RFQ-INJECTOR FOR HERA*

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For the HERA project at DESY an RFQ will be built as injector for a 20 mA H^- beam from 18 to 750 keV with a duty cycle of 10^{-4}. The low average power and the moderate electrode voltage of 70 kV allows a flexible and simple design of the resonator. The design of the RFQ is described and the status of the project is discussed.

Introduction

A proton linac is going to be built as an injector for the Hadron-Electron-Ring-Accelerator HERA at DESY in Hamburg[1,2,3]. While for the Alvarez the design of the CERN II linac is used, the preinjector part will have an H^--source of FNAL design and an RFQ closely attached to the Alvarez. Fig. 1 shows the RFQ preaccelerator layout.

The RFQ has replaced Cockroft-Walton-type preaccelerators in most new projects. It has the advantages of an ion source at extraction potential of very efficient bunching and of accelerating space charge beams with excellent beam quality, and it is a compact and economic solution.

Electrode Design

The RFQ is a multifunctional structure. With four modulated quadrupole electrodes along the beam aperture the ion beam is first matched to the time-dependend electric quadrupole field, then shaped and adiabatically bunched and accelerated. Parameters for optimizing beam properties are the choice of the injection energy, frequency and electrode voltage and the distribution of modulation and aperture along the RFQ structure. Using the standard approach developed in Los Alamos[4], the parameter variation in the radial matcher, shaper, gentle buncher and accelerator sections are shown in fig. 2. It should be mentioned that along the accelerator section the aperture is kept constant, which is mechanically simplier, gives less capacity and keeps cosμ constant rather than the focusing parameter B [5]. The design has been tested with PARMTEQ[4,6,7] and in table 1 the results are summarized.

The application of the H^- in the multiturn injection concept allows a design current of only 20 mA, which is rather low compared to the CERN RFQ design[8]. This has several advantages: Firstly the ion source extraction potential can be used as injection beam energy, secondly the low initial energy leads to a short RFQ with low electrode voltage. This has advantages for the mechanical design, the RF properties and the operation reliability.

Mechanical Design

The electrode design determines the properties of the output beam. The RF resonator has to provide the designed electrodepotential and should have good mechanical stability, reasonable dimensions and good efficiency. Because of the experience with operating RFQs a four-vane-structure has been chosen as RF resonator. It consists of a cylinder, in which four electrodes are mounted symmetrically. The pole-tips are milled with a modulation according to the specific electrode design described above. To provide a proper axial field distribution the manufacturing of the electrodes and the adjustment has to be done with high precision. In addition the RF properties of such a resonator require a highly symmetrical structure to avoid dipole components in the axial field, which leads to beam quality detoriation. Fig. 3 shows a cross section of our four-vane-cavity. The tank will be made out of copper plated steel while for the vane solid copper (CuCr) will be used. Due to the low duty cycle of the accelerator (rep. rate 1 Hz, 35 μsec beam pulse length) the average power will be below 25 W.

