

STATUS OF THE FOM-MEQALAC PROJECT

P. W. van Amersfoort, R. G. C. Wojke, W. H. Urbanus, A. E. van Putten, R. J. J. M. Steenvoorden

Association EURATOM-FOM, FOM-Institute for Atomic and Molecular Physics,
Kruislaan 407, 1096 SJ Amsterdam, The Netherlands

H. Klein, A. Schempp, T. Weis

Institute for Applied Physics, University of Frankfurt,
Robert-Mayerstrasse 2-4, 6000 Frankfurt/Main, Federal Republic of Germany

The current status of the MEQALAC project is reviewed. This project deals with multichannel acceleration of light ions in a resonator. The space charge dominated beams are focused by arrays of miniaturized electrostatic quadrupoles. In Stage I we accelerated four beams of He^+ ions with a current of 2.2 mA each from 40 keV to 120 keV. The channel radius was 2.5 mm. The objective for Stage II is to accelerate four beams of N^+ ions to 1 MeV. This Stage is under construction. Design tests on various components are presented.

Introduction

At the FOM-Institute in Amsterdam a novel device for acceleration of intense ion beams to MeV energies is studied, namely the Multiple Electrostatic Quadrupole Array Linear Accelerator (MEQALAC). In this approach, which was proposed by Maschke,¹ ions are accelerated through parallel channels. These contain a series of gaps carrying an accelerating rf voltage, with electrostatic quadrupole lenses placed between them. The quads are needed to provide radial stability. The power efficiency of a MEQALAC can be made an order of magnitude higher than the efficiency of an RFQ, in which rf power is used for acceleration and for transverse focusing. The total accelerated current can be increased via an increase of the number of channels.

Our experimental set-up is schematically shown in Fig. 1. It consists of a multicusp ion source with a 40-kV extraction system, a Low Energy Beam Transport (LEBT) section and the MEQALAC section, which is a modified Interdigital-H-resonator. The LEBT section provides space for pumping and a drift length for the buncher. Our experiment contains four channels with a diameter of 6 mm in the LEBT section and 5 mm in the MEQALAC section. The quadrupole lenses are arranged in a FODO structure. The quadrupole length in the LEBT section is 10 mm, and in the MEQALAC section it increases proportionally with the drift length between the gaps (i.e. proportionally with $\beta\lambda/2$, where β is the normalized particle velocity and λ is the wavelength of the rf field). All quadrupoles are kept at the same potential except for the first five of the LEBT section, which form the matching section. These are biased independently and serve to match the transverse emittance of the extracted beams to the acceptance of the channels. More information about our experiment can be found in Ref. 2.

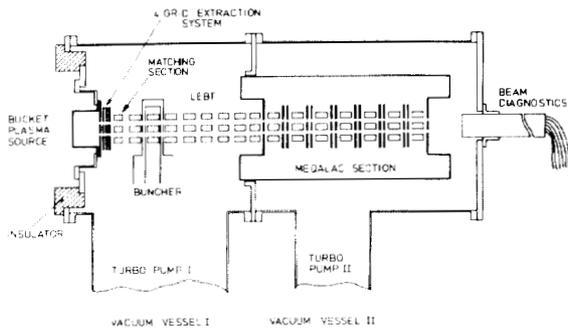


Fig. 1
Set-up of the FOM-MEQALAC experiment

The MEQALAC project consists of two stages. In stage I, which was terminated in 1986, we injected four parallel beams of He^+ ions into a cylindrical resonator with 20 rf gaps. A maximum time-averaged current of 4×2.2 mA was accelerated to 120 keV.³ Stage II is designed for acceleration of four beams of N^+ ions to 1 MeV in a new resonator with a rectangular cross section. The resonance frequency can be changed by varying the width of the cavity. This offers the possibility to vary the exit energy while maintaining the same accelerating structure.

In the following we first present measurements on production of N^+ ions with our source. The maximum allowable gradient of the gap voltage distribution in the resonator is discussed next, and rf measurements done in the course of designing a cavity with a suitable gradient are presented. Further, we report on the possibility to vary the resonance frequency.

