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Beam simulations and measurements of a helium beam accelerated by the LIS-RFQ.

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Introduction

Properties of the LIS-RFQ and the beam accelerated by it have been reported in 1996 [1]. Concerning the longitudinal phase plane, however, at that time only the energy and energy dispersion had been measured. Since then a 4 gap buncher has been built (similar to the one for the CERN linac3 [2], albeit with modified electrodes to take into account the different relativistic β) and installed, allowing to explore the longitudinal phase plane to greater detail. In this report the beam measurements will be described, as well as a comparison made with computer simulations. The layout of the experimental line is shown in fig.1.

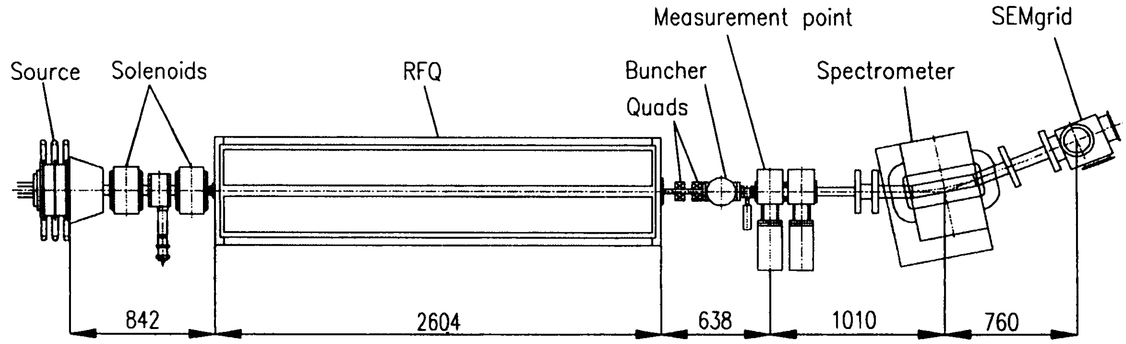

Fig.1 Layout of the experimental line (distances in mm).

Transmission rate of the RFQ

This RFQ, operating at 102 MHz, has been designed for installation behind a laser ion source [3]. In order to the test the RFQ proper, beam measurements have been made with a beam produced by a duoplasmatron ion source. The proton yield from such a source in the low energy regime is about 45 %. Therefore helium was chosen as ion species, having only a few percent of unwanted particles. The characteristics of the helium beam at the RFQ input (table 1) have been "scaled" from the nominal lead ion beam characteristics for which this RFQ has been designed, except for the beam current. The beam current used was the minimum intensity which could be obtained with stable operation.

Ion	He^{1+}
q/m	0.25
Current	6 emA
Relativistic β	0.0038
Energy	6.9 keV/u
Transverse emittance (total, not normalised)	100 π mm mrad
Transverse emittance (total, normalised)	0.384 π mm mrad

Table 1 Characteristics of the helium beam at the RFQ input

The measurement of the beam transmission through the RFQ as mentioned in [1] was made using a beam stopper as Faraday cup. This time it has been measured with newly installed beam current transformers (i.e. one directly at the RFQ input and one at its output) and yielded about 80 %, which fits with the theoretical value of 84 % as calculated by PARMTEQM for such an intensity.

Calibration of the buncher

In order to correlate the buncher RF power level with the effective voltage as seen by the beam, a series of measurements was made with the buncher operating at –180 deg (i.e. the phase giving maximum deceleration), acquiring the beam energy displacement at the SEMgrid as a function of buncher voltage (fig.2).

