RFQ DESIGN FOR SNQ

Ralf Lehmann
KFA Jülich, SNQ-ABT, Postfach 1913, D-5170 Jülich, West Germany

Summary

The Jülich ABT (Accelerator Technology Division) 100 MHz prototype RFQ is intended to be identical to the two RFQ's foreseen in the SNQ injector, which are to bunch and accelerate 100 mA protons each from 50 keV to 2 MeV at a duty cycle of 2.5 %. A beam dynamics design made in order to minimize particle losses and emittance growth is presented together with simulation results. RF and mechanical design features and status of the prototype RFQ are presented.

Introduction

The injector of the SNQ Linac[1] will have to deliver a 2 MeV, 200 mA proton beam (pulse length: 250 microseconds, repetition rate: 100 Hz) to a 201.25 MHz Alvarez DTL. It seems very unlikely that a single 200 mA, 201.25 MHz RFQ, in which the peak electrical field strength would have to be rather high, could operate reliably for years. Therefore the scheme outlined in fig. 1 was foreseen. Proton beams from two magnetic multipole sources[2] are bunched and accelerated from 50 keV to 2 MeV by two identical 100.625 MHz RFQ's. In a funneling section[3] the beams are combined and matched to the DTL.

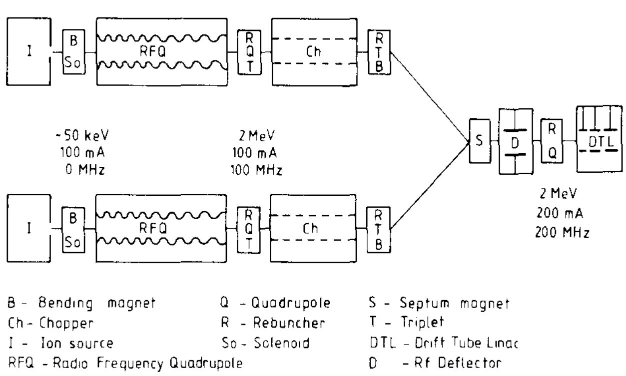

Fig. 1: Scheme of the SNQ injector

Beam Dynamics Design

The injection energy was chosen from ion source considerations; 50 keV seems to be a good compromise between high reliability of the preaccelerator and low emittance. The output energy of 2 MeV is a compromise between DTL requirements and RFQ length. The maximum surface field strength in the RFQ was chosen to be no more than 1.5 Kilpatrick for reliability reasons.

The design outlined in table I was made as follows: First the program CULI[4] found the parameters at the bottleneck such that the transverse and longitudinal current limits[5] are both equal to 200 mA. The final synchronous phase (which is an input to CULI) was chosen such that the tune without any defocusing is approximately 60°. The modulation depth m, and the synchronous phase in the Shaper (S), Gentle Buncher (GB), and Accelerator (A) sections[6] were generated by the program OPTI[4]. Finally the beam parameters at the input of the Radial Matching (RM) section[6] were computed with the program IMS[4]. In order to make the distance between the solenoid in front of the RFQ and the RFQ input large, the length of the Radial Matching Section was chosen to be 1ßλ (or 2 cells).

The design was tested with PARMTEQ[6] and found to meet the requirements[3] of the funneling section and the DTL. The computed transmission is 96 %. Fig. 2 shows the normalized transverse and longitudinal rms-emittances together with the particle losses plotted versus the cell number. The increase in the transverse emittance between cell number 41 and 50 coincides with the condition that the longitudinal tune is greater than the transverse tune.

