PS/HI/Note 93-05 (Tech)
28.6.93

Preliminary study of the performance of the LBL RFQ with a beam from the laser ion source

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Introduction

A new laser ion source is being studied and tested at CERN. In the future the source will be tested as injector to an RFQ built by LBL and delivered at CERN in 1988 as ion injector to LINAC1. The purpose of this work is to study the feasibility of this attempt and to have a rough estimate of the transmission efficiency of the RFQ.

Following is a brief (and necessarily incomplete) description of the existing RFQ and the intended characteristics of the beam from the laser ion source

LBL RFQ characteristics :

(refer to GSI REPORT 86-2 by B.H. Wolf et al. from where the following table has been taken)

- design ion 16 O 6+ (q/m=0.375)
- design current : 0
- frequency 202.56 MHz
- input energy 5.625 KeV/n
- output energy 139.5 KeV/n
- length 85.8 cm
- vane-vane voltage 35.6 KV
- transverse acceptance (total normalized) 0.9 π mm mrad

typical beam from laser ion source :

- ion : 32 S 12+ (q/m=0.375)
- energy: 4.5 to 6.75 KeV/n (extraction voltage : 12-18 KV)
- energy spread : 0.75 KeV/n (2KV on the extraction voltage)

- current : 1-5 emA (can go up to 10 mA ?)

- transverse emittance not measured yet, assumed to be 0.8 π mm mrad (total normalized)

It is important to point out that the quoted energy spread has a temporal structure deriving from the way the beam is generated. The beam is generated in the following way : a laser pulse (about 100 ns) shoots on a target; a hot plasma is produced and let drift in free space ("expansion chamber") till it reaches the length of about 10 µsec; the ions are then extracted by a DC voltage. During the drift in the expansion chamber the faster particles move to the front of the pulse whereas the slower move to the tail of the beam. Therefore the total energy spread of the beam is composed of a systematic part that depends on the drift length between the source and the rfq and an intrinsic part depending on the temperature of the beam. At the moment we don't have an estimate of the relative weight of the two components, but the systematic component, in principle, could be compensated for by a time-dependent voltage RF device.

Simulation and results

A typical beam from the laser ion source has the same q/m and average energy of the design beam. The acceleration should not present any particular beam dynamics problem . Nonetheless problems could arise from :

- the very large input energy spread , as the input rfq acceptance in energy spread is very low

- the space charge, as the LBL rfq was designed for very low space charge beams

The problem has been studied with the computer code PARMULT, a multi-particle program that can generate an RFQ structure and compute the dynamics of an input beam defined in six dimensions. The program includes space charge ("ring model") as well as the effects of the multipoles up to the 8th term.

The input file describing the structure of the rfq has been obtained from LBL and adapted to our version of the code.
As for the input beam some assumptions had to be made, due to lackness of experimental data. The initial distribution was taken as a 4D waterbag , i.e. the macro particles were generated randomly in a four dimensional transverse hyper space with uniform phase and energy spread. The transverse emittance was set to 90% the acceptance of the machine, the beam was assumed to be round and matched for the design case (the beam has not been rematched when any of the parameters was varied). The longitudinal characteristics of the beam have been varied case by case.
Three sets of run have been done : first the effect of an input energy spread for a zero-current beam was studied , second the effect of the space charge for a zero energy-spread beam,
and finally the combined effects of an initial energy spread and space charge. The results are reported in the following plots.

Effect of the energy spread:

