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1 GeV リニアック検討資料

1 GeV LINAC DESIGN NOTE

題目 (TITLE) Design Study on the Proton RFQ for the Japanese Hadron Facility

著者 (AUTHOR) N. Tokuda, S. Arai and N. Ueda

概要 (ABSTRACT)

The design study on the proton RFQ, the pre-accelerator of the 1-GeV linac chain in the Japanese Hadron Facility, is proceeding at INS in collaboration with KEK. The 432-MHz RFQ will accelerate 20-mA protons or H^- ions from 0.05 up to 3 MeV through a length of 2.7 m. The RFQ's performance, examined with a simulation code PARMTEQ, and considerations on the cavity are reported.

KEY WORDS:

Ion source, RFQ, DTL, CCL, Magnet, Monitor, Beam Dynamics,
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Design Study on the Proton RFQ for the Japanese Hadron Facility

Noboru TOKUDA, Shigeaki ARAI, and Nozomu UEDA
Institute for Nuclear Study, University of Tokyo

ABSTRACT

The design study on the proton RFQ, the pre-accelerator of the 1-GeV linac chain in the Japanese Hadron Facility, is proceeding at INS in collaboration with KEK. The 432-MHz RFQ will accelerate 20-mA protons or H^- ions from 0.05 up to 3 MeV through a length of 2.7 m. The RFQ's performance, examined with a simulation code PARMTEQ, and considerations on the cavity design are reported.

1. Introduction

For the pre-accelerator of the 1-GeV proton linac chain in the Japanese Hadron Facility, a four vane RFQ structure has been adopted because of its compactness and well established technology. The RFQ's performance requested by the ion source and the drift tube linac (DTL) following the RFQ are as follows: the operating frequency is 432 MHz, same as that of the DTL; the energy range is 0.05 through 3 MeV; the normalized emittance is 1.5 π mm•mrad; the beam current is 20 mA. A beam dynamics design has resulted in an 2.7-m long RFQ, satisfying the required performance. As this RFQ is quite long, 3.9 in electrical length L/λ (L is vane length, and λ free-space wave length), the cavity must be fabricated at a very high accuracy, or else the field tuning and the mode sepration will be difficult. To examine the feasibility of the long RFQ, a full-scale cold model is planned to be fabricated, and the design work is proceeding in collaboration of INS and KEK.

2. Beam Dynamics Design

Vane parameters yielding an RFQ, with the performance described above and with a length as short as possible, were found out after search with computer codes GENRFQ and PARMTEQ. The former generates vane parameters for each cell, and the latter receives them and simulates particle motion through an RFQ. The resulting parameters and performance of the RFQ are summarized in Table 1.

The transmission efficiency is 94% for a 20-mA input beam. The efficiency decreases for higher currents, and the limiting value of the output current is about 30 mA. At the exit of the RFQ, the 90% normalized emittance is about 1.3 π mm•mrad for an input beam of 20 mA in current and 1.5 π mm•mrad in 100% normalized emittance. The output emittance is

Tabel 1. Design parameters of the 432-MHz proton RFQ.

Frequency (f)	432 MHz	
Kinetic energy (T)	0.05 → 3.01 MeV	
Vane length (L)	269 cm	(305 cells)
Normalized emittance (ε_N)	1.5 π mm·mrad	(ε = 145 π mm·mrad)
Kilpatrick factor (f_K)	1.8	($E_{s,max}$ = 36.1 MV/m)
Intervane voltage (V)	90 kV	
Mean bore radius (r_o)	0.340 cm	(constant over the vane length)
Minimum bore radius (a_{min})	0.236 cm	
Margin of bore radius (a_{min}/a_{beam})	1.25	
Maximum modulation (m_{max})	1.83	
Focusing strength (B)	4.0	(constant over the vane length)
Maximum defocusing strength (Δ_b)	−0.078	
Transmission efficiency (0-mA input)	98%	(I_{out} = 0 mA)
(10-mA input)	98%	(9.8 mA)
(20-mA input)	94%	(18.7 mA)
(30-mA input)	84%	(25.1 mA)
Output beam emittance (20-mA input)		
$\varepsilon_{N,x}$ (90% emittance)	1.29 π mm·mrad	(ε_x = 16.1 π mm·mrad)
$\varepsilon_{N,y}$ (90% emittance)	1.16 π mm·mrad	(ε_y = 14.4 π mm·mrad)
phase spread	±15°	(full width)
energy spread	±0.03 MeV	(full width, $\Delta T/T$ = ±1%)