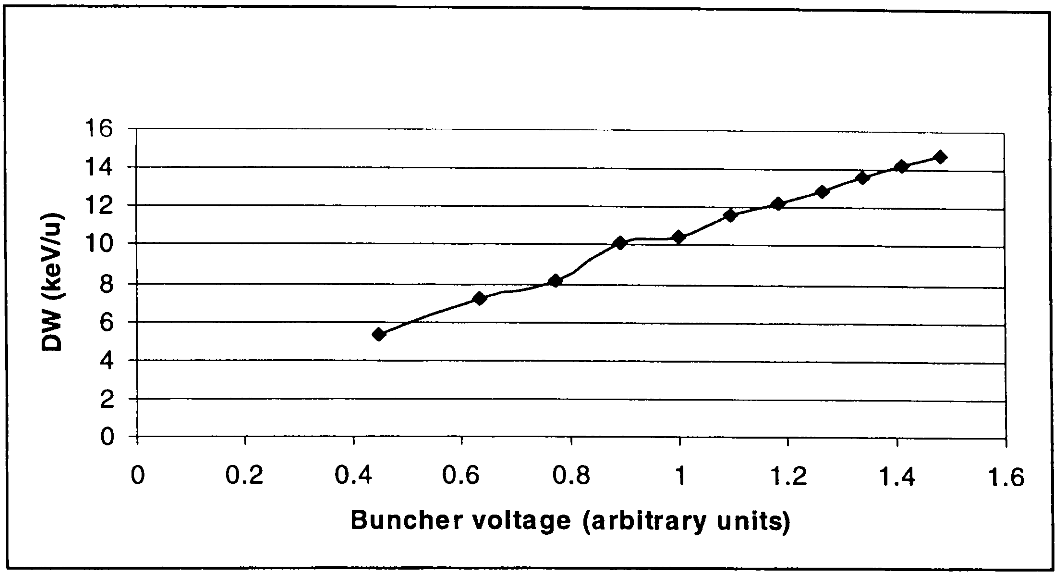

Fig. 2 Beam energy displacement as a function of buncher voltage for φ=-180 deg. From this graph it can be seen that close to 60 kV (i.e. 4*14.8 kV/u) effective voltage is feasible with this buncher.

Phase spread measurements using a fast probe

A fast probe located at the measurement point (see fig.1) was used to measure the phase spread of the beam for different buncher settings (measurement results in fig.3). At a buncher phase of –90 deg w.r.t. the crest with a buncher voltage for which the phase spread is minimal, the Twiss parameter α equals zero. This buncher setting corresponds to an effective voltage of 41.6 kV (i.e. 4*10.4 kV/u). The minimal phase spread was found to be 0.92 ns or 33.8 deg FWHH (fig.4). Measuring the energy spread for this setting would enable one to calculate the longitudinal emittance. However, as the fast probe is limited by its rise time, it yields a phase spread bigger than the real one. It was therefore decided to measure the phase spread once more, this time with a Bunch Length and Velocity Detector (BLVD) [4], giving a phase resolution better than 1 deg.

