A NEW INJECTOR CONCEPT : THE RFQ - CYCLOTRON COMBINATION AT ISL - BERLIN

B. MARTIN, W. BUSSE, H. HOMEYER, W. PELZER

Hahn-Meitner-Institut Berlin GmbH, Bereich Festkörperphysik, Glienicker Str. 100, D - 14109 Berlin, Germany

A. SCHEMPP, O. ENGELS, F. MARHAUSER

J. W. Goethe-Universität Frankfurt, Institut für Angewandte Physik, Postfach 111932, D - 60054 Frankfurt / M., Germany

A new injector for the ISL-Berlin Cyclotron is under construction. It consists of a 200 kV platform with a permanent magnet ECR source and a two stage frequency variable RFQ accelerator. The injector is specially designed to produce high intensity beams with energies of 90 to 350 keV/amu and charge to mass ratios of 1/8 to 1/5 without using a stripper. The final energies out of the cyclotron are 1.5 to 6 MeV/amu. The coupling of a RFQ to a cyclotron needs special matching requirements for frequency, energy and bunching. The beam transport calculation, the design of the injection beam line and the status of the project will be discussed.

1 Introduction

The scientific program of our department underwent a significant change in the last years. Nuclear physics is closed almost totally and the accelerator is now used for solid state physics, materials modification and -analysis. An additional application will be the therapy of ocular melanoma with proton beams[1]. Therefore the requirements on the properties of the beams changed drastically. There is no longer need for high energies, but for beams with high intensities and energies around 5 MeV/amu. In 1993 it was decided to modify the old VICKSI facility[2] : The tandem injector should be replaced by a high current injector for the cyclotron. Several types of accelerators had been investigated as possible alternatives. In this paper we describe the solution we found and the status of the project.

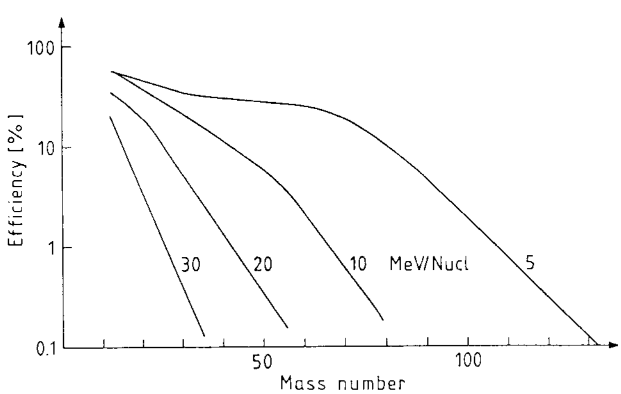

Figure 1: Stripper efficiencies for beams with different energies extracted out of the cyclotron versus ion mass.

2 Possible high current injector

As our cyclotron has no central region (the injection radius is about 43 cm) and as its energy gain factor is about 17, we have to inject the ion beams with energies of some hundred keV/amu to get beams with energies of several MeV/amu out of the cyclotron. The charge state Q of the ions which is needed for the cyclotron is given by :

$$Q / A = \mathrm{SQRT}\,(E / (K * A))$$

with E = extr. energy
K = 133
A = atomic mass

The only injector in use now is a 6 MV Van-de-Graaff with an ECR - source[3]. A stripper is used between injector and cyclotron to increase the charge state of the ions. This has the following disadvantages :

- For ion beams with masses higher than 40 a foil stripper is used. The stripper efficiency for the charge state needed for the cyclotron injection goes down exponentially as shown in fig. 1.

- The maximal current on a stripper foil is limited by the life time of the foil. For beam currents of some eμA and for heavy ion masses the life time is in the range of 15 minutes only.

To increase the beam current a solution without using a stripper was looked for. As there are powerful ion sources available, which deliver intense beams with high charge states we wanted to use such a source to produce directly ion beams with the desired charge state for the cyclotron. A suitable source for this purpose is an Electron Cyclotron Resonance (ECR) source[4]. To keep the energy variability, the injector should deliver beams with variable energy and with the needed time structure. At the start of the discussion in 1990 the only possible injector which met our conditions was a small cyclotron[5]. In 1992 we found a simpler solution by using a frequency variable **Radio Frequency** Quadrupole (RFQ) accelerator as injector.

