PERFORMANCE OF THE DESY RFQ's

A. Schempp, M. Ferch,+ P. Schastok,++ H. Klein,
Institut für Angewandte Physik, J.W.Goethe Universität, 6000 Frankfurt/M11, FRG
K. H. Pape°, S. H. Wang°°, H. S. Zhang°° DESY, 4000 Hamburg, FRG
C. Schmidt, Fermilab, P.O. Box 500, Batavia, Il., USA

A 4-Vane as well as a similar 4-Rod RFQ have been built for use at DESY to deliver at least 20 mA of H$^-$ beam current at 750 keV for the HERA projects 50 MeV linac. Both RFQ's have greatly exceeded the design current with minimum emittance growth.

Properties of both structures and recent 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 18keV, output energy 750keV, 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 0.7/1.0 πmm mrad (90%), 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 built 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.

4- VANE RFQ DESIGN

The 4-Vane structure was first proposed by Kapchinskij [1]and has been fully developed by the LANL[2,9] group. It consists of a cylinder in which four vane shaped electrodes, whose tips are sinusoidally modulated and symetrically installed as indicated in Fig. 2. The resonator is excited in TE$_{210}$ like mode which provides the necessary quadrupole field on the axis. In addition to the precision with which the electrodes have to be milled the resonator must be highly symmetrical to avoid dipole field components which would lead to beam detoriation.

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 or 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 tilts 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 Q_{SF} calculated with Superfish to the actual unloaded Q_o giving also the power consumption ratio. For the HERA RFQ this value has been measured to be as high as Q_o/Q_{SF} = 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 4-Rod structure utilizes cylindical rods with conical varying diameter as electrodes which have been firstly proposed by Kapchinskij[1] and extensivly 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 $\lambda/2$ oscillators in π-mode which provide the quadrupole field. Longitudinally all corresponding $\lambda/2$-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 4-Vane RFQ has been lineary 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 4-Rod resonator consumes somewhat less rf power for the

present adress: + Vacuumschmelze, Hanau, FRG
++Hartmann und Braun AG, Frankfurt FRG
° Dr. B. Struck, 2000 Tangstedt, FRG
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same electrode voltage than the 4-Vane resonator (67kW and 75 kW respectively for the design voltage) even compared with the optimum values achieved for the 4-Vane HERA RFQ.

BEAM TESTS

Tests of both RFQ structures have been done at DESY using the source and low energy transport system as planned for the HERA Alvarez linac injector. The source is a magnetron type similar to that used at Fermilab[13,14] producing pulsed H^- beams of 50 mA or more. Since the aperture is elongated, typically 1mm x 5 to 10 mm long, the beam is assymetric. Ions are extracted from the source at 18 kV and transported at this energy. This determines the low energy injection for the RFQ. The low energy beam transport is very short and uses two pulsed solenoids of the CERN type for matching the beam into the RFQ.

The normalized emittance following the source is 1.4π and 0.9π mm mrad along and perpendicular to the extraction slit respectively for 90% of a 41 mA beam. At the entrance to the RFQ the emittance is 2.1π and 1.4π mm mrad in each plane [15].

The 4-Rod RFQ, which has been tested first, reached operating power levels practically without multipactoring 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[6,14].

The 4-Rod 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 20.5 mA (90%) has been 2.9/2.0 π mm mrad (x/y plane) and the maximum H^- current has been as high as 36 mA.

The first test with the 4-Vane RFQ have been also very successful. After some multipacting the design current could be reached soon using the same injector settings as for the 4-Rod 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 and rf powers. Results show a better emittance of the beam with ε_N= 2.2/1.6 π mm mrad. Fig. 3 shows emittance ellipses with divergent beams in both planes (measured 16 cm behind the RFQ end).

