CHANGING VICKSI INTO ISL:
A VE-RFQ AS INJECTOR FOR THE CYCLOTRON

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1 INTRODUCTION

Since 1978 the HMI Berlin runs the accelerator facility VICKSI [1], which provides a large variety of heavy ion beams with energies in the range of 1 to 32 MeV/A. Originally designed for nuclear physics, the use of the machine has shifted to solid state physics applications, materials modification and -analysis [2,3,4]. Another important future application of our machine is to provide proton beams of 70 MeV for regular therapy of ocular melanoma [5,6]. These two fields demanded major changes of accelerator design and operation: The conversion of VICKSI into an Ion Beam Laboratory, ISL-Berlin [6,7].

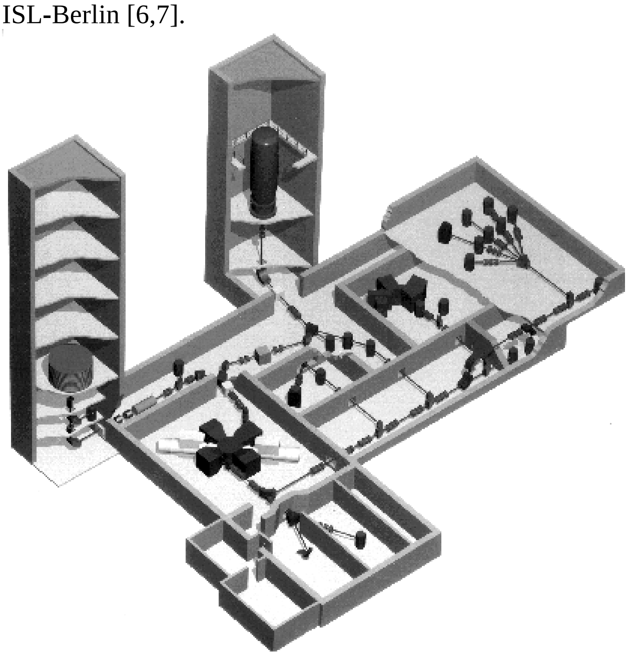

Fig. 1: Schematic layout of the main accelerators of ISL-Berlin

We report on the status of the new VE-RFQ injector project, which is under construction. This injector comprises some novel features. Its special RFQ-structure [8] with large-range frequency variability, continuous wave (CW) operation, and two-stage construction, was developed by IAP, the Institute of Applied Physics, at the Johann Wolfgang Goethe Universität Frankfurt.

2 ACCELERATOR CONCEPT

2.1 Reasons for reconstruction

The high-energy VICKSI ion beams are extracted from a cyclotron with radial injection. The ratio of extraction- to injection-energy corresponds to an energy gain of 17. The ions are injected to a fixed radius of 43 cm and require high charge to mass ratios for acceleration. At present this is achieved by stripping the preaccelerated beams from a 6 MV CN Van-de-Graaff injector. Up to 1994, an 8 MV UD Tandem was alternatively used as second injector.

The former nuclear physics use of our accelerators emphasized demands for heavy ion beams at a broad energy range but with moderate intensity. "Beam on target" was usually delivered for periods of days. Other applications require different features. Solid state physics experiments often demand more intense beams over a wide range of different masses. However, a clear preference for beam energies of around 5 MeV/A can be seen, as far as our high energy beams from the cyclotron are concerned. Runs are considerably shortened, sometimes down to only a few hours.

These changed requirements led to the decision to replace the Tandem by a VE-RFQ injector: It is this type of accelerator, if used together with an ECR-source at high potential, which will allow for faster setup of more intense heavy ion beams at moderately variable energy [9,10].

