CORRECTION OF SPHERICAL ABERRATIONS BY A PARTIALLY NEUTRALIZED BEAM PART FOR THE INJECTION OF IONS INTO A RFQ

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Abstract

The injection of ions into a RFQ suffers from aberrations by the last lens, either electrostatic or magnetic. A partially neutralized beam part can provide – at appropriate conditions – the inverse behaviour to spherical aberrations, hence correct the malfunction of the last lens. This has been shown theoretically for any charged particle beam and proven experimentally for electron beams of 40 mA at 20 keV. Examples will be given, how to use this tool of ion optics for the injection of either positive or negative ions into a RFQ accelerator.

1 INTRODUCTION

The proper injection of ion beams into a RFQ is still a matter of challenging ion optics, in order to minimize the emittance growth and the halo formation in subsequent accelerator parts. The difficulties arise mainly from the requirement to match an ion beam to a big radius with steep converging slope at the entrance flange of the RFQ. It has been proposed [1], but yet not realized, to decelerate the ion beam between the entrance flange and the RFQ-structure, but this needs either biasing the center part of the entrance flange or of the RFQ – structure with a dc voltage comparable to the ion acceleration voltage. The strong focusing needed for matching, usually results in aberrations, which increase the emittance of the beam significantly.

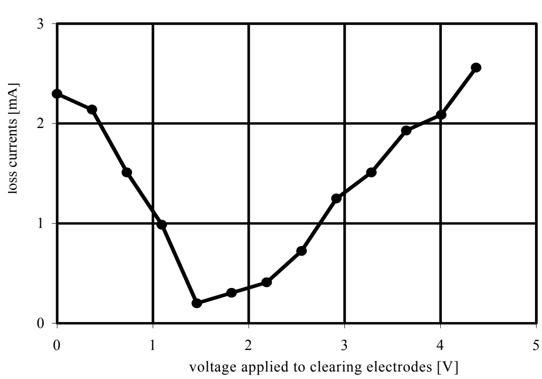

Figure 3: Loss currents onto the ion trap electrodes of an XEBIS/T in dependence of the voltage on the ion clearing electrodes of the lens system. The higher the electron beam current the more sensitive becomes the beam transport to a proper adjustment of the degree of neutralization in the drift tube.

For an XEBIS/T [2] (crossover electron beam ion source and trap), which works without confining magnetic field, an electron beam had to be focused as much as possible, which generally becomes limited by the aberrations of the focusing lens. We have investigated the correction of such spherical aberrations by means of a partially neutralized part of the beam [3] and sucessfully tested this unconventional tool of particle optics in the realization of the XEBIST [4]. A partially neutralized electron beam exhibits a very non-uniform radial potential function, which – at an ion temperature corresponding to 13% of the beam potential depression of the non-neutralized beam - can favorably counteract the spherical aberrations. To provide this behavior ion clearing electrodes have been installed and biased accordingly, to adjust the degree of neutralization and hence the ion temperature, trapping ions from the residual gas. The very sharp transmission window for the electron beam in dependence of the clearing voltage is shown in Fig. 1.

2 SIMULATION OF THERMAL NEUTRALIZATION

An essential tool for the simulation of the influence of a partly neutralized beam section on the propagation of the beam is the implementation of a thermal neutralization procedure into a suitable ray tracing program, like IGUN [5]. The basic mathematical formulations are similar to the sheath formation in the simulation of positive ion extraction from plasmas. New is, however, the search algorithm to find along the axis of symmetry either a local potential minimum or maximum for electron beam or ion beam neutralization, respectively. The user has the choice of the central degree of neutralization f_{neut} and of the temperature T_{neut} of the neutralizing particles. Both parameters, however, are strongly related to each other in a non-linear fashion, as found by self-consistent numerical modelling [6]. The program then modifies the space charge ρ_{beam} as determined by beam tracing in all mesh points with potentials lower/higher than the detected barrier potentials by:

$$\rho_{neut.} = \rho_{beam}\left(1 - f_{neut}\exp\left\{\pm\frac{e\left[U - U_{\min/\max}\right]}{kT_{neut}}\right\}\right)$$

3 CORRECTION OF A MAGNETIC LENS

A non symmetric magnetic lens with a maximum axial field of 1T has been calculated with INTMAG [7] and the output file of it, which contains all information about the surface elements, read in by a new option to IGUN. By reading this save file, IGUN is able to plot in Fig. 2 the windings and the iron contour (shaded) of the magnetic field problem superimposed on the cross section of the electrostatic boundaries, which form a drift tube structure. By +200V on the centre electrode a 30 mA proton beams creates a 500 V deep trap for electrons, which then cause partial neutralisation. The beam is started on the left side at Z=0 with a transverse temperature of 5 eV at a longitudinal energy of 20 keV.