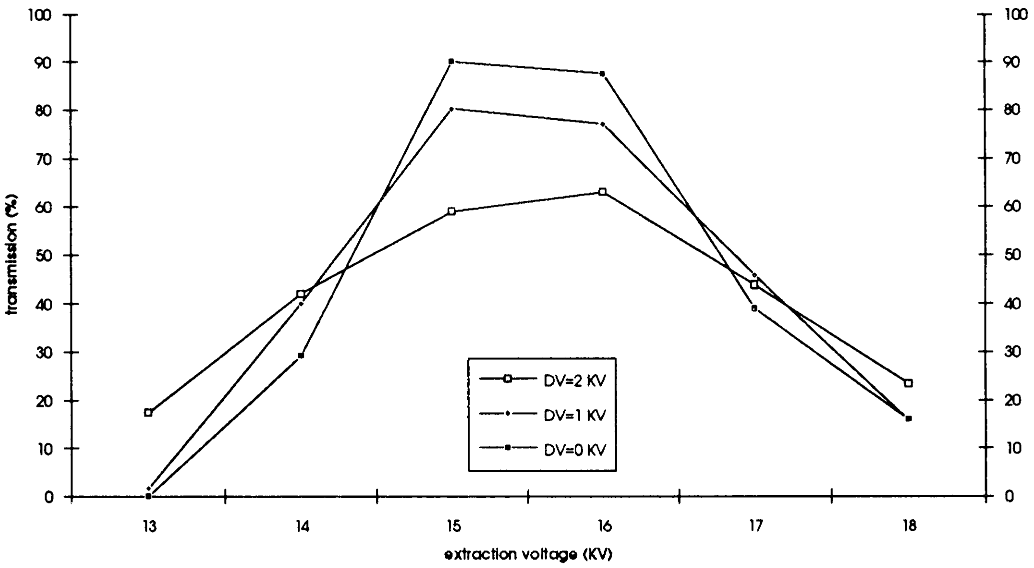
The following plot reports the transmission through the RFQ versus the extraction voltage for the above mentioned beam . At the output we have considered "good" particles the ones at the design output energy within plus/minus 5%. The input energy spread has been varied from zero to 2 KV. The current of the beam is set to zero.

- the DV=0 curve is the reference plot, it represents the design case.

- the DV=1 curve represents a beam with a 1KV energy spread i.e. where part of the energy spread has been compensated for. The results show that we can keep the transmission above 75%.

- the DV=2 KV case represents the pessimistic case, no correction has been made. The maximum achievable transmission is around 60%.

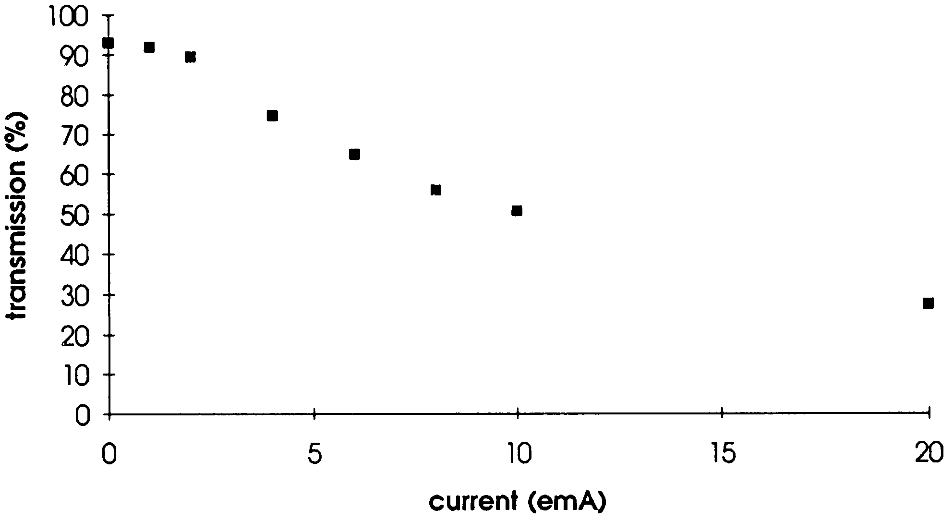
current=0



Effect of the space charge :

The following plot reports the transmission of the rfq as a function of the beam-current. The initial energy spread is zero, as we are interested in looking at the space charge limits of the rfq in ideal conditions. We can see that the rfq can tolerate current up to 5-7 emA currents above which the transmission drops below 60%.