The maximum beam current on target will be in the order of a magnitude higher than the one delivered by the recently upgraded CN-injector (new ECR-source on the terminal, [11]). The RFQ-injector offers the necessary high q/A ratio produced by the RFQ's ECR-source directly [12], up to very high masses with good beam intensities and without additional stripping. Due to the strong focusing within its structure the RFQ-transport has practically no intensity limit [13] for our applications as in the case of Van-de-Graaff tubes. Compared to the electrostatic machines, we expect less maintenance- and beam setup-time with the RFQ-injector. All the accelerator parts and the new source are easily accessible, a spark will not cause severe breakdowns, the charge state is selected at the source and not obscured by

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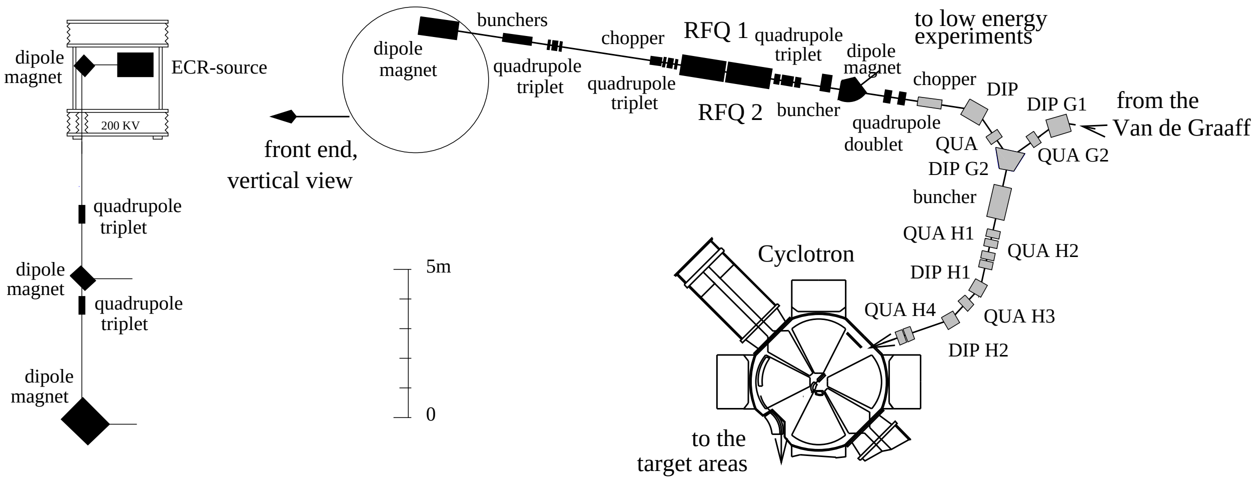

Fig. 2: RFQ-injector layout

further stripping, and a straightforward injection scheme with stable parameters will simplify the setup.

The project is attractive from an accelerator builders point of view, too. It is the first time for an RFQ-type of accelerator to be employed as an injector for a cyclotron. This poses several challenges to the designer, such as energy variability and CW-operation for the RFQ, or beam matching for RFQ-injection and -extraction.

2.2 RFQ Injection Beamline

The injection layout is shown in figure 2. The RFQ-injector is installed within the former Tandem area. As many of the components of the old beamlines as possible are reused.

Starting with the front end, the heavy ion beams are generated by an ECR-source of type SuperNANOGAN [12] from the company PANTECHNIK [17]. This source delivers analyzed beams with currents of more than 1 eμA up to a q/A ratio of 0.2 even at very heavy masses like these of Krypton or Xenon ions. The magnetic fields are formed with permanent magnets, the microwaves are supplied by a 14.5 GHz generator. Because of its low power consumption this source can be elevated to HV, with the power delivered from an isolation transformer. The former Tandem source platform is used to give up to 200 KV of preacceleration. Compared to other RFQ-machines, this preacceleration means a rather high injection energy of 15 to 30 KeV/A. This allows for a design of the transport line, which gives a reduction of beam spot size at the RFQ-entrance down to only 3 mm, and enables bunching. The beam line to the RFQ extends over a total length of 15 m. The first dipole magnet downstream of the platform leads to a target place for optional near-surface implantation and modification of materials. The second magnet is the monochromator for the RFQ. This magnet's large bending radius provides the means to ensure energy stabilization down to the 10^{-4} range, which is necessary for our double drift bunchers. The bunching introduces an energy spread of about 3 % with the available drift length preceding the RFQ, which is larger than originally assumed [14]. This energy spread is difficult to cope with especially in the transport-mode (see section 2.4).

