Two RFQs have been built as injectors for the 50 MeV H- Linac for the HERA project at DESY. A 4-Vane RFQ as well as a 4 Rod RFQ deliver 750 keV H- beam currents higher than the design value of 20 mA at minimum emittance growth. Properties of both structures and new experimental results are presented.

Introduction

For the HERA project at DESY 1-6 a RFQ has been chosen as injector for the 50 MeV Alvarez Linac. Fig. 1 shows the RFQ preaccelerator layout using a FNAL H- source and two CERN type solenoids for beam matching into the RFQ. The RFQ is closely attached to the Alvarez to avoid problems with matching. The beam dynamic design has been made using the standard LANL approach with some modifications and has been tested with the PARMTEQ code. The RFQ design is summarized by: input energy 18 keV, output energy 750 keV, total length 118 cm, frequency 202.56 MHz, inter-vane voltage 70.5 kV, beam current 20 mA, maximum modulation 1.88, number of cells 135, minimum aperture 3.5 mm, normalized input/output emittance 0.7/1.0πmm mrad (90%, ellipse appr.), energy spread 10.4 keV, transmission 96%.

The rf-resonator has to provide the quadrupole voltage and should have a good efficiency, mechanical stability and reasonable dimensions. Because of the existing experience with operating RFQs it was decided to build a 4-Vane cavity as HERA injector. This experience showed as well, that the 4 Vane structure had a lot of rf-problems and very tight mechanical tolerances.

We looked for a "simple" mechanical design with minimum interference of mechanical alignment, rf tuning and vacuum and for ways of rf-stabilization to solve resp. to ease these problems. The resonator consist of a copper plated steel cylinder and vanes milled out of solid CrCu blocks, aligned on a ZEISS 3D machine.10

RLC stabilizers 11 have been developed to stabilize the fields azimuthally, because even with the milling and the alignment better than 10 μm for all dimensions, field tills introduced by asymmetries like plungers and the coupling loop and from thermal effects during operation cannot be avoided. One RLC stabilizer in each end plate made the resonator insensitive against asymmetric detuning and enabled stable operation. The figure of merit of careful rf design and tuning is the ratio of the ideal quality factor QSF calculated with Superfish to the actual unloaded Q, giving also the power consumption ratio. For the HERA RFQ this value has been measured to be as high as Qo/QSF = 0.90 while usual values are between 50% and 70%. The field flatness after tuning is within 2% (azimuthally and longitudinally).

4-Rod RFQ design

The Four Rod structure utilizes cylindrical rods with conical varying diameter as electrodes which have been firstly proposed by Kapchinskij 1 and extensively studied by Junior and Deitinghoff. 12

The RF structure driving these electrodes is a new development consisting of a linear chain of supporting stems as indicated in Fig. 2. They form a chain of intercepting λ/2 oscillators in π-mode.
which provide the quadrupole field. Longitudinally all corresponding λ/2-oscillators are in phase. Dipole modes are possible but are much higher than the operating mode because each supporting stem drives and shorts two opposite electrodes. Frequency and efficiency depend on the number and sizing of stems forming the inductance of this resonant circuit.

The rod electrodes, for which the vane tip profile of the 4Vane RFQ has been linearly approximated by cones and cylinders, have been machined on a lathe and brazed to the radial stem structure. After tuning to the operating frequency the flatness was within 2%. Surprisingly (for 4 Vane proponents) this 4Rod resonator consumes somewhat less rf power for the same electrode voltage than the 4Vane resonator even compared with the optimum values achieved for the 4Vane HERA RFQ.

**Beam Tests**

As planned since the early phases of the HERA-RFQ project, beam tests with both RFQ structures have been done at DESY at the same Alvarez injector setup. The 4Rod RFQ, which has been tested first, reached operating power levels practically without multipacting and sparks and the design beam current could be accelerated also during the first runs. Energy spread, emittance measurements and also direct measurement of the microstructure with a fast faraday cup were in good agreement with the calculations respectively design values. The 4Rod RFQ proved to be an unsensitive and reliable cavity. Practically it served as rf load as well as beam dump and test beam source for reaching the first reliability level of the injector system. The normalized emittance at 205 mA (90%) has been \( \varepsilon_N = 0.95/0.7 \) mm mrad (x/y plane) and the maximum H-current has been as high as 36 mA.

The first test with the 4Vane RFQ have been also very successful. After some multipacting the design current could be reached soon using the same injector settings as for the 4Rod RFQ. The maximum current has been 43 mA corresponding well with the PARMTEQ value of 43 mA and using the emittance parameters measured at the LEBT at RFQ entrance. Emittance measurements could only be made after redesign of the measurement device for higher beam currents resp. rf powers. Results show even a better emittance of the beam with \( \varepsilon_N = 0.7/0.5 \) mm mrad. Fig. 3 shows emittance measurements with divergent beams in both planes. Fig. 4 shows the normalized emittance \( \varepsilon_N \) as function of the accelerated beam current and a constant rf power of \( N = 93 \) kW and the corresponding curves for \( \varepsilon_N \) as function of rf power \( N \) for constant beam of \( 44 \) mA. The emittance is very insensitive to changes of beam current. The increase of \( \varepsilon_N \) than is due to the reduction of electrode voltage due to beam loading. Fig. 5 shows beam spectra as function of rf power applied. Fig. 6 shows ellipse parameters along the beam pulse which to some extend reflects the beam neutralisation distribution in the low energy beam line and the resulting mismatch at injection. Constant neutralisation of the beam is obtained after approx 100 μsec. Matching and emittance measurements are done for the "saturation" part of the pulses. These effects are studied in detail by Weis for positive ions.

Fig. 7 shows beam current \( I_{\text{RFQ}} \) as function of the ion source current \( I_S \) for both RFQ structures. Although the tuning of the source and the injection beam line had been improved for the new runs (now \( I_{\text{max}} = 54 \) mA), the difference is marginal taken into account that the first 20 cells of the 4Rod RFQ are skipped that means the first part of the electrodes are unmodulated. PARMTEQ simulations give a 20% emittance increase and a 8% smaller transmission (for the design current of 20 mA) for this case which comes very close to the measurements.

**References**

2. G. Voss, this conference
7. J. Müller, A.Schempp, IAP Frankfurt Int. Rep. 79-1, LANL, LA-TR 82 28
8. A. Schempp et al. NIM, BlO/11, 1985, p 831
10. A.Schempp et. al., Linac 86, SLAC Rep. 303, p254
11. A. Schempp, Linac 86, SLAC REP 303, p251
14. I Weis et. al., this conference
Fig. 1: Scheme of HERA RFQ Injector

Fig. 2: Schemes of 4Vane- and 4Rod- RFQs

Fig. 3: Emittance (90% beam) of the 4Vane RFQ

Fig. 4: Normalized Emittance $\varepsilon_N$ as function of Rf-Power $N$ and beam current $I$

Fig. 5: Beam Energy spectra for different Rf-power

Fig. 6: Ellipse parameters as function of beam pulse time

Fig. 7: RFQ output current $I_{RFQ}$ as function of Ion source current