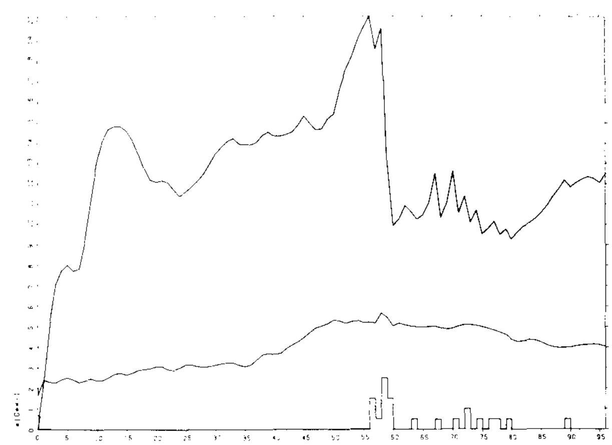

Fig. 2: Normalized rms emittances (upper: longitudinal, lower: transverse) and particle losses vs. cell number. Units for both emittances: Pi·mm · mrad.

TABLE I
RFQ PARAMETERS

Section		RM	S	GB	A
Cell Number	0	2	50	76	96
z (m)	0	0.03	0.79	1.49	3.05
B	0.4	9.009	9.009	9.009	9.009
W (MeV)	0.05	0.05	0.075	0.50	2.01
r_0 (mm)	63	13.2	13.2	13.2	13.2
a (mm)	63	13.2	12.3	7.9	7.5
m	1	1	1.15	2.3	2.3
φ_s (deg)	-	-90	-70	-30	-30
E_0 (MV/m)	0	0	0.47	2.15	1.14

Ions	H^+, H^-
Frequency	100.625 MHz
Intervane Voltage	165.3 kV
Max. Electric Field	17 MV/m
Nominal Current	100 mA
Current Limit	200 mA

PARMTEQ Results:	Input	Output
Current (mA)	110	105
Normalized Emittance,		
Transverse (90%, Pi·mm·mrad):	0.7	1.8
(rms)	0.17	0.40
Longitudinal (rms, Pi·deg·MeV):	0	0.14

RF Design

A Four Vane cavity with Vane Coupling Rings[7] (VCR's) and without manifold was chosen. It will have one loop coupler to feed the rf power of approximately 500 kW (peak, expected value) and 3 probe loops and 4 piston tuners in each quadrant. In order to study its behaviour and to work out tuning and aligning procedures, two approaches were made:

1. Equivalent Circuit Analysis

If opposite pole tips are assumed to be perfectly strapped together, then one "slice" of a Four Vane cavity can be represented by one section of a ladder circuit shown in fig. 3. It is identical to the equivalent circuit of Hutcheon[8] if the quadrants are connected in parallel. The parallel elements can be computed from SUPERFISH[9] results, the series resistance is estimated and the series inductance follows from (see also[8])

$$L_s \, C_p = c^{-2} \qquad (1)$$

The end regions of the cavity were represented by open circuits. VCR's were represented by locally increased values of the parallel capacitors and the tuners by locally decreased values of the parallel inductors.

The computed relative local voltage peaks caused by tuners in 4 "slices" are:

$$\Delta V/V = 0.7 \;\; \Delta f \text{ (all tuners)}/f \qquad (2)$$

With d = distance between VCR's and L = vane length, the computed voltage peaks at the locations of VCR's are:

$$\Delta V/V = -10.1 \cdot L \cdot d/\lambda^2 \cdot \Delta f \text{ (1 VCR)}/f \qquad (3)$$

The computed effect of beam loading is a relative voltage variation of $1.6 \cdot 10^{-4}$.

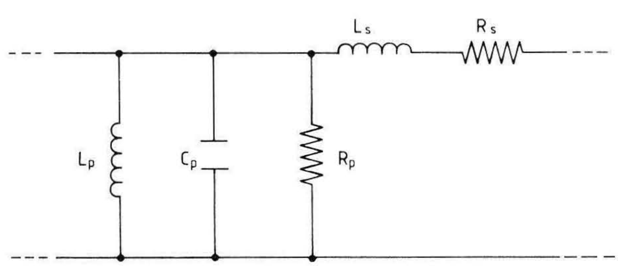

Fig. 3: One section of equivalent circuit

Reasonably chosen combined perturbations caused a voltage variation of less than 2%, which is greater than the sum of the effects of isolated perturbations.