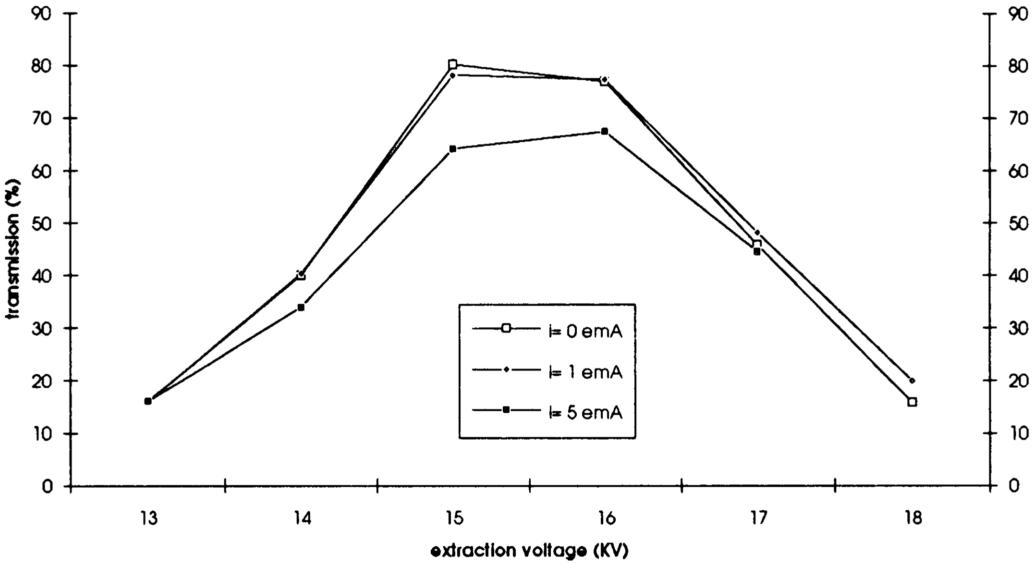
DV=0



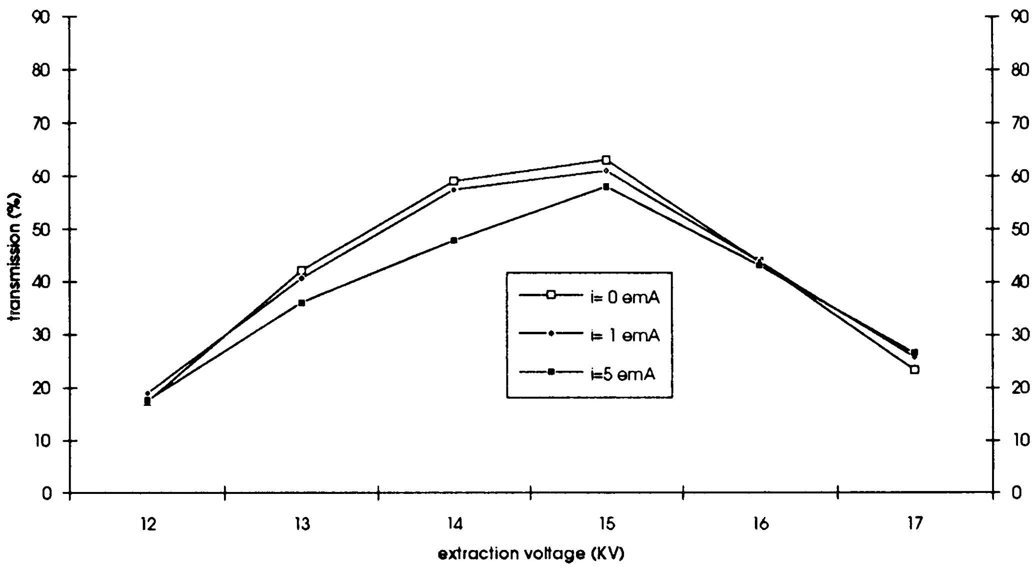
Combined effects of space charge and energy spread :

The following plot reports the transmission through the RFQ versus the input energy for an energy spread of 1KV and 2KV respectively . The current has been varied from 0 to 5 emA. As we can see from the plots the energy spread is the dominating factor for currents up to 1 emA, whereas for current of 5 emA (rfq saturation current) the space charge induced losses become not negligible compared to the energy spread induced ones.

DV=1KV (0.325 KeV/n)



DV=2KV (0.75 KeV/n)



Conclusions

This first preliminary study has shown that a 1emA beam of s12+ , with an energy spread of 2 KV over an extraction voltage of 15 KV, can be transmitted through the LBL rfq with an efficiency of about 60% . The transmission could be improved to 80% if the energy spread was reduced to 1 KV. For a 5emA beam the improvement in transmission achieved by reducing the energy spread to 1KV would be of 10% (from 55% to 65%).
As already pointed out, this is a preliminary study and several assumptions had to be made.
More precise conclusions could be obtained when more experimental data will be available (e.g. a measure of the transverse emittance, the longitudinal structure of the pulse, an estimate of the energy spread induced in the expansion chamber).
Further studies could include the matching line to the RFQ and the development of a time dependent RF device to correct the systematic part of the energy spread.