Fig. 4 shows the normalized emittance ε_N as function of the accelerated beam current and a constant rf power of N=93 kW and the corresponding curves for ε_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 ε_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 approximately 100 µsec. Matching and emittance measurements are done for the "saturation" part of the pulses. These effects are studied in detail by Weis[17] for positive ions.

Fig. 7 shows beam current I_{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_{max}= 54mA) , the difference is marginal taken into account that the first 20 cells of the 4-Rod 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.

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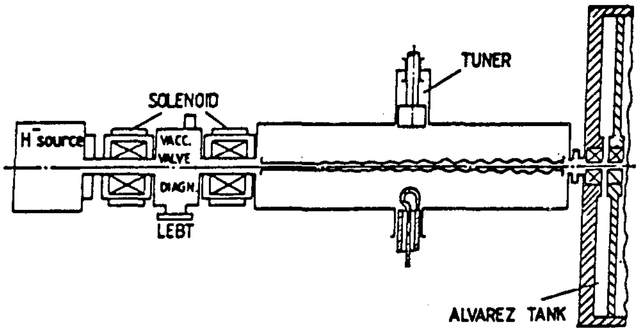

Fig. 1: Scheme of HERA RFQ Injector

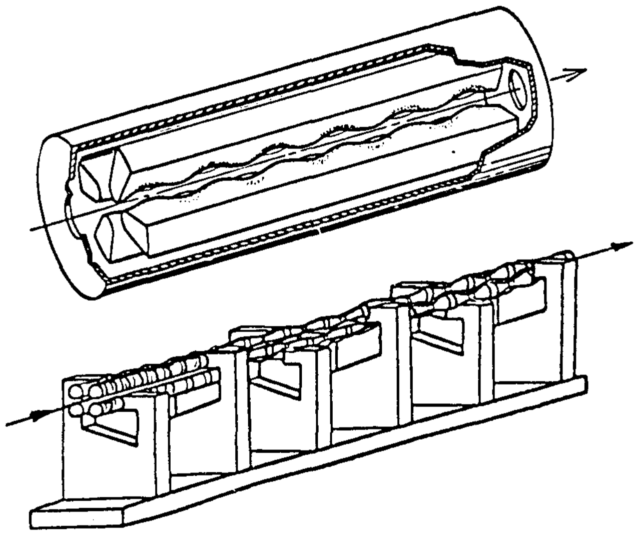

Fig. 2: Schemes of 4-Vane and 4-Rod RFQs

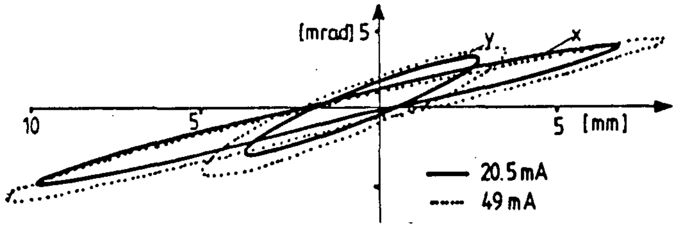

Fig. 3: Emittance (90% beam) of the 4Vane RFQ

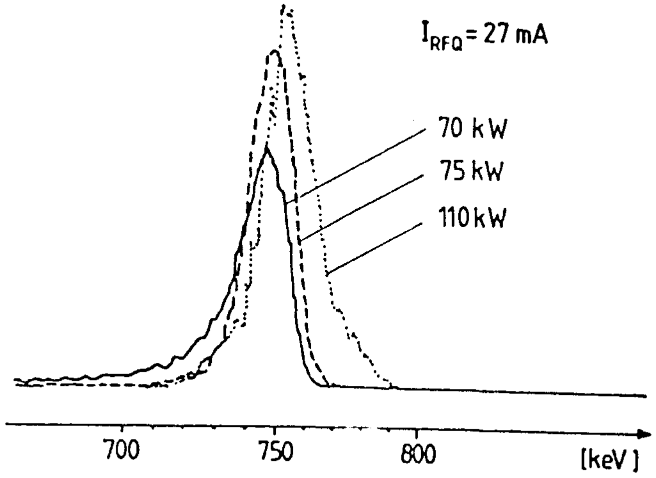

Fig. 5: Beam energy spectra for different rf-power

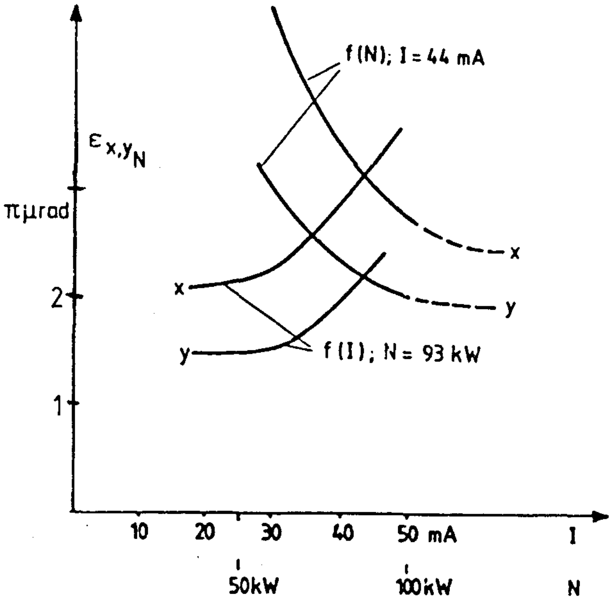

Fig. 4: Normalized emittance ε_N as function of Rf-Power N and beam current I

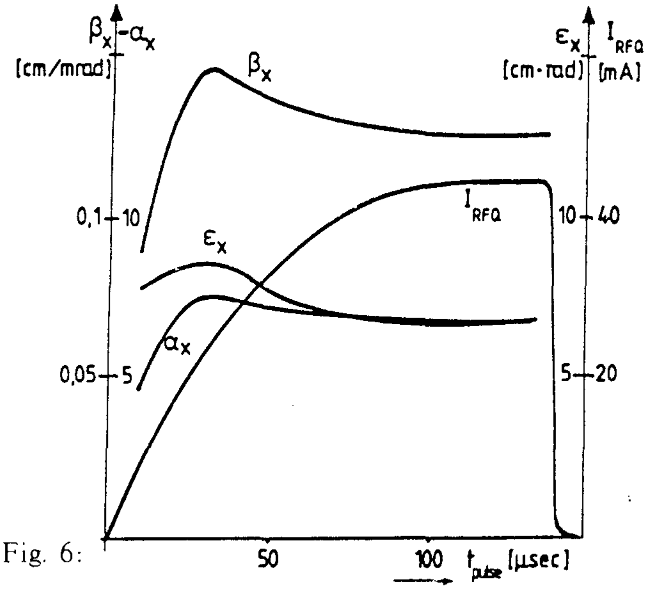

Fig. 6: Ellipse parameters as function of beam pulse time

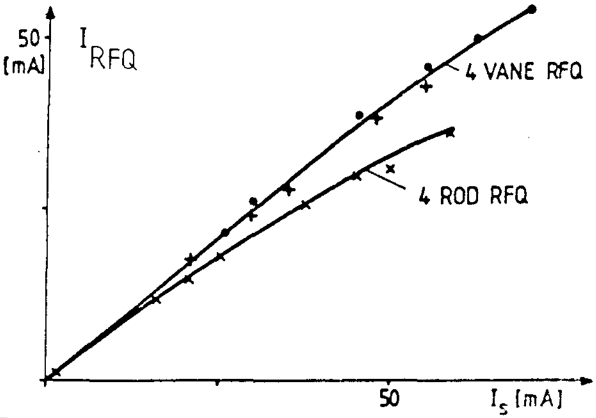

Fig. 7: RFQ output current I_{RFQ} as function of Ion source current