2. Cold Model

A one meter long 300 MHz aluminum cold model (see fig. 4) without vane modulation was made for bead pull measurements of the longitudinal voltage distribution. A cylindric dielectric bead on a thread can be pulled along the sides of the pole tips in any of the quadrants. The resonant frequency shift is measured and used for computing the longitudinal voltage distribution. Measurements showed that the field was distributed uniformly in the four quadrants when 6 uniformly spaced VCR's were mounted. The measured voltage peaks at the locations of the VCR's agreed well with the computed values.

The longitudinal voltage distribution was influenced by modifying the vane cutback areas by inserting different size brass blocks. The 4 cutback areas at each end of the RFQ were kept equal, so two degrees of freedom remained, which turned out to be sufficient to achieve good flatness. For correcting a tilted distribution while keeping the resonant frequency the same, one has to change the cutback areas in a push-pull mode; for correcting a nonlinear (curved) distribution one has to modify all 8 cutback areas in unison, thus changing the resonant frequency. The nonlinear (quadratic) term in the longitudinal voltage distribution depends linearly on the frequency[10]. The slope found with the cold model will be useful for the tuning of the final RFQ. The area of each cutback for flat distribution turned out to be 38 % of the quadrant area.

Rough tuning (several % of the frequency) can be achieved without changing the voltage distribution by modifying the thickness of all VCR's within the range of permissible VCR surface field strength. Fine tuning will be done with piston tuners.

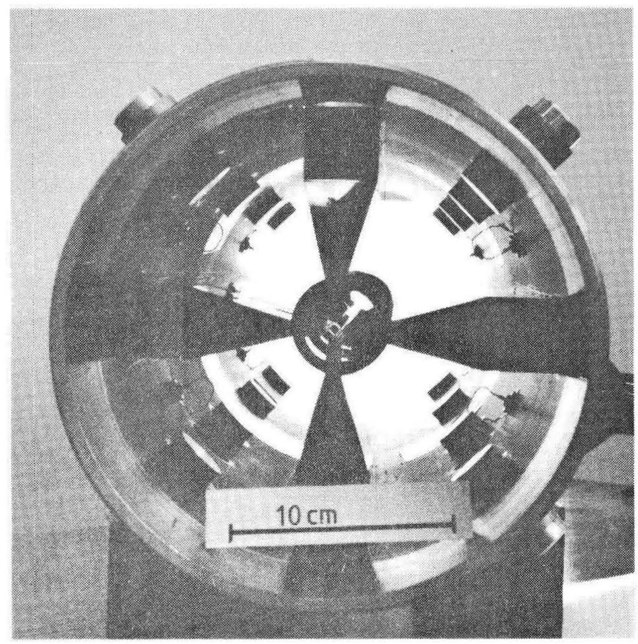

Fig. 4: RFQ cold model

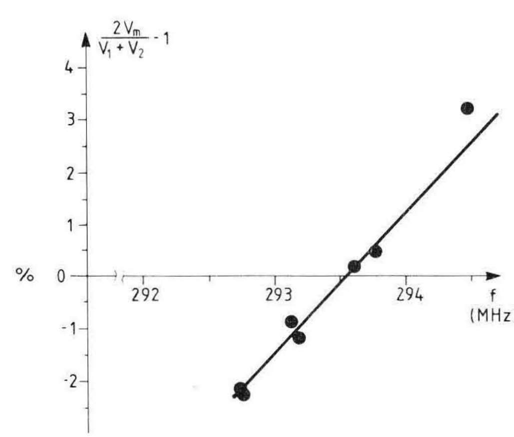

Fig. 5: Nonlinear term vs.frequency

Mechanical Design

The RFQ will be manufactured outside the KFA according to our design specifications and tolerances.
The radius of curvature of the pole tips is constant enabling them to be easily machined on a conventional 2-D NC mill having a bed travel of slightly more than one meter. The vanes and the tank are broken down into 3 sections. The tank sections will be connected to each other and the end walls with flanges. Cooling for the vanes, tank walls, tuners, vacuum grills and coupling loop had to be designed carefully to accomodate dissipation design values corresponding to 1 kW/m^2 in the vane and tank walls. The 12 vane sections will be welded constructions, made mainly of stainless steel with cooling channels on the inside. The pole tips cannot easily be directly cooled because of the VCR holes. Therefore they will be made of high termal conductivity copper brazed to the remainder of the vanes. Fine machining will be done after welding, annealing, and brazing.