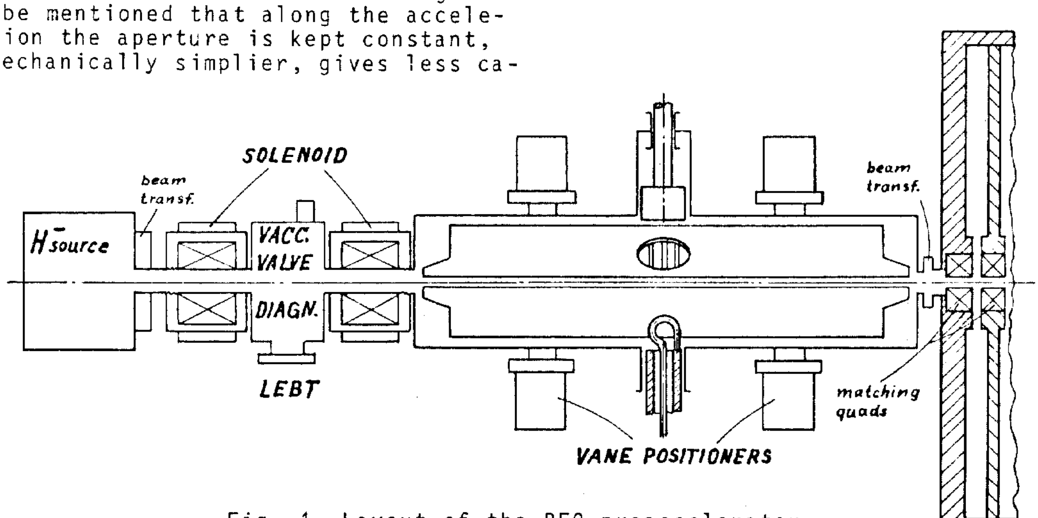

Fig. 1 Layout of the RFQ preaccelerator

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So cooling can be provided via the RF contacts at the vane base, the cooling of the cylindrical tank is done with 8 long bore-holes near the vane base contacts. Each vane will be fixed with two vane positioners, which allow adjustment in all three dimensions. In the center of the RFQ in two opposing quadrants pumping ports for a 300 l turbopump and a 500 l cryopump are located . In the same cross sections the drive loop and one single piston tuner for temperature control are installed. The milling of the vanes and the pole-tips will be done with ± 20 µm accuracy. The total accuracy of the vane will be 0.1 mm. The control of the tolerances is as important as the precision of the manufacturing [9,10]. We will control the single parts and the adjustment of the vanes on a computerized 3D-measuring machine with bed lengths of 2 m and an accuracy of ± 3 µm outside our lab. This high accuracy will add approximately 20 % to the cost of the tank, but we need this as a solid base for our tuning. As a consequence the design uses no combined RF vacuum seals and RF contacts and vacuum seals can be exchanged without changing the vane adjustment. The RF contact bars at the vane base can be exchanged allowing a simple method of fine tuning to the proper frequency of 202.56 MHz.

RF Aspects

The cross section of the RFQ has been optimized with SUPERFISH to get a theoretical power loss of less than 65 kW for the design field. Using a driver stage of the Alvarez transmitters (150 kW max.) we look for a safety margin, because most RFQs reach only up to 60 % of the theoretical Q-value. First high power tests with a short, 25 cm long structure have shown that drive loops and tuners can be adopted from our RFQ resonators with the 4-rod-design[11].

A basic problem in four-vane-structures is the balancing of the four quadrants[12], which is one reason for the required precision of the manufacturing and tuning. The four quadrants are very weakly coupled such that the frequencies of two dipole modes, which have unwanted polarity of the electrode voltages, are approximately 0.5 MHz aside the quadrupole modes. This gives rise to mode mixing that makes the voltage distribution in the resonator "unflat". The next longitudinal mode is about 15 MHz higher, because the length L of the structure is smaller than the free space wavelength λ_o of the frequency and the perturbation of this mode is proportional to $(L/\lambda_o)^2$ [13]. In general the flatness is proportional to the mode separation. There are two ways to increase the mode separation and relax tuning sensitivity[12]. The first method is the use of vane coupling rings[14] VCR, which directly connect opposite vanes with a low inductance, forcing them to the same voltage. The second method makes use of resonantly coupling the quadrants[15] via the magnetic field with a resonant loop ring (RLR). Both methods shift the unwanted dipole modes away by coupling to the dipole modes and changing their resonant frequency f_d. One goal of our design, to keep the RFQ short, is helpful for this stabilization. Mechanically very simple, the VCRs resp. the RLRs need to be applied only at both ends of the structure. The stabilizations will not perturbate the cut-off-mode along the structure, which is the case with VCRs connected through adjacent vanes. The frequency shifts through the capacitive load of the VCRs are now part of the end cell tuning. The VCRs can be used for the end cell tuning like vane and capacitors or vane-cut-back-blocks. With only one ring at each end the dipole mode can be shifted approximately 5 MHz away. Fig. 4 shows an end VCR arrangement, in which a ring is screwed to the vane in the cut back and uses the cut-back space without any additional vane modification.