Extraction of nitrogen ion beams

Our source is of the "bucket" type. It has a diameter of 14 cm and a depth of 11 cm, and contains two tungsten filaments. CoSm permanent magnets are placed on the outside (except for the front plate) giving a line-cusp magnetic field. The front plate is kept at the same potential as the filaments to repel plasma electrons. The

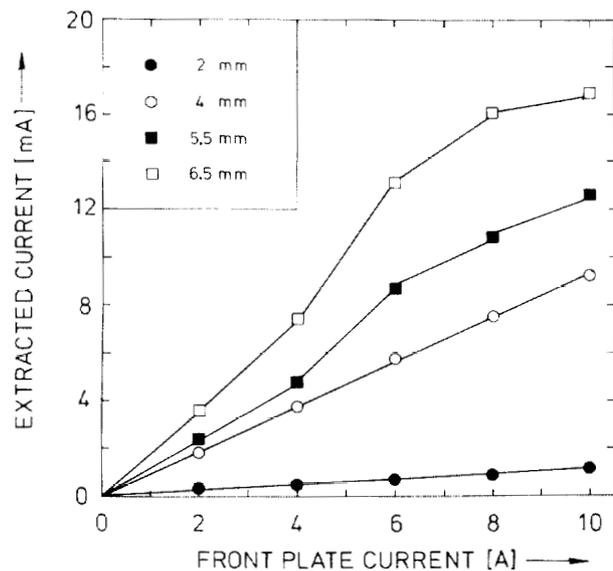


Fig. 2.
The extracted nitrogen ion current as a function of the current to the front plate of the source, for extraction apertures with diameters ranging from 2 mm to 6.5 mm. The arc voltage and current are 120 V and 10 A, respectively. The source is kept at a potential of 40 kV, and the first electrode of the extraction system is biased at 36 kV. The unnormalized emittance of the extracted beams is typically 10π mm mrad.

extraction system consists of four grids. During the past years we routinely extracted 40-keV beams of He⁺ ions with currents upto 16 mA, at an unnormalized emittance of typically 10 π mm mrad.

Results on production of nitrogen ions are shown in fig. 2, where we give the ion current extracted from a single aperture as a function of the plasma current to the front plate. The latter is proportional to the plasma density. It is seen that a maximum current of 17 mA can be extracted from an aperture with a diameter of 6.5 mm. The mass distribution of the extracted beams is shown in fig. 3. The N⁺ ion fraction rises with increasing plasma density, upto a maximum of 50% at a front plate current of 10 A. Space-resolved measurements have shown that the N⁺ and the N₂⁺ component are homogeneously distributed over the cross section of the beam. The Reiser limit for the maximum current that can be transported through a channel of our LEPT section amounts to 7 mA at a particle energy of 40 keV and a phase advance per cell of 60°. In calculating this limit we assumed that the beam radius in the periodic channel is 2 mm.

At the time of this conference we are investigating the transport of beams containing N⁺ and N₂⁺ ions through the LEPT section. A point of interest is, whether there is a difference in transmission for the two species.

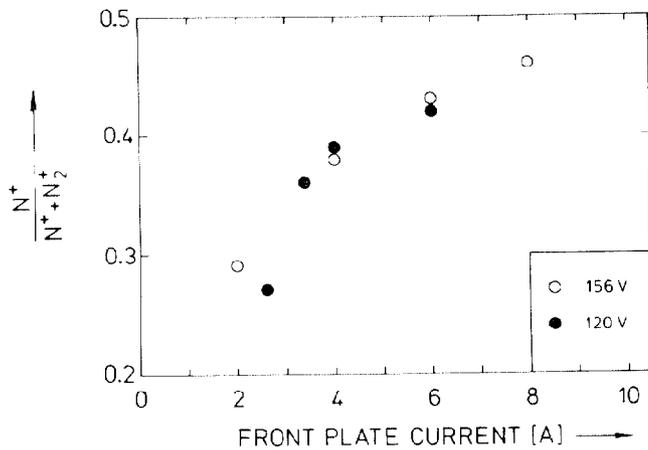


Fig. 3

The N⁺ ion fraction in the extracted beam as a function of the current to the front plate, for two values of the arc voltage. The arc current is 10 A.

