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LOW ENERGY BEAM TRANSPORT IN A PERIODIC FOCUSING QUADRUPOLE CHANNEL

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Abstract: In the FOM MEQALAC (Multiple Electrostatic Quadrupole Array Linear ACcelerator [1]) experiment the Low Energy Beam Transport section (LEBT) transports the four 40 keV He^+ beams from the ion source to the RF accelerator. The transport section consists of an array of four parallel channels each made up of 34 electrostatic quadrupole singlet lenses. The first five lenses are excited independently to match the cylindrically symmetric beams extracted from the source to the acceptance of the periodic focusing quadrupole channel. Typical beam losses are of the order of 15%. We report measurements of currents and emittances of DC and bunched beams performed behind the ion source, matching section and LEBT section. The injection energy of the He^+ ion beamlets is 40 keV. The current per beamlet is 7, 10 and 14 mA. Typical (RMS) emittance values are 10-30 π mm mrad. The phase advance per cell μ_0 is varied between 40° and 115°.

Introduction

The space charge loading of an ion beam limits the current that can be transported or accelerated. The total current can be increased if, instead of a single beam, multiple beamlets are transported in parallel. The radial stability of each beamlet is achieved by use of periodic transverse focusing elements.

Experimental set-up

A schematic picture of the FOM MEQALAC experiment is shown in figure 1. Four He^+ ion beams are extracted from a bucket type plasma source. The LEBT section transports the ions from the high pressure ion source region to the low pressure RF acceleration region [2,3,4]. The accelerator properties are discussed in an accompanying paper [5]. The first five quadrupole singlets of the LEBT are used to match the beamlets to the periodic focusing system.

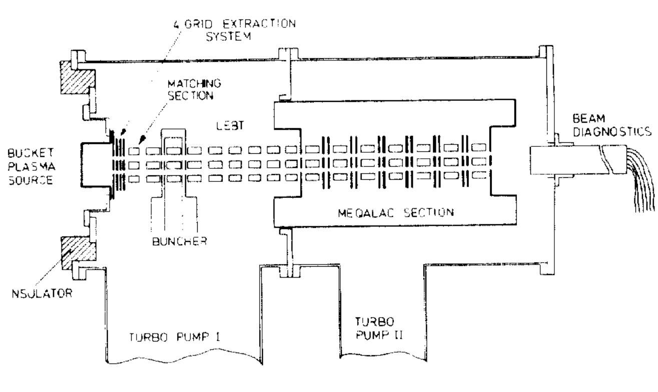

Fig. 1. The experimental set-up. For details, see text.

The LEBT section

The LEBT section consists of a series of 34 electrostatic quadrupole singlet lenses per channel, the first of which is located 18.7 mm behind the last grid of the extraction system. All LEBT singlets are held at the same potential except for the first five quads, which can be excited independently. The characteristic dimensions of the LEBT section and of the two-gap buncher are given in figure 2.

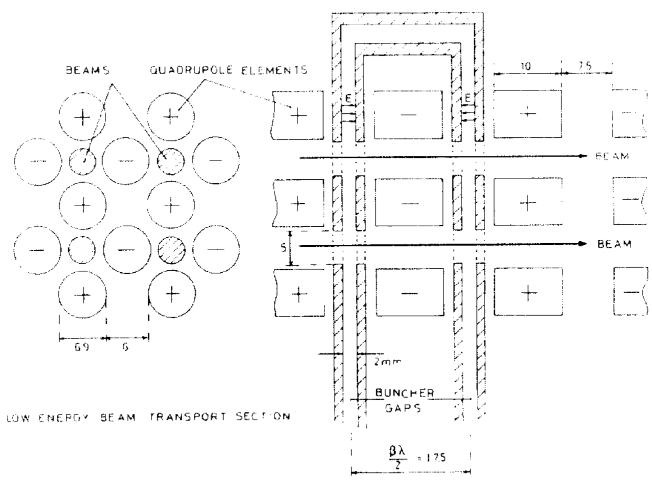

Fig. 2. Characteristic dimensions (in mm) of the LEBT section and the two-gap buncher.