2.3 RFQ Accelerator

Acceleration is achieved in two stages with RFQ-structures of the VE-RFQ-type, mounted in one common vacuum tank. The design is described in several reports [e.g. 9, 15]. The main RFQ-data are given with table 1:

Table 1: Main RFQ data

One RFQ-tank with 2 RFQ-structures (2 "stages"). Continuous wave operation of both stages at the same frequency, but with beam injection phase of the second stage either tuned (Acceleration-mode), or detuned (Transport-mode)
Operating frequency band: 85 to 120 MHz.
Maximum voltage amplitude: 50 KV, at maximum power losses of 20 KW per stage
Length per stage: 1.44 m; Beam aperture: 4.5 mm,
Beam input: energy from 15 to 30 KeV/n; charge to mass ratio 1/8 to 1/5; bunched to 1 ns pulse width at cyclotron frequency 10.6 to 15 MHz.
Beam output: energy from 90 to 360 KeV/A

The most advanced features are

- wide-band frequency variability (approximately 40 %, resulting in a factor of 2 in energy variability)
- Continuous wave operation (special milled copper profiles with integrated cooling channel)

- Two stage construction (additional factor of 2 in energy variability)

2.4 Transport to the Cyclotron

The extracted RFQ-beams are injected into the cyclotron via 20 meters of beam line (see figure 2). Just the first 5 meters after the RFQ-tank need reconstruction to cope with special emittance requirements. The rest (shaded parts) is the unaltered former transfer line. Experience from earlier RFQ-projects set the startup data for the calculation of the extraction layout [14]. These data had to be revised after the final RFQ-design was achieved:

- Enlarging the beam aperture of the RFQ-channel at the exit helped the beam divergence to be kept below 12 mrad. Still, due to this large divergence the first quadrupole triplet had to be moved close to the RFQ-exit, at cost of less effective beam diagnostics.

- In Transport-mode, up to 1/3 of the beam will be lost within the second RFQ-stage. The time- and energy-spread of the remaining beam at the RFQ-exit will reach 5 ns and 1.8%, respectively. The injection of this beam into the cyclotron calls for an additional buncher. A deflection magnet will be installed to use the RFQ-beam for future implantation and ion-solid-interaction experiments.

3 STATUS

At present, the RFQ-manufacturer NTG [18] is finishing the production and started assembly and alignment. Fig. 3 shows the structure in the vacuum tank, electrodes not yet installed. The delivery of the RFQ-accelerator was originally planned for the end of 1995. Mainly due to late amplifier manufacturing the project is delayed by about a year. The contractor will demonstrate full RFQ operational vacuum and rf data before delivery.

The ECR-Source has been tested successfully with several different beams. The 200 KV high voltage platform is ready for acceleration and will be tested with beam together with the vertical part of the injection beam line as soon as the cabling is finished.

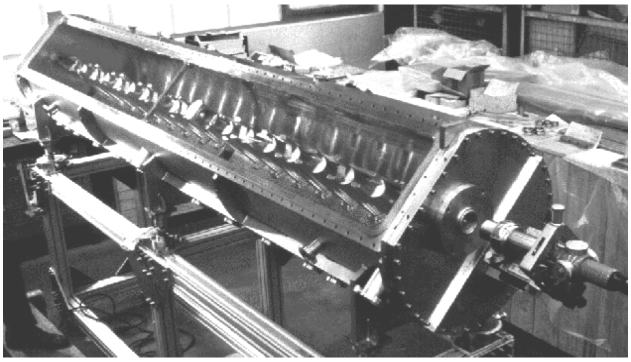

Fig. 3: RFQ under assembly

The horizontal part of the injection beam line is presently being aligned. Later beam tests will include full emittance probing at the location of the RFQ-entrance.

Since the extracted beams from the RFQ-injector can be transported through the former Tandem/Cyclotron beam line, only the first 5 meters of beam line after RFQ- extraction have to be reconstructed. The assembly will start after delivery and alignment of the RFQ-structure.

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