3 The new RFQ - cyclotron combination

The desired energy for this combination should reach from 1.5 to 6 MeV/amu. The needed charge to mass ratio for those beams are 1/8 to 1/5. Ions with these charge states can be produced by ECR sources with sufficient intensities. At the time of our discussion the first frequency variable Radio-Frequency-Quadrupole accelerator designed by A. Schempp came in operation[6]. A variation of the frequency by a factor of 1.4 is possible, which results in an energy variation of a factor of 2. When the RFQ is splitted up in two cavities, an energy variation of 4 is possible : With both in "normal" operation, energies of 3 to 6 MeV/amu should be attainable. Accelerating only with the first one and using the second one for transporting the beam, this system should deliver beams from 1.5 to 3 MeV/amu. A comparison of intensities of beams made with the Van-de-Graaff injector + stripper and with the RFQ for a beam energy of 5 MeV/amu out of the cyclotron is shown in fig. 2.

This figure shows, that the RFQ - cyclotron combination equipped with a powerful state of the art ion source can deliver by a factor of 5 to 10 higher beam currents and a larger variety of ion species especially for heavier elements

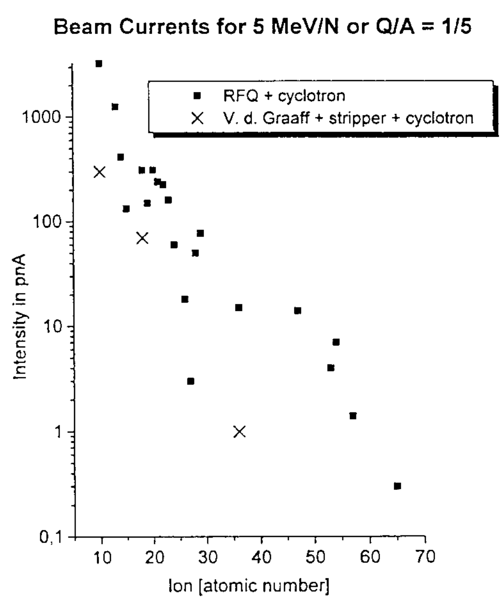

Figure 2: Intensities of ion beams with an energy of 5 MeV/amu out of the cyclotron for 2 different injectors versus atomic number (for the RFQ injector a total transmission from the source to the experiment of 10 % is assumed).

than the V.-d.-Graaff - cyclotron combination with a stripper. As the ion source of the V.-d.-Graaff is inside the pressure tank, it is relatively complicated to produce ions from other materials than gases. Whereas the ECR source for the RFQ is relatively easy to access and allows the production of practically all ion species.

The RF-frequency of our cyclotron is variable from 10 to 20 MHz and the working frequency of a RFQ is typically in the range of 100 MHz. Therefore the RFQ frequency was chosen as the 8. harmonic of the cyclotron frequency. To get the desired energy from the cyclotron, the energy of the beam extracted from the RFQ has to be between 90 and 350 keV/amu, which can be reached easily. To make the RFQ as simple and short as possible, the beam will be preaccelerated and prebunched, especially as we have almost all the parts needed for this purpose from our old tandem injector.

The conditions for the new injector are :

- High currents of highly charged ions with charge to mass ratio of 1/8 to 1/5.
- Preacceleration to energies in the range of 60 to 180 kV times charge state.
- Emittance matching of the beam to the acceptance of the RFQ :

  Beam size : 1.5 x 1.5 mm
  Divergence : about 30 mrad
  Puls length : 1 nsec
  Energy width : +/- 1.5 %

3.1 Preinjector

To preaccelerate the beam, the old 200 kV platform from the tandem injector will be used. The platform had been dismantled at its old position and is now installed in the tandem tower on a lower floor. As there is only limited electric power available on that platform, a permanent magnet 14.5 GHz ECR source will be used. This source had been designed by P. Sortais, GANIL, and is being built by PANTECHNIK S. A., Caen, France, and will be

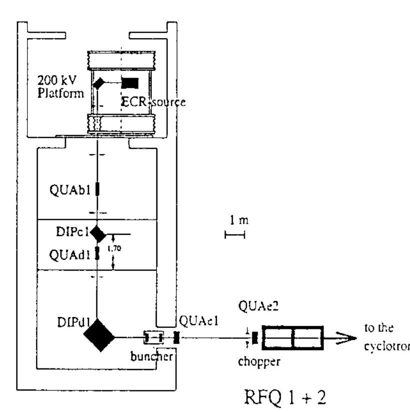

Figure 3 : Injector assembly

delivered end of 1995. The beam line system is under construction using the old components of the tandem beam line. A target place to use the low energy beam from the platform is foreseen. The buncher and the chopper to produce one nsec long beam pulses in front of the RFQ are under construction. The first tests of the injection system with beam are planned for spring 1996. A sketch of the injector is shown in fig. 3.

