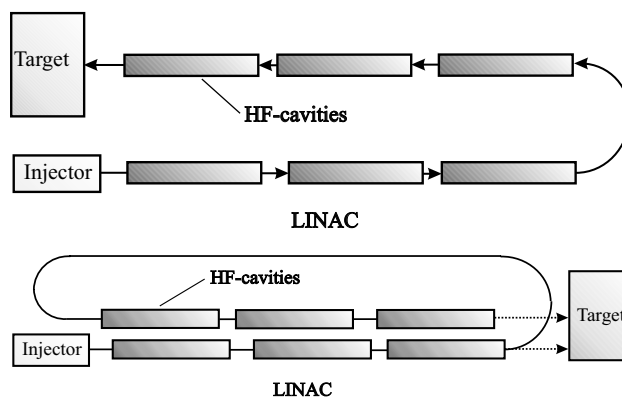


Figure 1: Anti-parallel and parallel configuration

2 LORASR

The LORASR code serves as a flexible and fast tool to generate drift-tube structures for ion accelerators, up to $\beta \sim 0.5$ typically. For the study of high current beams the space charge effects are taken into account by particle-particle interaction. A straightforward strategy is used to investigate a transversal and longitudinal beam dynamics, where the difference in energy between the synchronous particle and the centre of the transported particle pulse is used as an additional free parameter (KONUS - Combined Zero Degree Structure beam dynamics [2]). Recently LORASR code was successfully used for planning and optimizing the new prestripper section of Unilac.

In connection with this study, which investigates heavy ion linac designs with beam recirculation, it was necessary to include an algorithm for bending dipole magnets with fringing fields in LORASR.

3 DIPOLE ROUTINE FOR LORASR

A new dipole routine was developed and implemented. The particle motion through constant dipole fields is solved by the standard theory of Taylor's multipole expansion in a 6D-phase space and by applying the matrix formalism. First- and -second order coefficients were evaluated via a Green's function integral. The whole theory was described in detail by K.L.Brown [3].

Each dipole is defined by the bending radius, bending angle, quadrupole and sextupole coefficients and optionally by 6 parameters defining the entrance and exit fringing fields. The number of calculation steps per unit length has to be chosen carefully in case of high beam current.

Different options for the description of fringing fields were studied. Finally, the method of impulse approximation was selected [3].

The coordinates of selected single particles with defined starting condition are read out and plotted. This allows the study of dispersion effects.

4 BENDING ARC LAYOUT

Bending arc layouts were designed for two versions, a room temperature (*rt*) and a superconducting (*sc*) one (Fig.2). The assumed beam parameters at the entrance of the bending arc and the design magnetic fields are given in Tab.1. The appropriate rebuncher frequency $f = 150$ MHz was chosen, which corresponds to the suggested linac rf frequency at that section.

In order to get the best imaging at the arc exit, the quadrupoles, dipole magnets and bunching cavities are integrated into a periodic structure, that offers focusing in the longitudinal and transversal planes and bending in the x-plane.

A first design without re-buncher cavities was based on the well-known achromatic bending system, that offers a

(1:1) transversal plane imaging in the centre of the bending line. It means, that the whole bending arc consists of two achromats.

Tab.1 Input parameters for the bending arcs

| | room temperature | super-conducting |
|-----------------------------------|------------------|------------------|
| B_{max} [T] | 2 | 6 |
| I_{max} [mA] | 100 | 100 |
| A/q | 100 | 100 |
| W [MeV/u] | 5 | 5 |
| $\Delta W/W$ [%] | 0.2 | 0.2 |
| $\epsilon_{x,y}$ [π mm*mrad] | 5 | 5 |
| ϵ_x [keV/u*ns] | 2.8 | 2.8 |
| f [MHz] | 150 | 150 |
| ϕ_x [deg] | -90 | -90 |

The system was analysed by the Courant-Snyder theory for FODO channels with dipole fields. Then the rebuncher cavities were included in every period and amplitudes were set to conserve additionally energy imaging (1:-1) in the centre of the line. In this way the chromatic aberrations from the first and second part of the line were cancelled. Quadrupole gradients were also corrected due to the rf-defocusing. This system is limited because of the non-linearity of the cavity fields. Therefore the amplitude and transit time factor profiles must be checked carefully.

Gap voltage amplitudes from 0.26 MV to 0.5 MV (*rt* case case, 6 gap rebuncher) and from 0.6 MV to 0.9 MV (*sc* case, 8 gap rebuncher) were required for beam currents varying from zero current to 100 mA.

Typical oscillations of the beam envelopes in x-, y-, W-, ϕ -planes at 50 mA for the *rt* layout are given in Fig. 3. The dispersion effects can be seen very clearly from the dispersion curve in the x-z plane.