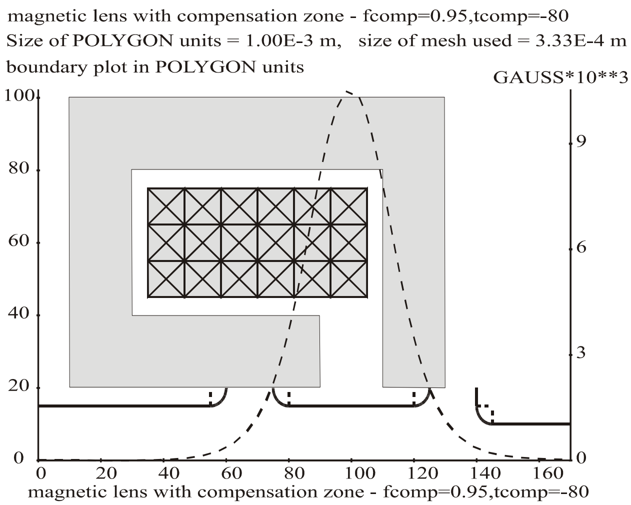

Figure 2: IGUN plot, which shows the magnetic and electrostatic elements of the problem together with the axial magnetic field strength

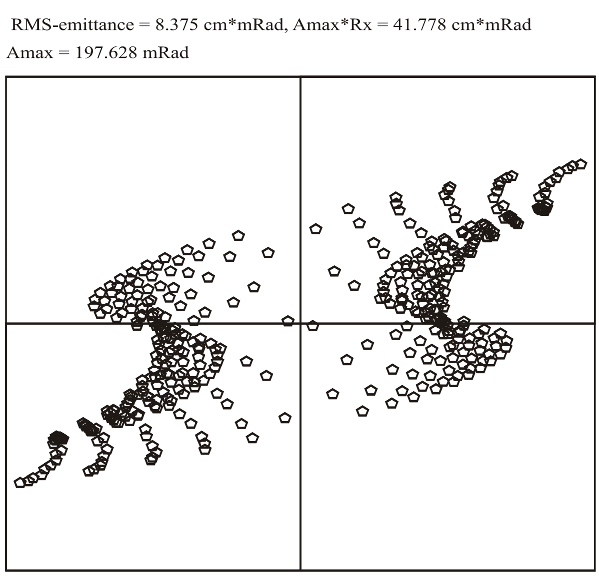

Figure 3: Emittance of the 30 mA H^+-beam focused by the magnetic lens of Fig. 2 and with beam neutralization

The emittance at the assumed begin of the RFQ-electrodes on the right at Z=170 is shown in Fig. 3; it has a reasonable compact distribution and the rms-value amounts to 8.4 cm mRad. This changes dramatically, if no neutralisation is simulated, as shown in Fig. 4. The rms-emittance increases to 14.4 cm mRad and the emittance shape shows the typical wings of spherical aberration.

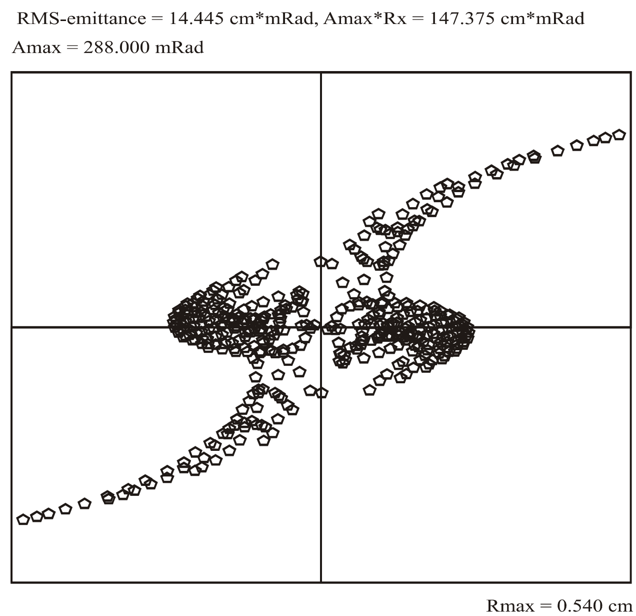

Figure 4: Emittance of the 30 mA proton beam without lens correction by neutralization

4 CORRECTION OF AN ELECTRIC LENS

While beam neutralisation seems to be simple for magnetic lenses, it is also possible for electrostatic lenses. In this case additional electrodes are needed to form – together with the space charge of the beam – a 3D trap for neutralizing electrons. A possible arrangement, also oriented at the problem of matching the incoming beam to a RFQ at the right, is shown in Fig. 5.