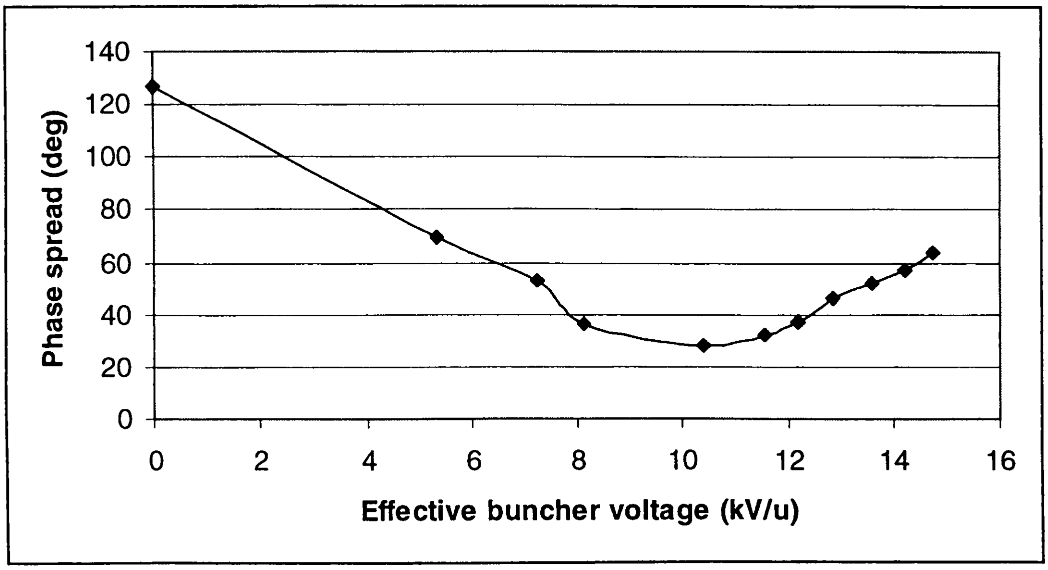

Fig.3 Bunch phase spread as a function of effective buncher voltage

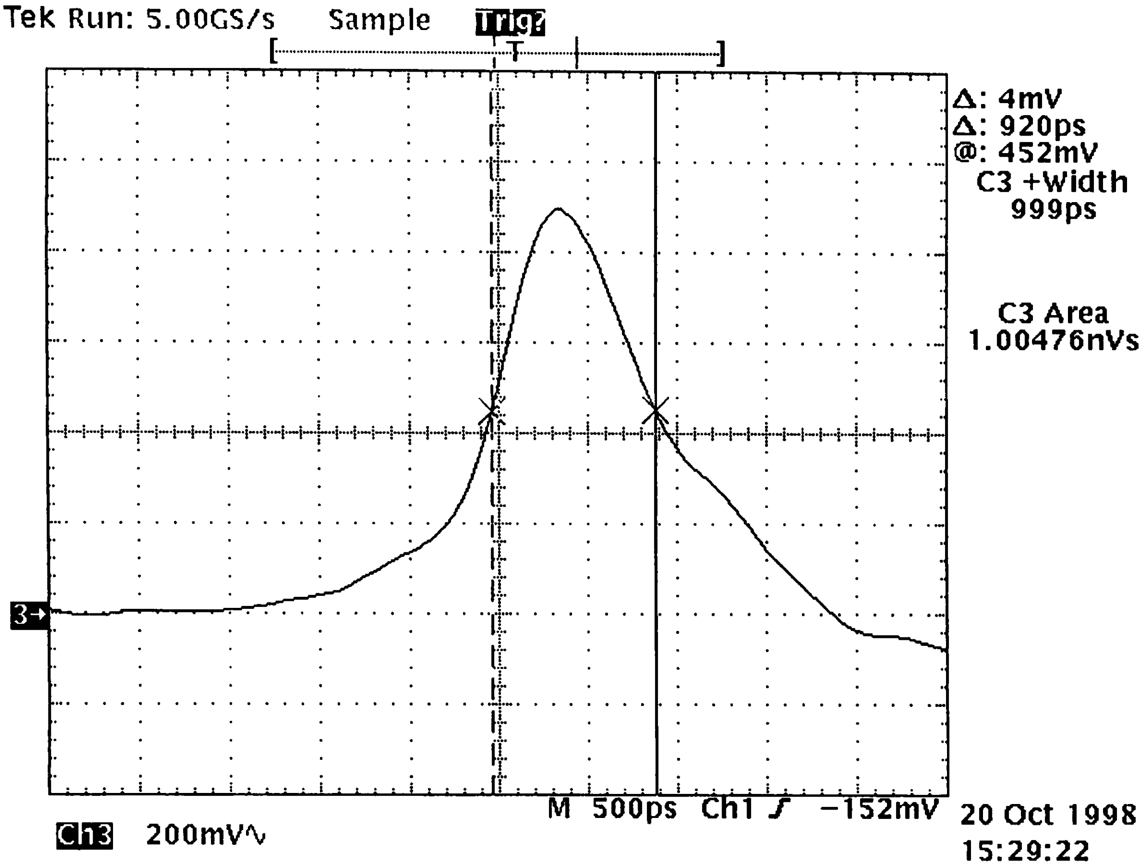

Fig.4 Bunch shape for buncher setting giving minimal phase spread, as measured with a fast probe

Energy and energy spread measurements

With the buncher phase set to φ=-90 deg, a series of energy dispersion measurements was made (fig.5), using a slit of the emittance measurement device, a spectrometer and SEMgrid (see fig.1).