small enough for the following DTL with a normalized acceptance of about 10 π mm·mrad. The energy spread of the output beam is ±1%, sufficiently small for the DTL, and the phase spread is ±15°. The phase spread at the input of the DTL is narrower than ±45° if the RFQ-DTL distance is shorter than 1 m; in this case, no rebuncher is necessary. If quadrupole magnets will be inserted for perfect emittance matching between the linacs, a rebuncher is necessary. The scheme of the linac connection deserves further investigation.

3. Cavity Design

The cross sectional shape of the RFQ is designed using a computer code SUPERFISH. Though the final design has not been fixed, the estimated cavity diameter is about 18 cm, and the cavity wall loss is about 700 kW, assuming a Q-value 60% of an ideal value. As the duty factor will be 3%, the averaged loss power is about 20 kW. The cavity must be accordingly cooled with water.

In order to attain a good field distribution and suppress the harmful TE110 mode, accurate vane mounting in the cavity is an important issue, particularly to this long RFQ. According to a theory, the allowable error is proportional to $(L/\lambda)^{-2}$, where L is vane length, and λ free-space wave length. The electrical length L/λ of the 432-MHz RFQ is 3.9. This is quite a large value; it is reported that field tuning was a hard work at the Los Alamos 425-MHz ATS RFQ, similar to our RFQ in geometrical size: L = 2.89 m and L/λ =

4.1.[1,2,3] At INS we have ever constructed a 100-MHz and 7.25-m long RFQ, TALL.[4] The L/λ-value is 2.4, and the measured alignment error is ±30 μm. If this error is scaled down in proportional to $(L/\lambda)^{-2}$, the allowable error for our RFQ is ±11 μm. This value seems difficult to be realized; even if possible, the fabrication cost will be very high. It is hence reasonable to fabricate a cold model, with which we could find a vane-mounting method minimizing the error, ±30 μm or less, and a field stabilization technique.

Vane coupling rings (VCR's), shorting opposing vanes, are effectual devices to enhance the quadrupole mode and to suppress the unwanted dipole mode. The VCR method was invented and developed at LBL, and is now employed in several RFQ's, including the ATS RFQ.[5,6,7] Contrary to the above merit, locally increased intervane capacitance brings about some problems: the longitudinal field distribution has local maxima at VCR positions, several-percent increase in amplitude; the resonant frequency shifts down, emperically 3 ~ 5 MHz per ring pair. Another problem is water cooling: water channels for vane cooling must detour VCR's, and direct cooling of VCR's is almost impossible. Because of these disadvantages, VCR's might not be used in our RFQ. (The 433-MHz and 2.2-m long RFQ at Kyoto has no VCR.[8]) VCR's will be examined in the cold model in case that they are indispensable.

4. Concluding Remarks

An RFQ structure satisfying the required performance has been worked out through the beam dynamics design. As there still remain some examination on beam matching between the RFQ, the ion source, and the DTL, the design presented here is not a final one, but no drastic change is expected. Because of the long electrical length, the most important issue in this RFQ work is accurate vane mounting; this is essential to stabilize the electro-magnetic field. A cold model with the same size as the real machine is to be fabricated for studies on technical items: accurate vane mounting, field tuning, mode separation, vane coupling rings, a loop coupler(s) for power feed *etc.*.

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