THE HERA RFQ

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Abstract

The HERA RFQ for DESY (20 mA H-, 750 keV) has been built, tuned and tested. The rf structure is a four vane cavity with resonantly coupled quadrants. Properties and special features of this structure will be discussed and results of first beam tests will be presented.

RFQ design

An RFQ will be the injector for the 50 MeV Alvarez-Linac for the HERA Project at DESY in Hamburg [1,2,3]. The H^- scheme allows for a design current of only 20mA. Beam dynamic calculations have shown that, starting with the extraction energy of the FNAL-type magnetron source of 18keV, a modest RFQ-elecrode voltage of 70kV can be chosen resulting in a short RFQ of length 1.2 m to reach the final energy of 750keV with proper beam properties.

Fig. 1 shows a scheme of the injector and some relevant data. The beam dynamic design was made using the standard LANL [4] approach with minor modifications and has been tested with PARMTEQ. The results show a high transmission and a good beam emittance.

It was decided to built a 4-vane cavity, the RFQ-structure developed by LANL [4,5] and succesfully operated at several big labs.

Mechanical and rf-problems go along with this structure. To make the tuning easier and ensure operational stability we looked for ways to simplify the mechanical design and for an appropriate rf stabilisation.

The 4-vane resonator consists of a cylinder in which four vanes with sine-wave like vane tips are mounted symmetrically. The resonator is exited in a TE-210 like mode which provides a electrical rf-quadrupol field on the axis. In addition to the precision with which the pole shape has to be produced to give proper axial field distribution, the rf properties require a highly symmetric cavity to avoid dipol components in the axial field which deteriorate the beam quality.

Based on the experience with the RFQ development in Frankfurt [6,7] a resonator was designed which is simplier and makes use of a separate function scheme, which means minimum interference of critical points of mechanical and electrical design. Mechanical alignment, rf-tuning and vaccum can be done independantly.

For the HERA resonator for the first time resonant coupling of the quadrants with resonant loop couplers (RLC)[7,8] are applied. These couplers make use of pi/2 mode operation without perturbation of the operation mode and additional losses. With these RLCs azimutal symmetry of the fields, which is one of the basic problems of 4-vane RFQ resonators, can be obtained without operating below cut off mode as would be the case with with vane straps [9].

The high precision machining of the RFQ has been done by Pfeiffer (Balzers) in Asslar (W.Germany).

The vanes as the most critical parts have been milled out of a forged CuCr-block. Measurements on a computerized measuring machine (ZEISS-UMC850) showed that all dimensions fell within a +-10 µm range from the design values. The most critical parts, the vane tip modulation and the reference edge are even better by a factor of two [10].

The RFQ tank is made of mild steel with cooling drills along the vane bases. It has been copper plated at GSI. The Vanes are fixed with two 3D positioners per vane. Mechanical alignment has also been done on the ZEISS machine to get a good bases for rf-tuning. The position of the axis has been defined by the cavity which is round within +- 7µ . With this axis the middle of the first vane is taken as a reference plane by adjusting the parallel parts of the vane (thickness +-10µm max) and correcting with the measurements of this individual vane [11].

Within two weeks all vanes had been adjusted and all critical values are well within this 10 µm margin taking the fabrication deviations of the individual parts into account.

Rf-tuning

After the transport of the RFQ to Frankfurt at end of September 86 the vane positions have first been checked to be still within the accuracy of 10 µm.

After installation of the contact bars the frequency of the quadrupole mode was 197.01MHz (Q_0=6700). This was measured with .5m extensions of the RFQ tank (cut-off pipes). With flat endplates closing the tank the frequency increased to 198.1 MHZ (Q_0=3880). The dipole modes had frequencies of 198.6MHz and 198.3MHz respectivly.

The frequency deviation of the quadrupole mode from the superfish value of 201.9MHz had been greater than expected, so tuning by modifiing the cut-back area of the vanes had been done for coarse tuning. To obtain a "smooth" path for the magnetic field turning around at the vane ends, the tuning blocs were made with the cross section of the vanes and flat to shorten the path for the currents charging the endplates resp. the vane ends.