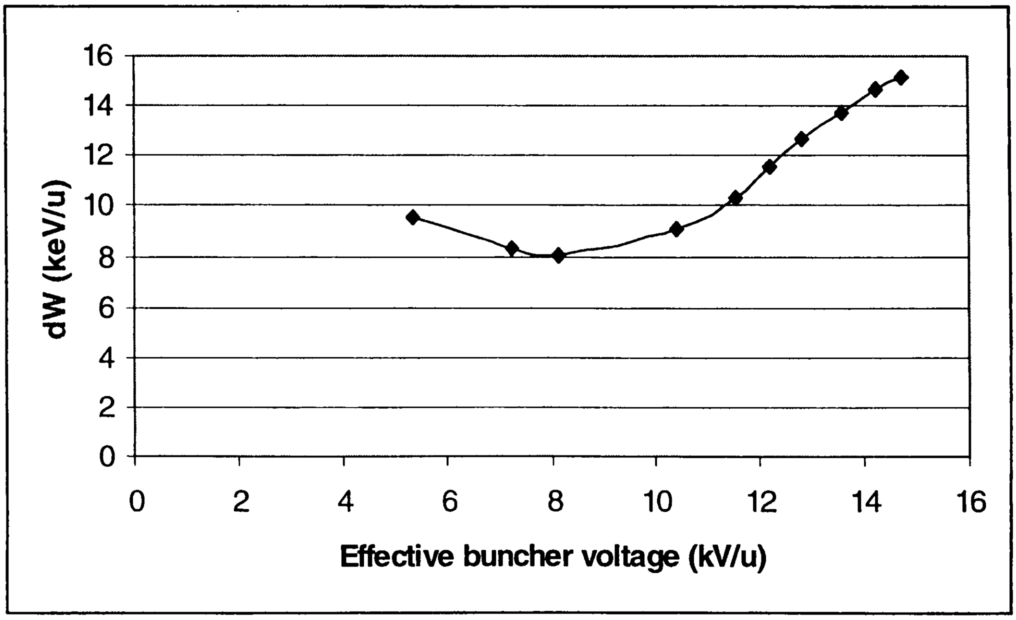

Fig.5 Beam energy spread as a function of buncher voltage

From this measurement the energy spread for the buncher setting giving minimal phase spread was found to be 8.5 keV/u.

Phase spread measurements using a Bunch Length and Velocity Detector (BLVD)

A BLVD was installed at the measurement point (see fig.1), taking the place of the emittance measurement device in order to repeat, with higher precision, the measurements with the fast probe. After some teething problems (the buncher was hampered by multi-pactoring due to electrons emitted from the BLVD) the buncher was again set to the phase giving minimal phase spread in the beam. Fig.6 shows this phase spread as measured by the BLVD, yielding to a value of 27.6 deg for FWHH or 23.1 deg RMS. Combining this measurement with the 8.5 keV/u energy spread found for this buncher setting yields to a longitudinal emittance of El ≅ 197 deg.keV/u.