Coupling the quadrants with resonant loops is a new method, which makes use of the resonant coupling of the end cells[12,15]. Fig. 5 shows the experimental arrangement for the connection of two opposite end cells, which should have the same currents (as indicated with arrows) and the same vane end potential. This $\lambda/2$-oscillator will be excited by a dipole mode (fig. 6a) and changes the stored energy of this mode and its frequency f_d. The quadrupole mode doesn't store energy in this resonator (fig. 6b) and the frequency f_q isn't changed. The symmetric coupler would couple to the Q-mode, as indicated in fig. 6c. Fig. 7 shows mode spectra with one VCR and one RLR and without stabilizers for comparison. Fig. 8 shows a spectrum with one RLR at each end plate (90° turned), model RFQ: diameter 15 cm, L = 65 cm. The RLR is tuned to the operating frequency by changing the distance between the ring and the end plate. We plan to use the RLR scheme, because the vanes are mechanically unstressed, the RLR is mounted at the end plates, a resonance device cancels the unwanted modes symmetrically, because the operational mode is no longer at cut-off, and because the frequency of the quadrupole mode is not changed.

End tuning will be done with Cu-blocks mounted at the end plate. The volume sensitivity is weaker[16] compared to vane-"cut-back"-blocks, but the distribution of the magnetic field around the vane ends is not perturbated and the vane itself is not mechanically stressed during tuning. If an increase in capacity is needed during tuning, the vane end capacity can be increased by adding a Cu-ring at the center of the end plate.

Status

The parameters of the RFQ have been frozen, the design drawings and specifications have been completed and offers have been submitted. The orders will be placed in June, so that the projected delivery can be in January 86. After RF tuning and after final tests in Frankfurt in May the RFQ will be delivered to DESY.

Acknowledgement

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Table 1 RFQ parameters and PARMTEQ results

Input energy W_{in}	18	keV
Output energy W_{out}	750	keV
Radio frequency f	202.56	MHz
Beam current I	20	mA
Current limit I_{max}	60	mA
Transmission efficiency η	96	%
Total length L_{tot}	117.7	cm
Total cell number N_o	135	
Intervane voltage V	70.5	kV
Maximum electric field E_{max}	21.9	MV/m
Vane modulation m	1 to 1.88	
Minimum aperture radius a	3.5	mm
Average radius r_o	5.0 - 5.2	mm
Radial focusing strength B	0.4 - 6.5 - 6.14	
Synchronous Phase Angle ϕ_s	90 - 30	degree
Normalized input emittance (90 %) E_{ni}	0.7	π μm rad
Ellipse parameters, input (> 90 %)		
$\alpha_x = \alpha_y$	0.57	
$\beta_x = \beta_y$	20.58	mm
Normalized output emittance (90 %) E_{ne}	1.0	π μm rad
Ellipse parameters, output (90 %)		
α_x	2.41	
β_x	157	mm
α_y	- 1.46	
β_y	- 120	mm
Envelope in x (90 %) $\hat{x}_{max}$	2.1	mm
Envelope in y (90 %) $\hat{y}_{max}$	1.8	mm
Energy spread (90 %) ΔW_{max}	10.4	keV
Phase spread (90 %) $\Delta\phi_{max}$	22.8	degree