Limits on longitudinal focusing

At a negative synchronous phase, the rf field in the gaps of a linear accelerator increases during the time a particle is travelling through a gap. This leads to longitudinal focusing: particles in front of the synchronous particle experience a smaller electric field, and particles behind it experience a higher field. In case of injection of a cw beam this results in formation of a bunch. In the following we briefly discuss the influence of the focusing field on the accelerated current.

Our initial idea was to give the voltage in the first gaps of our Stage-II MEQALAC a value close to the Kilpatrick limit (which is roughly 50 kV for the planned gap width of 4 mm), to minimize the overall length of the structure. However, PARMILA simulations have shown that, at our injection energy of 40 keV, this gives rise to severe particle losses, which are due to three effects: (i) the strong compression in the longitudinal direction causes a space-charge induced blow-up in the transverse direction, (ii) the transverse component of the rf field at the entrance and exit side of the gaps causes strong defocusing, and (iii) the large energy spread in the bunch causes mismatch. A solution for these problems is to reduce the ratio of the voltage in the gaps at the entrance of the cavity and the extraction voltage. This way, we arrive at a scheme in which the gap voltage increases smoothly along the first cells of the structure, so that the particle energy is significantly above the injection energy once the full gap voltage of 50 kV is encountered.

The resonator

A schematic of our resonator is shown in fig. 4. This modified Interdigital-H-cavity has a rectangular cross section, which is convenient for frequency tuning. It contains two meander-like structures. The "fingers" of these meanders form the accelerating gaps. Quadrupole lenses are placed in the field-free drift spaces inside the fingers. Shorting plates can be mounted between the first gap and the front plate of the cavity.

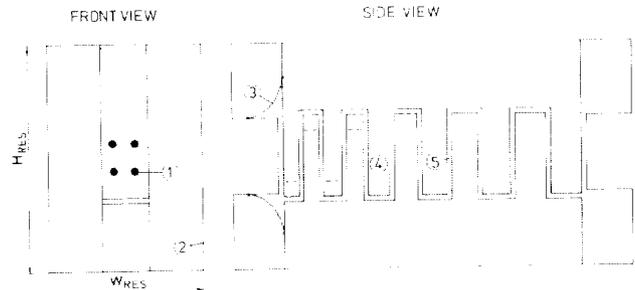


Fig. 4

The MEQALAC resonator: (1) beam apertures, (2) side plate, (3) shoring plates, (4) fingers, (5) accelerating gaps.

The voltage distribution over the 25 rf gaps, as obtained on a 1:3 scale model without shoring plates, is shown in fig. 5. When shoring plates are mounted a "linear ramp" of the field is obtained at the entrance side of the cavity. With this approach the demand of weak acceleration in the first gaps is satisfied. However, it has the disadvantage of a reduction of the R_p-value, which cannot be completely explained by the accompanying shift of the resonance frequency. This effect can be counteracted by decreasing the length of the first eight fingers of the meander structure (as indicated by the broken lines in fig. 4), which fortunately also leads to an even steeper ramp of the field.

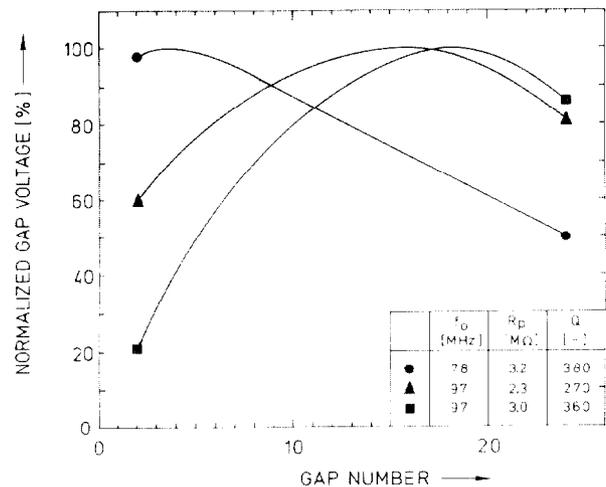


Fig. 5.