The tuning elements have been contacted with silver plated mesh seals and screwed to the vane base end blocs as illustrated in fig. 2. Fine tuning has been done with perturbation rings screwed to the end plate, which is a simple and symmetric way of tuning. The dimensions drawn in fig.2 would increase the frequency by appr. 0.4 MHz per ring. It was planned to get an operating frequency slightly above the cut-off frequency which results in a somewhat concave longitudinal field distribution like shown in fig. 3, which was measured near the vane tips. The magnetic field B near the outer cylinder in the midplane between the vanes is shown for comparison. The B field shows a stronger variation due to the different distributions at the end of the resonator. The small bumps

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are indicating the position of the four pick up loops and the central drive loop in this quadrant. The fields at the low energy end are 2% smaller because there is less capacity due to the smaller vane tip modulation.

Before tuning the azimutal field symmetry had been good (+-5% field amplitude variation in different quadrants) due to the excellent positioning of the vanes. This has been measured with tank extension tubes (cut off pipes). Attaching the end plates, the vane base blocks and the tuner blocks, the fields varied up to 40% and were sensitive to changes of the drive loop and the tuning ball.
The azimutal fields were stabilized with one RLC at each end of the cavity. The mechanical design is simple, because the RLCs are fixed to the tank end plate (fig.2) acting on the fields in the end cells. Tuning the RLCs to a frequency of 201.9 MHz (outside the tank, like shown in fig.4) a symmetric shift of the dipole modes could be achieved and a very symmetric (+-2%), very stable field distribution in the quadrants.
Figs.5 and 6 show mode spectra without azimutal coupler and after tuning of the RLC couplers respectivly. Even after detuning the cavity asymmetrically with the plunger, placed in the quadrant opposite the feeding loop, by 0.5 MHz no change of the field distribution could be detected.
Part of the tuning procedure had been the operation of the cavity with rf-power up to 1.5kW and up to 100% duty cycle. Thermal effects of rf heating could be studied and operation in this typical multipactor level should facilitate rf conditioning under higher power and small duty cycle at DESY.
The results of the tuning procedure show, that the design goals have been achieved successfully. The field flatness is excellent (+-2% longt. and azim.) and stable against detuning and temperatur changes and the impedance is very high for this kind of cavity. The R_p-value (ratio of electrode voltage U^2 to rf-power N : $R = U^2/N$) is as high as 57kΩ with a Q value of Q_0=11200 (Q_0(Superfish)=13500). The ratio of Q/Q_{SF}=.83 is high, so we are close to the minimum rf power of 66 kW calculated for the design voltage of 70.5kV (without beam loading).

Beam experiments

After delivery to DESY in Jan. 87 rf-conditioning has been done to achieve the necessary field levels without breakdowns. Starting with 40 kW pulses of length 250 µsec at 1Hz rep.rate the power could be increased with a rate of appr. 2kW/h. After connecting the RFQ to the LEBT line and using the settings for the solenoids from the 4-rod RFQ tests [12] a accelerated beam of appr. 20mA has been analysed immediatly. A number of beam spectra have been taken showing the dependance of beam properties from the rf level as shown in fig.7 for three power levels at an injected beam of 24 mA. The accelerated beam (100kW) has been as high as 23 mA despite a mismatch by an asymmetric input emittance. The rf pulse shape shown in fig.8 demonstrates the beam loading effect of a 20mA beam. The voltage drop of the pickup signal (no control loop) is perfectly correlated to the beam power of 16 kW. Increasing the ion source current to 55 mA without changing the LEBT settings we were able to analyse an accelerated beam of 42mA (fig 9).