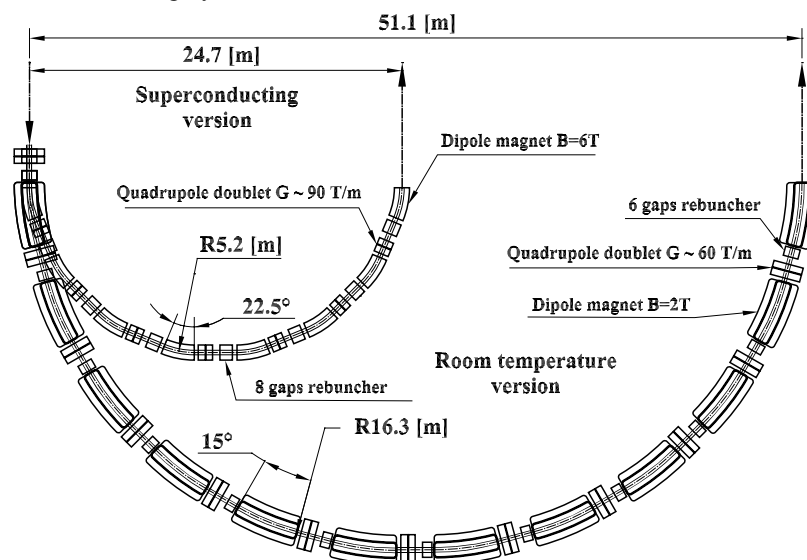


Figure 2: Room temperature and superconducting layout of a 180° arc for A/q = 100, W = 5 MeV/u.

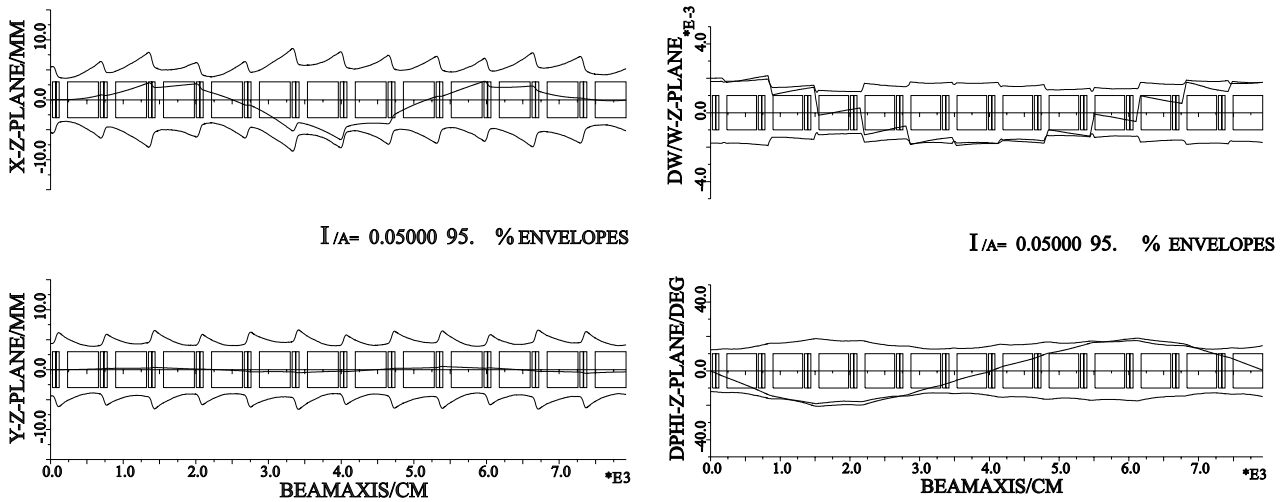


Figure 3: Envelope oscillations in x, y, W, ϕ planes along the rt 180° arc.

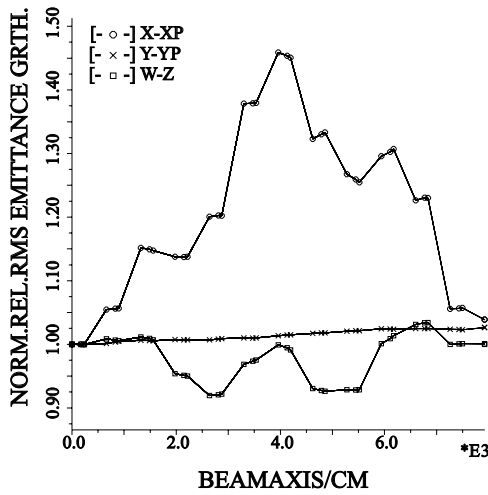


Fig 4: rms emittance growth.

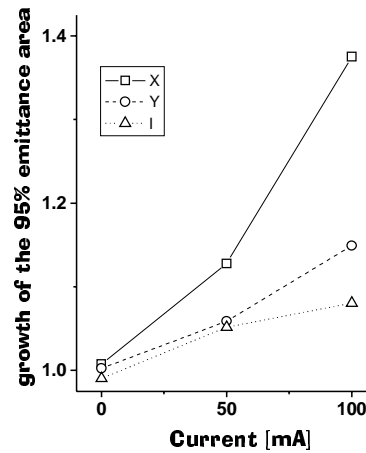


Fig 5: Dependence of the emittance growth on the beam current.

The small dispersion in y-z plane is related to space charge effects. The trace of set particle is also shown in the two longitudinal planes. The growth of the rms-emittance in dependence on the distance (Fig. 4) is in accordance with theory.

The growth of the 95% emittance ratio in dependence on beam current is shown in Figure 5. The superconducting layout is much more compact. As a consequence the fields are much higher and the rms-emittance growth is a bit higher at increased beam currents when compared to the rt case.

CONCLUSION

Room temperature as well as superconducting versions of 180° bending arcs were designed, which keep the typical micro pulse structure as well as the emittance values of high current linac beams acceptably well. The aim of further development on this field will be the option to create compact linac arrays in case of a large total

acceleration length. To reach that goal bending arcs at different energies and for still higher current limits have to be investigated in detail. The beam simulations including tolerances are to be performed to find technically relevant apertures for the layout of the arc components.

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