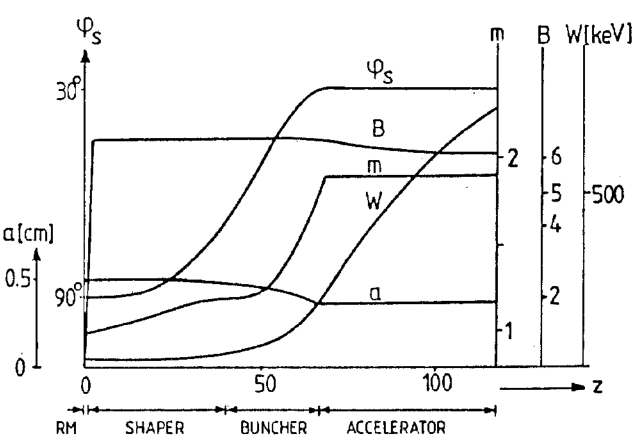


Fig. 2 Structure parameters along the RFQ

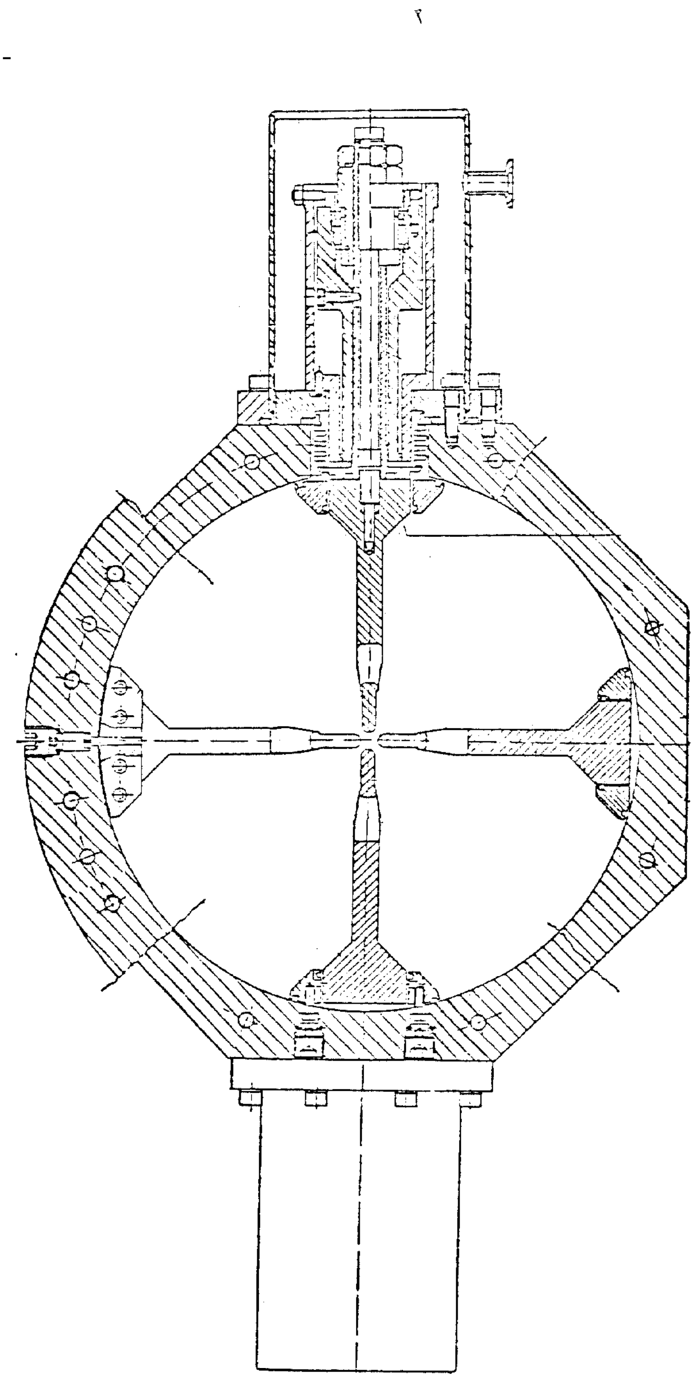


Fig. 3 Cross section of the HERA-RFQ

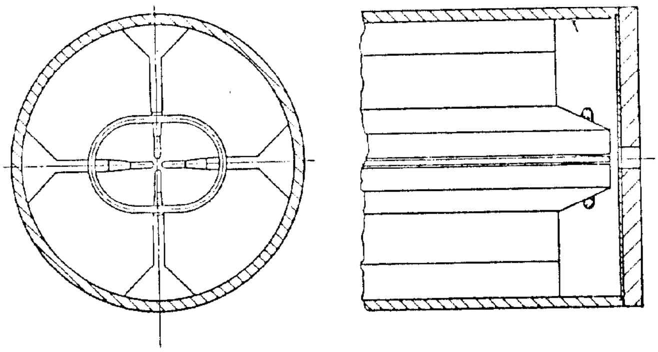


Fig. 4 End cell VCR scheme

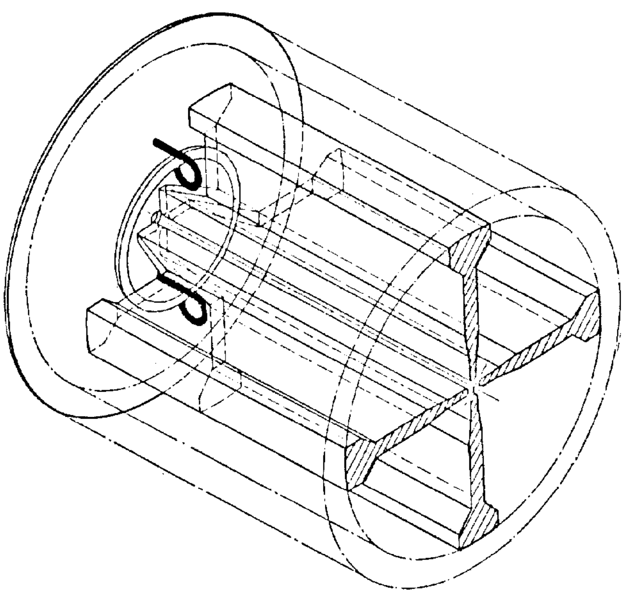
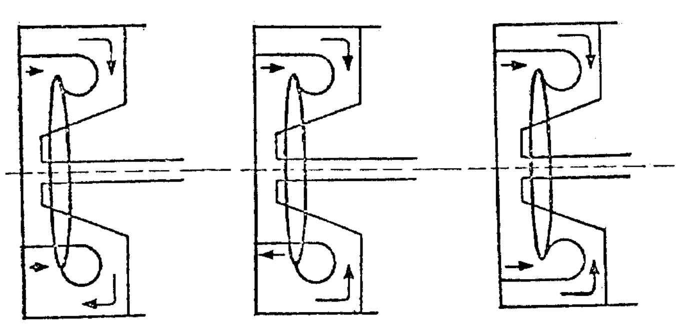