A "zero current" beam has been used to measure the impedance of the RFQ. Without beam loading effects the minimum power level N_{min} necessary to accelerate a small fraction of the beam to the design energy corresponds to a stable phase φ_0 =0 and to a voltage of 61 kV. With N_{min}=65kW the resulting impedance R_p is R_p=(57 +-5)kΩ which is in good agreement with the Superfisch calculation corrected by the Q_0 value measured at low power level.
For beam currents up to 30mA there is no change of energy spread of the accelerated beam from fig 7. The transmisssion is well over 90%, the energy spread is appr. +-14keV (90% beam) which is close to the resolution of the simple spectrometer set up used at these first tests [13].
So the measurements will be repeated with an improved spectrometer. Next steps will be emittance measurements and a fine tuning of the injection line.
Concluding, the design, manufactoring, tuning and the first tests have been a full success.

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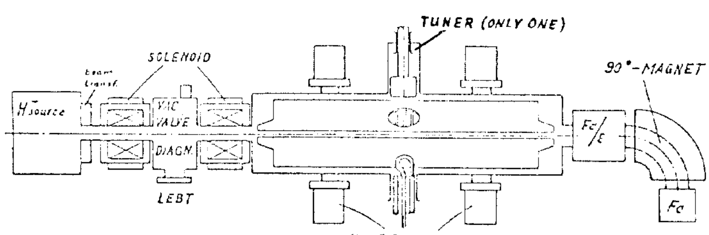

Fig. 1 Scheme of HERA-RFQ injector with analyzing magnet
Input-output energy 18-750keV, 20mA H^-
Frequency 202.56MHz, Length 1.18m,
Quad. voltage 70.5kV, aperture 3.5mm