A calculation of the beam envelope from the exit of the 200 kV acceleration tube to the entrance of the RFQ is shown in fig. 4. The upper curve shows the horizontal, the lower the vertical beam size. The lowest curve shows the puls length.

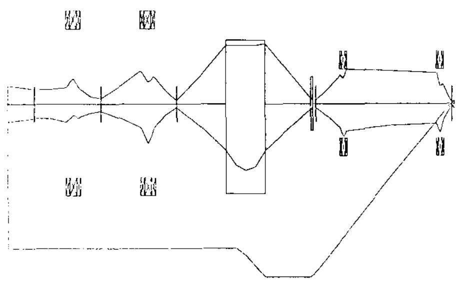

Figure 4: Beam envelope from the exit of the 200 kV acceleration tube to the entrance of the RFQ.

3.2 RFQ injector

The RFQ injector has been designed by A. Schempp and coworkers. It is being built by NTG Neue Technologien GmbH & Co. KG, Gelnhausen, and should be delivered together with the RF amplifiers and the control system in summer 1996. A detailed description of this device is given in ref. 7. The parameter of the RFQs and some other relevant parameter are given in table 1. The RFQ tank is nearly completed and the quadrupole rods are under fabrication.

One problem in the design of the RFQ was to match the parameters of the extracted beam to the requirements of the cyclotron [8]:

- The RFQ extraction energy should agree with the cyclotron injection energy better than 0.2 %.

- The energy width of the extracted beam should be smaller than about 1 % and the puls length smaller than 1 nsec.

- The emittance should be smaller than 10 π mm mrad.

Calculation shows, that the extraction energy agrees well with the cyclotron injection energy. When only one RFQ is used (for the low energy band), the energy width and the pulse length of the beam extracted from the RFQ is rather large. An additional buncher just behind the RFQ may cure the problem.

3.3 Beam line system from the RFQ to the cyclotron

The layout of the beam line system from the RFQ to the cyclotron is shown in fig. 6. It is about the same as used with the tandem injector before. An additional dipole will be installed to use the beam from the RFQ for low energy experiments. The beam envelope is shown in fig. 5.

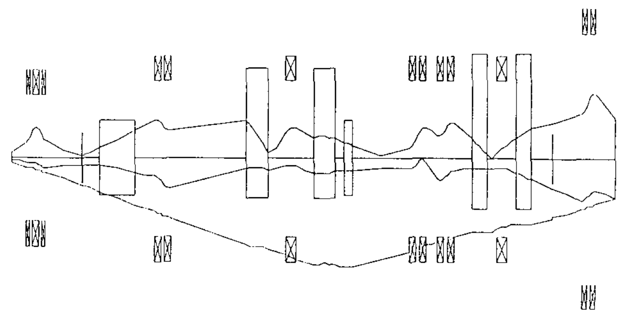

Figure 5: Beam envelope from the RFQ to the cyclotron.

4 Conclusion

The combination of an ECR source with preinjector and buncher, a frequency variable RFQ and a cyclotron should be a rather simple and reliable accelerator system to produce intense heavy ion beams with energies in the range of several MeV/amu. The new injector will deliver a wide variety of ion species up to masses of about 180.

This new accelerator will mainly be used for solid state experiments beginning in 1997, while the old V.-d.-Graaff cyclotron combination will be used for the proton tumor therapy. While one injector is in use with the cyclotron the other one can be used for low energy experiments.

References

1. H. Homeyer, this conference.

2. W. Busse, B. Martin, R. Michaelsen, W. Pelzer and K. Ziegler, EPAC 1988, Rome, (World Scientific 1989), p. 448.

3. P. Arndt et al., NIM B 89 (1994) 14 - 16.

4. P. Sortais, NIM B 98 (1995) 508 - 516.

5. W. Pelzer, Cyclotrons '92,Vancouver 1992, (World Scientific 1992) p. 519

6. A. Schempp et al., Proc. 2nd Europ. Particle Accelerator Conf., Nice, 1990, eds. P. Marin and P. Mandrillon (Editions Frontieres, Gif-Sur-Yvette, 1990) p. 40.