Fig. 5 End cell resonant loop ring (RLR) coupler scheme



Dipole Quadrupole Quadrupole-Mode

Fig. 6 End cell excitation of an RLR

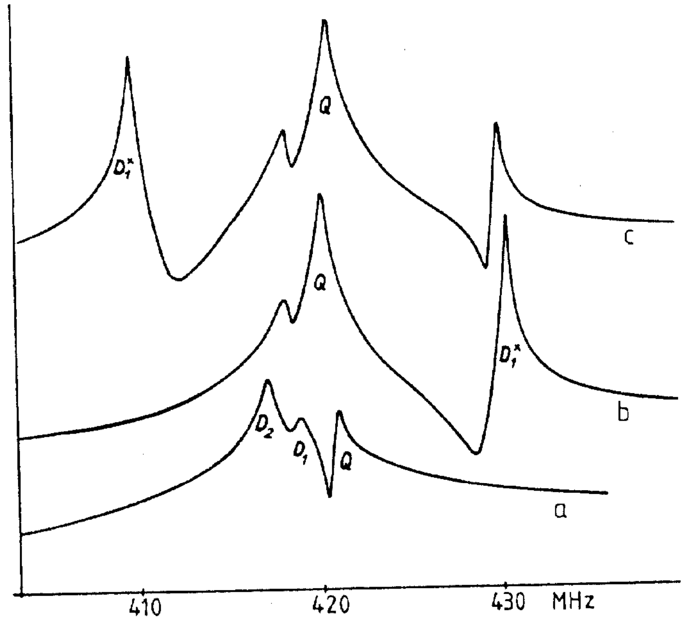


Fig. 7 Mode spectra of an RFQ

a) without coupler
b) with one VCR
c) with one RLR

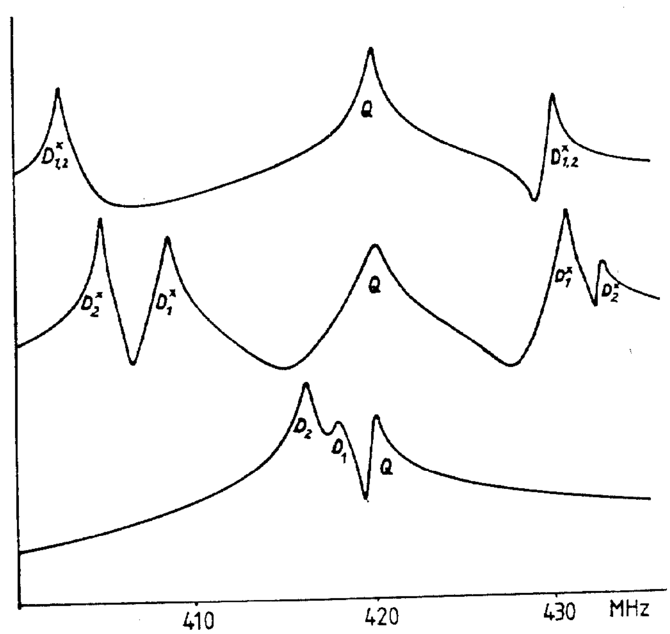


Fig. 8 Mode spectra with two RLR couplers