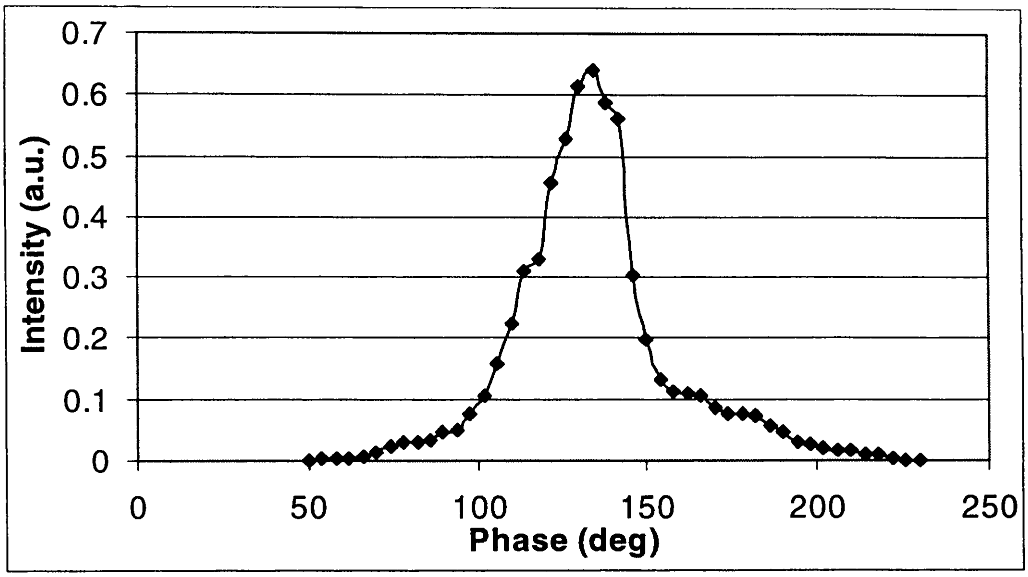

Figure 6 Bunch shape measurement with a BLVD for the buncher setting giving minimal phase spread.

Comparison of measured beam data and computer simulation results

Computations were made taking the output beam of the RFQ as calculated by PARMTEQM, and transporting this beam using the computer code DYNAC [5] to the measurement point. This resulted in a calculated longitudinal emittance at this point of 150 deg.keV/u comprising 98% of the particles. Fig. 7 compares this emittance to the measured one, which is about 31% bigger.

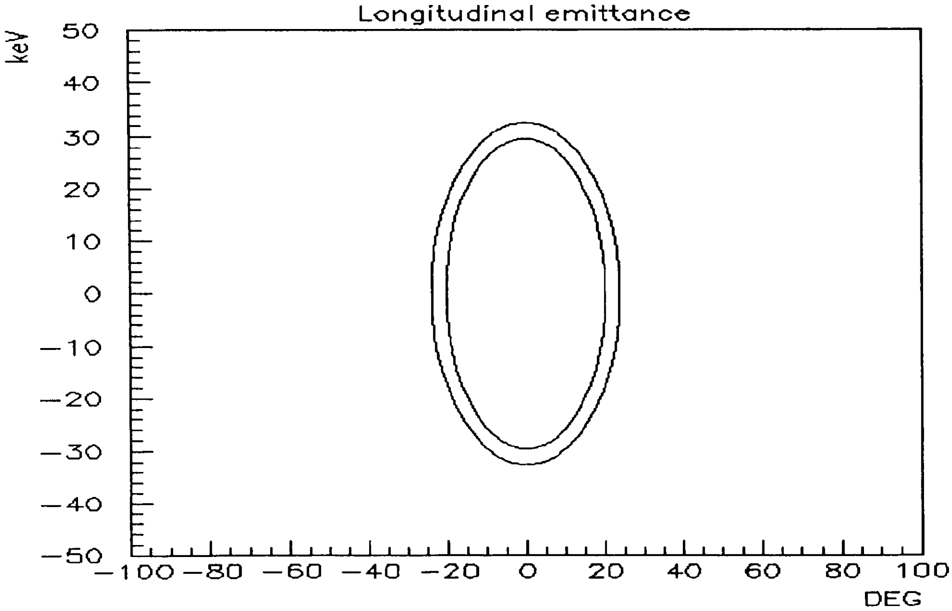

Fig 7 The (total) longitudinal emittance at the measurement point as measured using the BLVD (bigger ellipse) and calculated by DYNAC (smaller ellipse) for the same buncher setting.

Conclusion

The Twiss parameters of the longitudinal emittance at the output of this RFQ are well predicted by theory. The longitudinal emittance measured is about 31% larger than the calculated one. This can be explained by the fact that the size of the calculated emittance corresponds to 98 % of the beam only. Another reason is the assumption in the measurement that the energy spread at the SEMgrid is the same as at the phase measurement point (see fig. 1) whereas in reality, due to space charge effects, it is bigger.

From the above results one can find an estimate for the longitudinal emittance of the beam at the output of the RFQ. Consider the line between the RFQ output and the measurement point : According to simulations with DYNAC, for the buncher setting giving minimal phase spread the longitudinal emittance growth between RFQ output and the measurement point is about a factor 1.4. This is due to the large phase extent of the bunch, which then gets affected by the non-linearity of the RF in the buncher as well as due to space charge effects.

Applying this factor to the longitudinal emittance measured yields to 141 deg.keV/u at the RFQ output, 31 % larger than the one obtained through simulation with PARMTEQM.

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References

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