7. A. Schempp et al., EPAC 1994, London, (World Scientific 1994) 566 - 568.

8. W. Pelzer, A. Schempp, NIM A 346 (1994) 24 - 30.

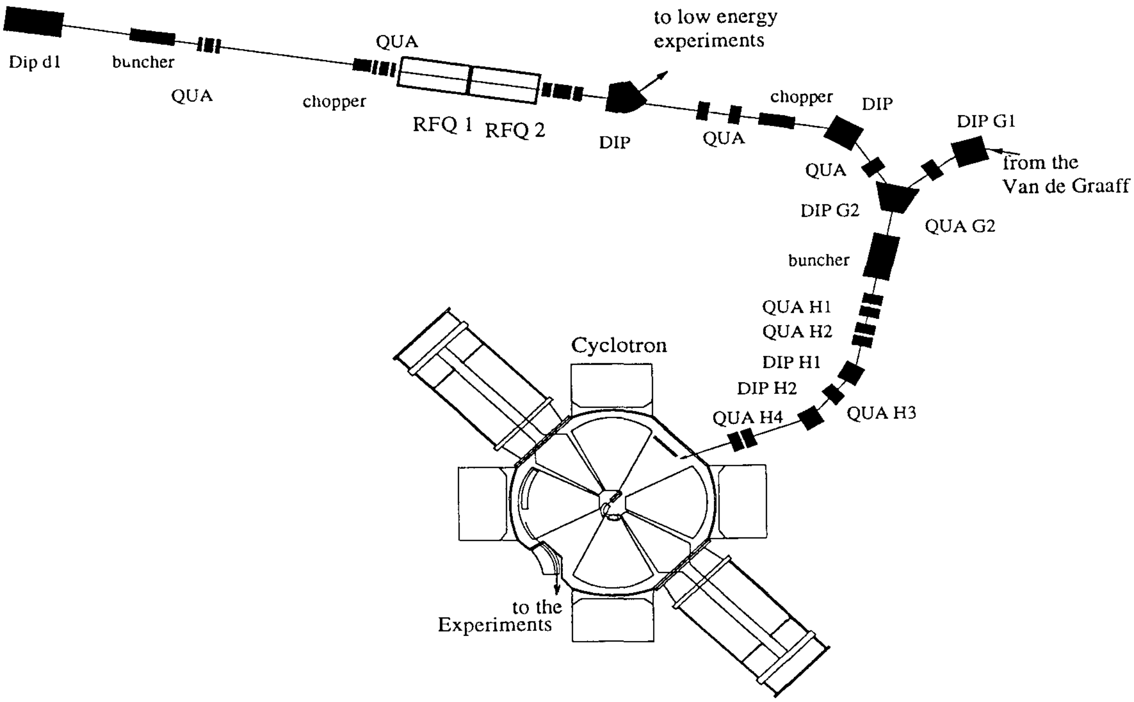

Figure 6: Beam line system from the end of the vertical part to the cyclotron.

Table 1: Parameter of the accelerator system

	RFQ 1 (RFQ 2 transporting)	RFQ 1 + 2	
CYCLOTRON			
Extr. Energy	1.5 - 3	3 - 6	MeV / amu
Frequency	10.6 - 15.	10.6 - 15.	MHz
Harmonic No. *)	7	5	
Energy Gain	16.5 - 16.8	16.8 - 17.2	
Puls Length	1	1	nsec
RFQ			
Extr. Energy	91 - 178.3	178.1 - 349.6	keV /amu
Frequency	85.6 - 119.8	85.6 - 119.8	MHz
Harmonic No. **)	8	8	
Energy Gain	6	11.76	
Inject. Energy	15. - 30.	15. - 30.	keV / amu
Acceptance	39 - 27	39 - 27	π mm mrad
Emittance	13 - 11	10 - 7	π mm mrad
Energy Width (extr.)	0.9	0.4 - 0.5	+/– %
Puls Length (extr.)	5.8 - 4.6	0.5	nsec
Transmission	60 - 81	90 - 98	%
ECR SOURCE			
Charge / Mass	1/8 - 1/6	1/6 - 1/5	
Extr. Voltage	20	20	kV
Emittance	100	100	π mm mrad
200 kV PLATFORM			
Voltage	100 - 173	40 - 120	kV

*) Harmonic No. of the particle revolution frequency   **) Harmonic No. of the cyclotron frequency