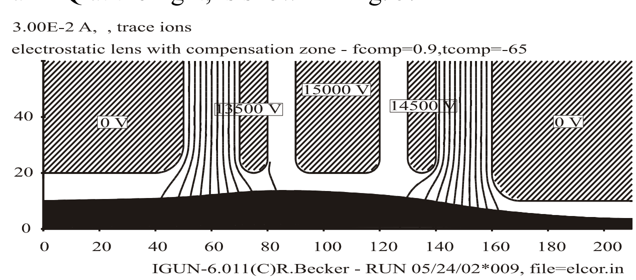

Figure 5: electrostatic lens with guard electrodes to provide a trap for neutralizing electrons, correcting the spherical aberrations

Under conditions of beam neutralization the resulting emittance is given in Fig. 6 and amounts to 5.8 cm mRad Without pronounced wings.

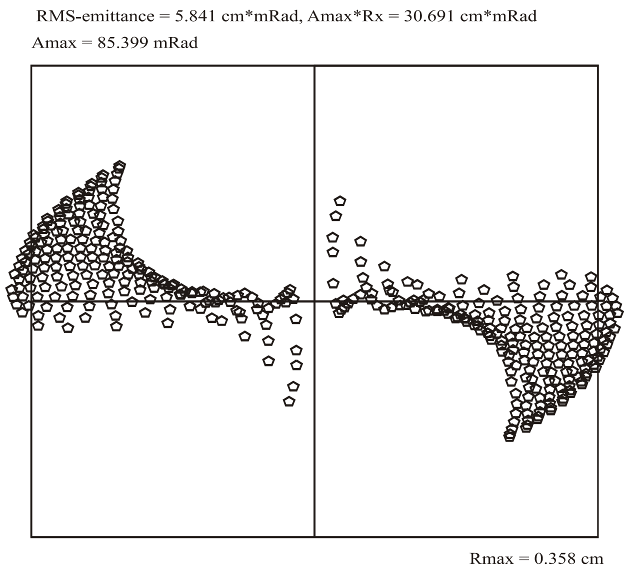

Figure 6 Emittance of the 30 mA H^+-beam focused by the electric lens of Fig. 4 with beam neutralization

Again this changes dramatically, if potentials are applied, which do not provide trapping of electrons. Then the emittance shows in Fig. 7 pronounced aberration wings and the rms-value increases to 18 cm mRad.

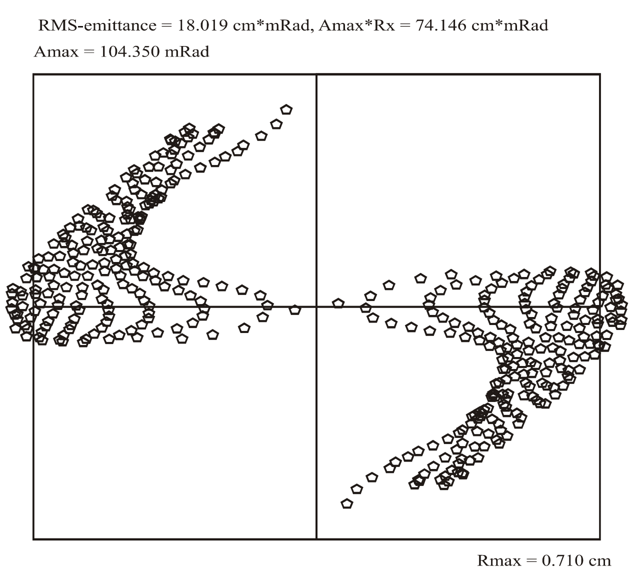

Figure 7: Emittance of the 30 mA H^+-beam focused by the electric lens of Fig. 6 without beam neutralization

5 CONCLUSIONS

It has been shown that partial neutralisation of a controlled beam part is an essential tool to counteract the aberrations of strong focusing lenses, both magnetic and electric. Examples have been given, how this method can be applied to the problem of injection of ions into a RFQ and the simulation results demonstrate the efficient reduction of the aberration wings for the emittances. The numerical data show a reduction of the rms-emittance by a factor of 1.7 and 3.1 for the magnetic and the electric focusing lens, respectively. It has been shown by an experiment, reproduced in Fig. 1, that the spherical aberrations of magnetic lenses for electron beams can be corrected by partially neutralizing a part of the beam. The same method is suitable for the injection of positive or negative ions into a RFQ.

6 REFERENCES

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