A quadrupole voltage of ± 2.4 kV is required to achieve a zero-current phase advance per cell of 60° for the 40 keV He^+ ion beams. For a typical beam emittance of ~ 20 π mm mrad and a maximum filling factor of $F = a^2/a_0^2 = 70\%$, a = maximum beam radius, a_0 = channel radius, the theoretical space charge limited current is 18 mA [6].

As beam diagnostics are used: Faraday cup, emittance measuring device and a capacitive phase probe. The latter device is used to determine the bunch length and bunch peak current.

Beam transport measurements

In the entrance plane of the first lens of the matching section, indicated by A in figure 3, first the current and the emittance of one of the beams is measured. The beam envelope and its derivative are deduced from the emittance diagram. The periodic solution for the focusing channel and the voltage setting of the matching quadrupoles are calculated. The computer program employs the so-called KV equations [6,7]. The potential field of the quadrupoles is calculated from the Laplace equation. The average r^2-dependence of the field as a function of z is then used in the transport program.

The next step is the installation of the matching section together with the first quadrupole lens of the periodic channel. Behind this section, indicated by B in figure 3, the emittance diagrams are measured in the xz and yz planes with the calculated voltages applied to the matching quadrupole elements. At this point the different voltage settings can be adjusted to allow

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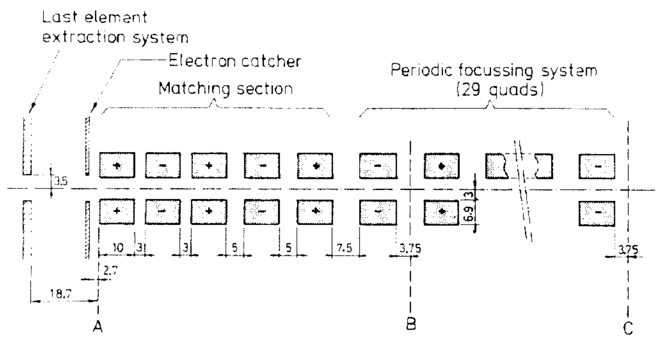

Fig. 3. Characteristic dimensions of the LEBT section. The three planes in which the emittance diagrams are measured are indicated with A, B and C. All dimensions are in mm.

fine tuning to the desired beam parameters. Finally the whole LEBT section is installed. The emittance diagrams are measured in the plane indicated by C in figure 3, behind the last quadrupole element.

The emittance diagrams of a 10 mA beamlet measured at the three indicated positions, are shown in figure 4.

