A COMPARISON OF HIGH CURRENT ION BEAM MATCHING FROM AN ION SOURCE TO A RFQ BY ELECTROSTATIC AND BY MAGNETIC LENSES

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Abstract

In order to improve the direct injection scheme of the Riken Nd-YAK-laser driven ion source into a RFQ rf-accelerator [1], several basic methods have been investigated and compared, in order to transform the initially divergent ion beam into a convergent one, needed for matching the high current (100 mA C^{6+}) ion beam at an energy of 100 keV to a RFQ. From the point of power supplies and break down characteristics, the simplest solution is a decelerating electrostatic lens [2], with the decelerating electrode operated on ion source potential. Due to the strong divergence of the ion beam after acceleration, this lens will be filled to more than half of the aperture, which causes strong aberrations. Therefore, we also investigated the use of an accelerating potential on the lens electrode. This reduces significantly the filling of the lens and the emittance growth is only a factor of 3, as compared to the decelerating lens with a factor of 30! We have been looking also into a magnetic matching system, which can match the ion beam to the RFQ with virtually no emittance growth. By increasing the length of the magnetic solenoid and reducing the axial field strength, still good matching is obtained, however, at the expense of an emittance growth, which seems to be proportional to the length.

INTRODUCTION

In general, focusing lens(es) are needed to convert the divergent ion beam from a high intensity ion source into a convergent one, needed for proper matching to a RFQ accelerator. Starting with a decelerating electrostatic lens [2], we also investigated and compared the results for an accelerating electrostatic lens, as well as for a magnetic lens. The calculations have been performed with IGUN [3,4,5], a positive ion extraction simulation tool. Recently a new feature has been added to IGUN, to take into account the rf-focusing of the RFQ electrodes as a reduction of beam spreading, as caused by space charge [6]. By this feature, the matching point between the ion source and the RFQ program Parmteq can be chosen at the inner end of the radial matching section, where beginning modulation of the electrodes starts acceleration. This makes it much easier to optimise the focusing lens with respect to the aperture constraints given by the shape of the RFQ electrodes.

ELECTRIC LENSES

The simplest electrostatic lens decelerates the ion beam, widens it up and by subsequent acceleration the focusing action is achieved. This is shown in Fig. 1, upper panel, where additionally the potential of the ions source has been applied, avoiding the need for an extra power supply. The high intensity ion beam from the laser ion source deeply penetrates into the non-linear fields of this lens, exhibiting an enormous emittance growth of about 30 (see Fig. 3). The electrodes have been optimised to keep the surface fields as low as 35 kV/cm (see Fig. 2).

An accelerating electrostatic lens first accelerates the beam, which becomes narrower and then decelerates it by an “anode lens” effect, which is known to be quite linear. Fig. 1and 3 (central panel) are showing, that in this case the emittance growth amounts only to about 3, however for a 100 KV source potential a power supply of –500 kV will be needed and the surface fields are in the range of 250 kV/cm, which is not practical at all.

MAGNETIC LENS

As an alternative, a short solenoid has been introduced in place of the electrostatic lenses (see Fig. 1 and 3, lower panels). This gives an excellent matching without emittance growth, however the central field of this solenoid is around 3T, which means that either a short pulsed coil is used, appropriate for the short ion pulse of the laser ion source, or a super-conducting one. In order to reduce the central field of the coil, the length of the solenoid has been increased in equal steps of 4 cm, finally separating the winding into 2 parts. The results are still acceptable, but with increasing length of the solenoid the emittance growth also increases, as shown in Fig. 4.