The voltage distribution over the rf gaps, normalized to the maximum value. Circles: no shoring plates mounted. Triangles: shoring plates mounted. Squares: shoring plates mounted and fingers with a 30% shorter length at the entrance side.

Our explanation for these observations is as follows. Without shoring plates, rf magnetic field flows around the meanders, through the free volume of the resonator. The induced azimuthal

wall current produces the accelerating gap voltage. The observation that this voltage decreases at the high-energy side of the cavity is probably related to the increasing cell length, which reduces the magnetic coupling of succeeding gaps. Mounting shorting plates forces the magnetic field to flow through the narrow space between these plates and the meander structure; the corresponding extra wall current leads to increased losses. By reducing the finger length we provide more free space for the magnetic field, thus reducing the losses.

Next, we discuss frequency tuning. The resonance frequency f_0 of our cavity can be changed via a variation of the resonator width, which is equivalent to a variation of the inductance. Results obtained on the scale model are shown in fig. 6, where we give f_0 as a function of the ratio of the resonator width w_{res} and height h_{res} . It is seen that f_0 decreases rapidly with increasing width for $w_{res}/h_{res} < 1$, and saturates for $w_{res}/h_{res} > 1$. This is related to the fact that, at a large width over height ratio, a fraction of the current in the walls flows around a path which is shorter than the outer circumference of the cavity, i.e. it flows along the end plates closing the cavity. The inductance is then no longer a function of w_{res} . A reduction of f_0 by a factor $\sqrt{2}$ is easily obtained by increasing w_{res}/h_{res} from 0.5 to 1. The corresponding reduction of the exit energy of the N^+ ions is from 1 MeV to 500 keV.

References

1. A. W. Maschke, Brookhaven Natl. Lab. Rept. BNL-51209 (1979).
2. E. H. A. Granneman *et al.*, Proc. Third Int. Conf. on the Production and Neutralization of Negative Ions and Beams, BNL, Upton, 1983, Ed. K. Prelec, AIP Conf. Proc. 111, New York, 1984.
3. P. W. van Amersfoort *et al.*, Proc. Linear Acc. Conf., SLAC, Stanford, 1986, SLAC Rept. 303 (1986).
4. M. Reiser, J. Appl. Phys. **52** (1981) 555.

Acknowledgements

This work is part of the research program of the association agreement between the Stichting voor Fundamenteel Onderzoek der Materie and EURATOM, with financial support from ZWO, EURATOM and the Nederlandse Ministerie van Onderwijs en Wetenschappen.

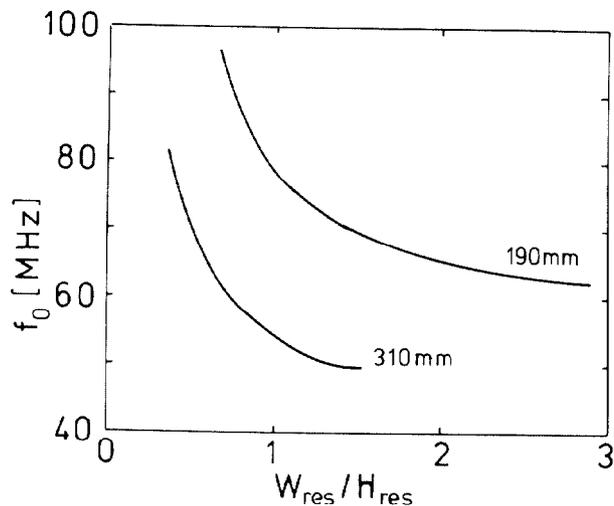


Fig. 6. The resonance frequency f_0 as a function of the resonator width w_{res} divided by the height h_{res} , as obtained on a 1:3 scale model without shorting plates. Results for a height of 190 mm and 310 mm are shown.