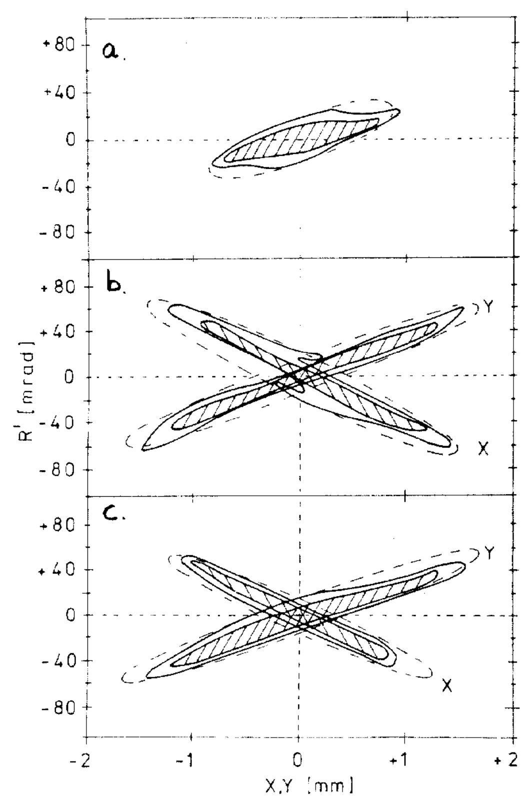

Fig. 4. Emittance diagrams. The outer solid lines indicate the contours where the intensity is 10% of the maximum value. The solid lines enclosing the shaded area represent the 1/e contours. The dashed lines give the RMS ellipse as deduced from the measured intensity distribution. a: Emittance diagram of a 10 mA beam at the entrance plane (A in figure 3) of the first quadrupole. The RMS values are: Envelope radii $X = Y = 0.86$ mm, envelope derivatives $X' = Y' = 25.9$ mrad, $\varepsilon = 17.3$ mm mrad. b: Emittance diagram of the beam x and y planes, measured behind the sixth quadrupole (see figure 3,B). The x and y diagrams are not fully symmetric because the actual location of the entrance slit of the emittance measuring device is 2 mm behind its front plate. This grounded front plate is placed at the centre of the gap separating two successive quadrupoles. $X = 1.45$ mm, $Y = 1.64$ mm, $X' = -64.2$ mrad, $Y' = 58.5$ mrad, $\varepsilon_x = 26.8$ π mm mrad, $\varepsilon_y = 24.3$ π mm mrad.
c: Emittance diagram of the beam x and y planes, measured behind the last quadrupole of the LEBT section (figure 3,C). $X = 1.25$ mm, $Y = 1.68$ mm, $X' = -51.3$ mrad, $Y' = 56$ mrad, $\varepsilon_x = 17.3$ π mm mrad, $\varepsilon_y = 24.9$ π mm mrad.

All measured and calculated values agree within 15%. The current measurements show that 15% of the current is lost inside the matching section, while practically no beam loss is observed in the subsequent transport channel. These measurements are carried out with a quadrupole voltage of ± 2.4 kV ($\mu_0 = 60°$) in the LEBT section. The matching quadrupole voltages range from 1.3 to 3.3 kV. Injecting a 14 mA beam the same transmission is obtained.

Figure 5 shows the results of transport measurements of a 7 mA beamlet for different quadrupole voltages and therefore for different values of μ_0. As can be seen from figure 5 the transmission is of the order of 90% for values of $60° \lesssim \mu_0 \lesssim 85°$. For values $\mu_0 \lesssim 85$ and $\mu_0 \lesssim 60°$ the decrease in current is of the order of 40%. All losses are observed in the LEBT section. No losses are found in the matching section.

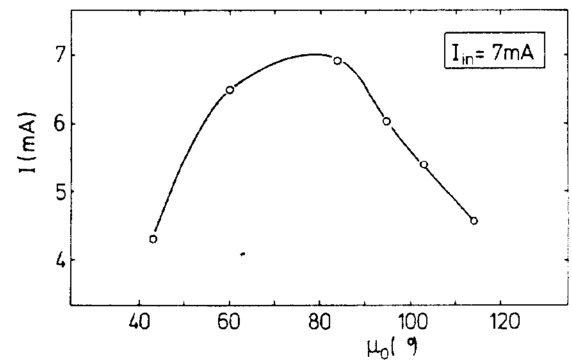

Fig. 5. The transmission of an injected 7 mA beamlet as a function of the zero current phase advance per cell μ_0.

Measurements with bunched beams

The 40 MHz two-gap buncher consists of a capacitively shorted λ/4 resonator. The gaps are at 17.5 mm distance. In between the two gaps one quadrupole singlet is situated, in order to continue the periodicity of the transport section [8]. The drift length from the buncher up to the end of the LEBT section is 35 cm.

Injecting a 10 mA beam into the matching section we found the time averaged transported current to decrease gradually from 8.5 mA to 7.5 mA when the buncher RF power P_B increases from zero to 400 W. This power corresponds to a total buncher peak voltage of $U_B = \pm 4.5$ kV. The minimum bunch length of 6 ns is measured at $P_B = 200$ W, $U_B = \pm 3.2$ kV. The emittance diagrams measured while the buncher is excited with 60 and 200 W, are shown in figure 6. For comparison the diagrams measured without buncher excitation are also given in this figure.

In contrast to our measurements the calculations done with the KV-transport program show a considerable increase in beam envelope. The action of the buncher is modeled in this time independent program via the assumption of a current linearly increasing with distance between buncher and exit of the LEBT section. The discrepancy is partly explained by the fact that the emittance measuring device integrates over 500 ms, i.e. it measures the time averaged emittance diagram, while in the program only the middle (the "peak value") of the bunch is traced.