Alternatively, if the brazing of 1 meter long pieces of different thermal expansion is too difficult, the vanes can be made entirely of mild steel with a cooling channel close to the pole tips. The tank wall will be made of mild steel and will have cooling pipes on the outside surface. All rf surfaces will be copper plated. Aluminum C-seals will provide rf contact and vacuum sealing at the vane bases and the flanges.

In order to minimize manufacturing costs and to reduce alignment work, a set of mechanical tolerance requirements for several dimensions, for the curvature of the axis and for angles and offsets between the axes of adjacent sections has been established from rf and beam dynamics considerations.

These tolerances turned out to be feasible for several manufactures. The manufacturer will thus supply the RFQ with fixed vane alignment. However, the trimming for final field flatness by exchanging copper blocks in the vane cutbacks and rough tuning by choosing the appropriate VCR's remains to be done by us.

Status and Outlook

The compilation of our specifications is presently (May 1984) in progress and the preliminary design is being made. Tendering will start in June and the start of the manufacturing is expected in September 1984. Manufacturing is expected to last 9 months, i. e., until June 1985. By that time we expect to have an operating 100 MHz power amplifier, a proton source and low energy beam transport.

References

1. C. Zettler, this conference
2. G. Crecelius, priv. comm.
3. K. Bongardt, this conference
4. R. Lehmann, Einsatz eines Hochfrequenz-Quadrupol-Beschleunigers in der Spallations-Neutronenquelle, KfK 3446, Ph-D. thesis, 1982/1983
5. T.P. Wangler, Space Charge Limits in Linear Accelerators, LA-8388, Dec. 1980
6. K.R. Crandall, R.H. Stokes, T.P. Wangler, RF Quadrupole Beam Dynamics Design Studies, 1979 Lin. Acc. Conf.
7. H.R. Schneider, H. Lancaster, Improved Field Stability in RFQ Structures with Vane Coupling Rings, IEEE Trans. NS-30, 3007 (1983)
8. R.M. Hutcheon, An Equivalent Circuit Model of the General 3-Dimensional RFQ, IEEE Trans. NS-30, 3524(1983)
9. K. Halbach, R.F. Holsinger, SUPERFISH-A Computer Program for Evaluation of RF Cavities with Cylindrical Symmetry, Particle Accelerators 7, 213 (1976)
10. E. Boltezar et al., Experimental RFQ as Injector to the CERN Linac I, 1981 Lin. Acc. Conf.

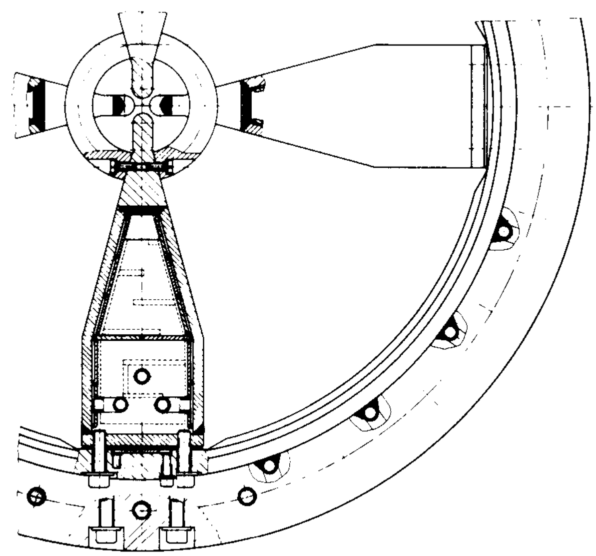

Fig. 6: Cross section of the preliminary design