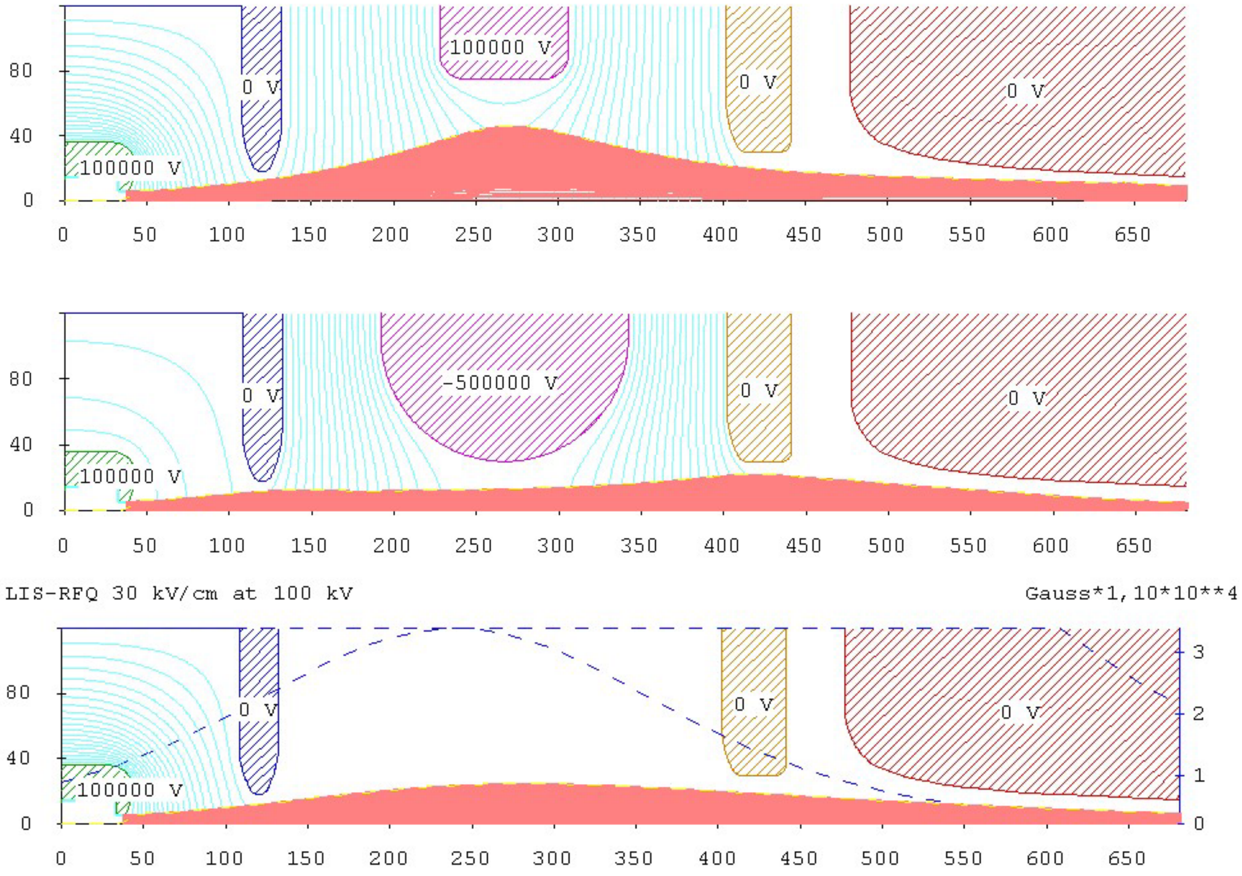

Figure 1: Matching with a decelerating electrostatic lens (upper panel), accelerating electrostatic lens (central panel) and with a magnetic lens (lower panel).

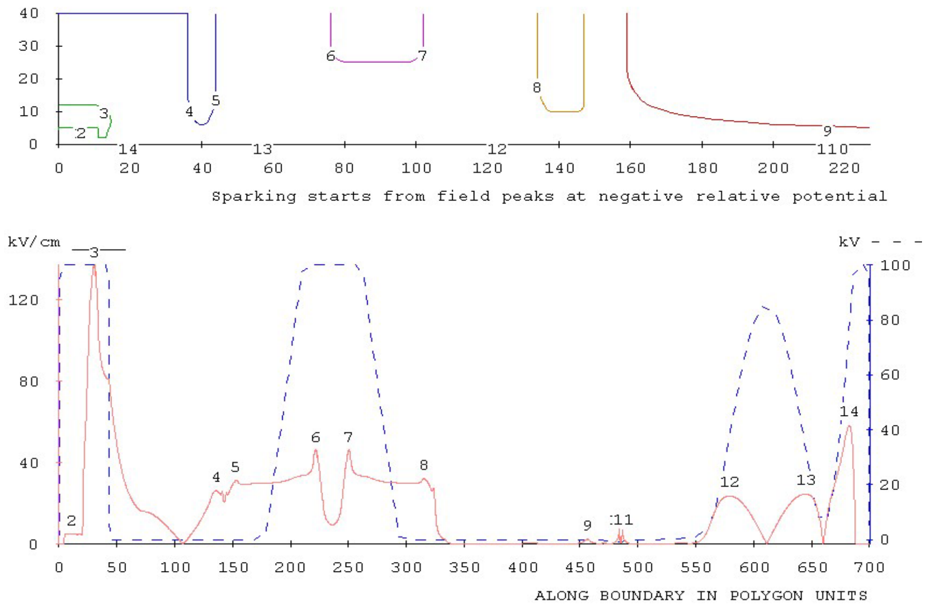

Figure 2: Boundary plot (upper panel) and surface electric fields (lower panel) with related labels for field maxima for the case of the accelerating electrostatic fields. The maxima 4, 5, and 6 are on relative negative potential and are spots, where sparking may start. The fields there are below 35 kV/cm, as compared to the accelerating electrostatic lens, where the fields exceed 250 kV/cm.