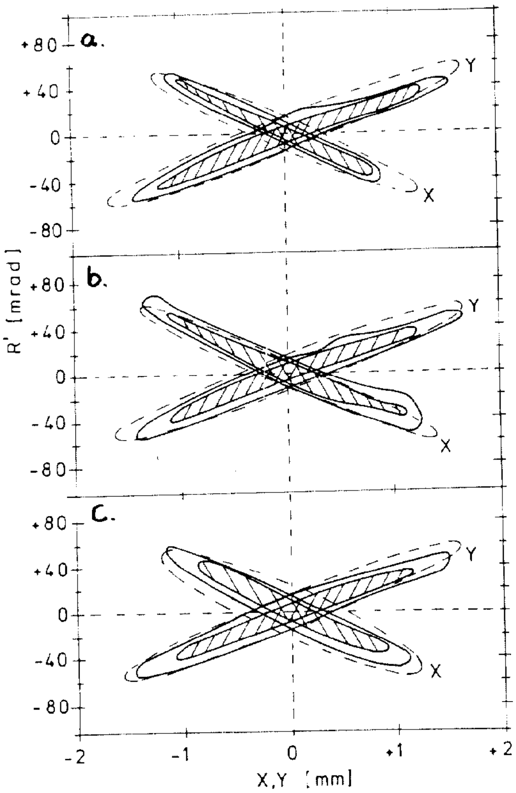

Fig. 6. Emittance diagrams of an injected 10 mA beam, measured behind the LEBT section (see also figure 4).
a: Emittance diagrams of the beam in x and y planes, measured without buncher excitation.
b: $P_B = 60$ W, $U_B = \pm\ 1.75$ kV, bunch length $\sim$ 9 ns.
c: $P_B = 200$ W, $U_B = \pm\ 3.2$ kV, bunch length $\sim$ 6 ns.
Note that the dimensions and the orientations of the emittance ellipses do not change as a function of RF power.

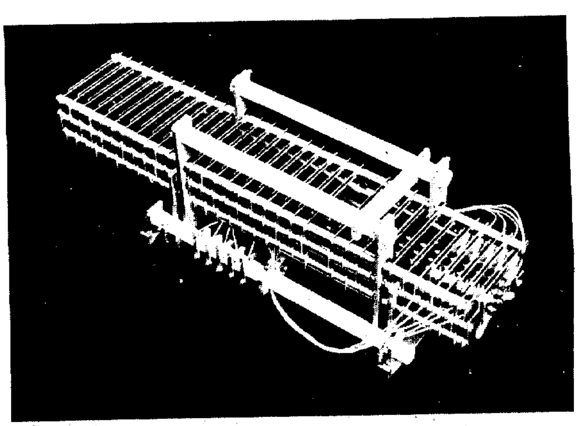

Fig. 7. Part of the Low Energy Beam Transport section.

Conclusion

The matching procedure using a computer model based on the KV-equations and "soft edge" quadrupole elements work satisfactory. The transport of DC beams with quadrupole voltages which corresponds to $60° \leq \mu_0 \leq 85°$ show that a transmission of 80% - 100% is obtained. For smaller and larger values of μ_0 the transmission is found to decrease clearly. Results of measurements with bunched beams are not fully understood. Therefore measurements with other beam currents will be investigated in the near future.

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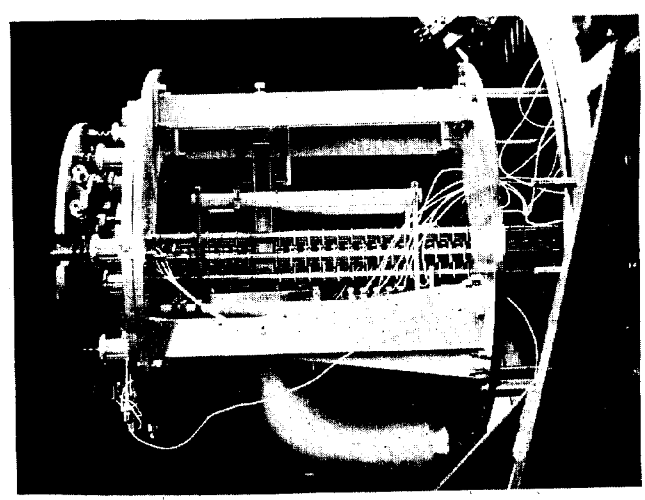

Fig. 8. The LEBT section. The 40 kV extraction system is mounted on the left side of the supports which also holds the quadrupole lens elements. The buncher with the (90° bended) coaxial pipe and the capacitive tuning mechanism is seen in the middle.