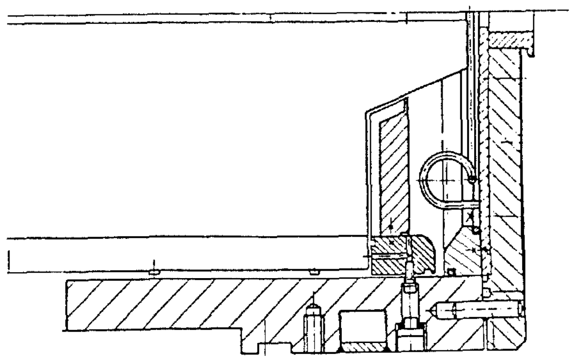

Fig. 2 End cell configuration with RLC

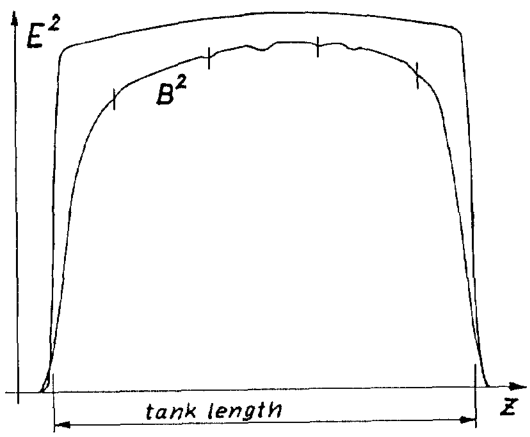

Fig.3 Electric and magnetic fields along the RFQ

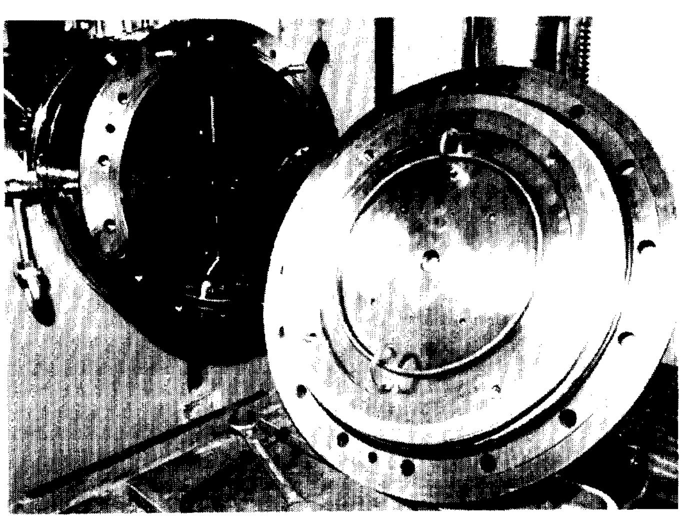

Fig. 4 View of RLC end plate

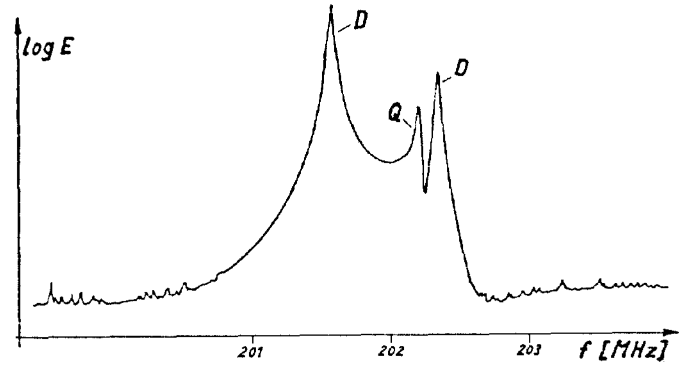

Fig. 5 Mode spectrum of the RFQ without coupler

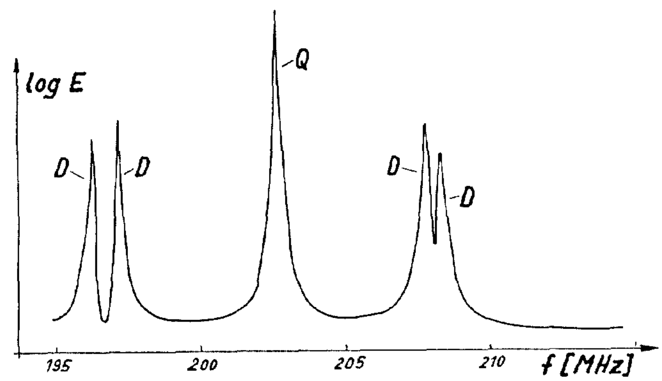

Fig. 6 Mode spectrum with two RLC couplers

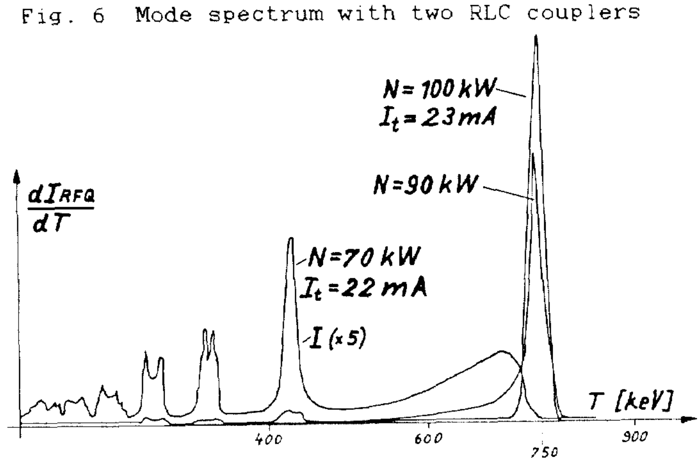

Fig. 7 Beam spectra for different rf-powers

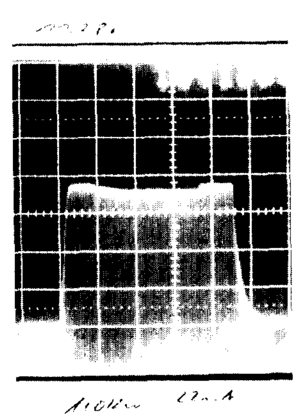

Fig. 8 Rf pulse (100kW, 20mA)

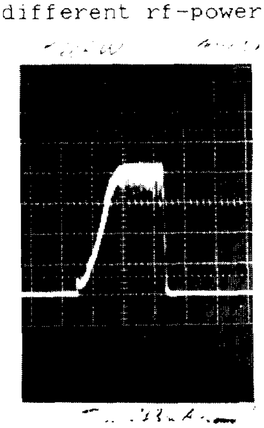

Fig. 9 Beam pulse (125kW, 42mA) of the HERA-RFQ