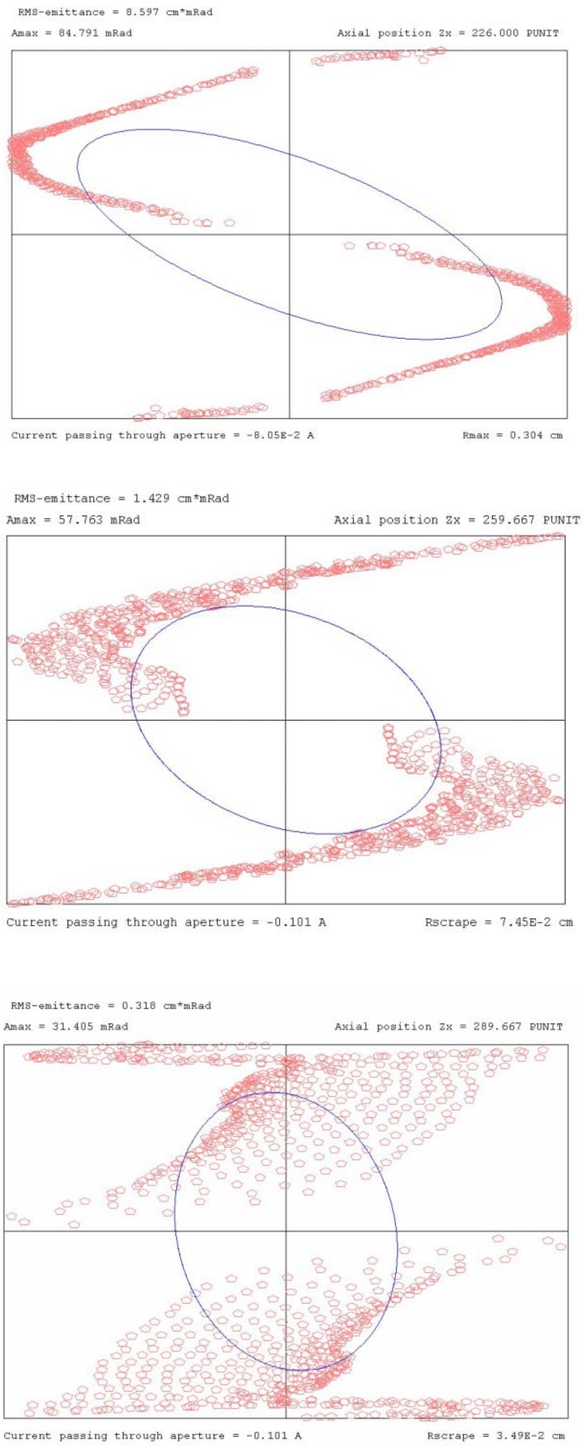

Figure 3: Comparison of emittances in the matching points for decelerating (upper panel), accelerating electrostatic lens (central panel) and for a magnetic lens (lower panel). The emittance growth are about 30, 3, and 1!

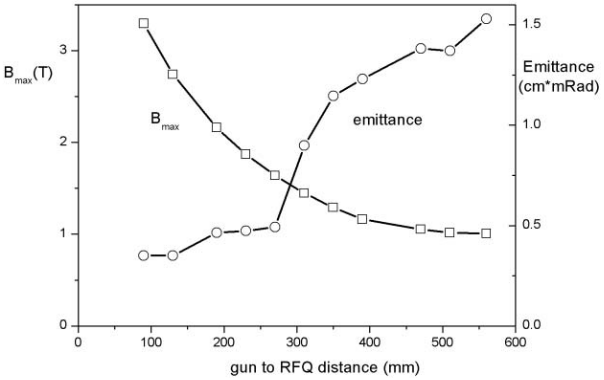

Figure 4: Emittance growth and decrease of the solenoid axial field strength by increase of the solenoid length.

CONCLUSIONS

A comparison of different matching scenarios for the high intensity C^{6+} beam of a laser ion source shows negligible emittance growth for a magnetic lens, a higher one (factor 3) for an accelerating electrostatic lens and a factor of 30 for a decelerating electrostatic lens. All variants have disadvantages: the magnetic lens needs a super-conducting coil or a short-pulsed solenoid with about 3 T central field, the accelerating one exhibits surface fields of 250 kV/cm and needs a 500 kV power supply for this lens, while with the decelerating lens a highly aberrated ion beam will be injected into the RFQ, which is certainly undesirable with respect to beam losses in the RFQ.

The outstanding performance of a short super-conducting solenoid suggests to consider today's technology of "dry" super-conducting magnets, which are operated without filling in liquid helium into a cryostat, but resemble cryo-pumps, driven by a compressor and well accepted in the accelerator community. For all high intensity accelerators, where beam loss is a serious issue, the price of about 10^5 EURO for such a system compares favourably with its advantages.

References

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