DESIGN OF 4.5 MEV RFQ FOR PROTONS /H^- IONS

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Abstract

It is proposed to construct a Spallation Neutron Source based on a 1 GeV proton synchrotron at CAT. A 100 MeV linac will inject the 20 mA H^- ion beam into this synchrotron. The linac in turn is injected by a 4.5 MeV RFQ. This injector linac will additionally form the first 100 MeV part of a 1 GeV super conducting linac to be built in future for Accelerator Driven Sub-critical System (ADSS) applications. Therefore both, the RFQ and the linac are required to be capable of operating at very high duty factors and/or in CW mode. In this paper we describe the results of our beam dynamics and RFQ cavity optimization studies for the 4.5 MeV RFQ.

1 INTRODUCTION

The SNS synchrotron needs 20 mA pulsed beam from the linac where as the ADS linac will need about 10 mA CW beam. Therefore the RFQ is designed for a beam current of 25 mA. The choice of main parameters for the RFQ is mainly governed by the high duty factor / CW mode of operation. The operating frequency, just like the other designs for similar facilities is selected to be 350 MHz, which is mainly governed by the availability of the CW RF power sources. The input energy from the ion source is chosen to be 50 keV. The RFQ out put energies for the operating machines range from 3 MeV to 6.7 MeV around the world. Higher output energy from RFQ is preferred from the injection point of view into the following linac structure DTL / CCDTL or SDTL. An energy of about 4.5 MeV seemed to be appropriate for injection into following SDTL structure which we have investigated [1]. Inter vane voltage is a very important parameter which decides the transverse focusing strength, the transmission efficiency, the limiting currents, the acceleration efficiency and in turn the structure length. And above all it governs the power loss in the structure and the break down limit or maximum surface electric field on the vane tips (Kilpatrick's Criterion). Almost all of the above characteristics except the power loss and the breakdown limit favor the choice of higher vane voltage. A lower vane voltage is preferred for a CW machine for lower power dissipation per unit length of the structure, which will ease the cooling. Also there will be less probability of sparking at lower voltages which adds to the reliability of operation. Table-I lists the main specifications of the RFQ.

2 BEAM DYNAMICS DESIGN

The multi-particle simulation code PARMTEQM [2] is used for the beam dynamics design studies. Several hundred runs of PARMTEQM were taken to optimize the RFQ parameters. The energy gain in the accelerator varies with V and the power dissipated in the walls varies with V^2, V being the inter-vane voltage. For fixed output energy, the lower inter-vane voltage will result in a longer length of the RFQ accelerator. But at the same time, it reduces the power loss per unit length of the structure, which is an important consideration for a high duty factor/CW accelerator. Additionally, the contribution of the nonlinear beam dynamics will be less severe if we work at lower voltages or gradients in general. With this in mind, we have worked out designs at 85, 80, 75, 70 and 65 kV to perform the thermal design studies with ANSYS. In each of these cases, the design parameters such as the minimum radius (a_{min}) and modulation parameter (m) along with the parameters of the shaper and gentle buncher sections are optimized to have transmission efficiencies better than 96% with 10,000 particles when simulated with PARMTEQM. Table II gives a comparative summary of these designs.

Table 1: Design Specifications of the RFQ

	ADSS	SNS	
Input energy	50		keV
Output energy	4.5		MeV
Beam current	10	20	mA
Particles	H^+	H^-	
Operating mode	CW	Pulsed	
Pulse duration	–	500	μsec
Repetition rate	–	25	Hz
Frequency	350		MHz
Structure	Four Vane cavity		

Experience at other laboratories [3] shows that, the power loss per cm in the structure should be kept much below 1 kW including the difference in the theoretical and measured quality factors and also for some safety margin. Based on these considerations and results of our thermal analysis studies [4], an inter-vane voltage of 65 kV is decided.

Figure 1 depicts the variation of the design parameters along the RFQ. Choice of lower inter-vane voltage reduces the transverse focusing strength B. In the designs with 75 through 85 kV inter-vane voltages, the minimum radius parameter a_{min} is chosen to be 2.4 mm. To compensate for the reduction in B at lower inter-vane voltages of 65 and 70 kV, a_{min} is reduced to 2.2 mm. A further reduction in a_{min} increases B and transmission through the RFQ, but we wanted to limit it to 2.2 mm to avoid higher frequency sensitivity of the vane tip region.

Table 2

V →	65	70	75	80	85	kV
L	6.52	6.32	5.95	5.43	5.03	m
Esmax	28.7	28.0	27.8	29.8	31.0	MV/m
P_{TOTAL} †	539	556	589	616	620	kW
η_{Trans}	96.9	97.8	96.9	97.5	97.7	%
$\varepsilon_{x,rms}(n)$	0.20	0.20	0.20	0.21	0.21	πμm.rad
$\varepsilon_{y,rms}(n)$	0.20	0.19	0.20	0.22	0.22	πμm.rad
$\varepsilon_{z,rms}(n)$	0.10	0.11	0.10	0.11	0.12	deg.MeV

† Excluding beam power of 111.25 kW in each case

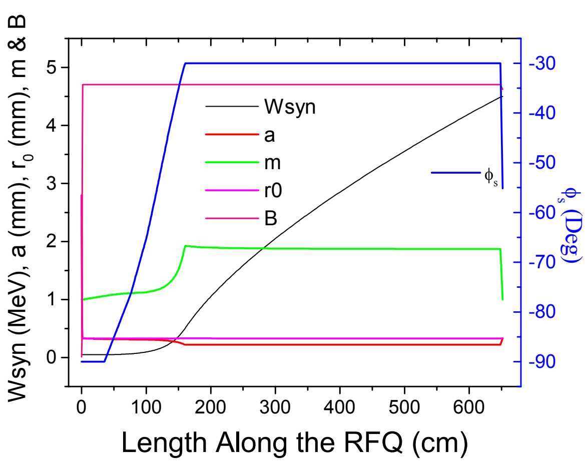

Figure 1: Variation of RFQ parameters along its length

Beam transmission through RFQ is shown in Fig.2 for protons. PARMTEQM simulations with 10,000 and 100,000 particles show 96.7% and 96.3% respectively. Figure 3 shows the phase space ellipses at the input and output of the RFQ. The beam used at the RFQ input was with random distribution in 4 dimensional transverse phase space and uniform phase and random energy spread in the longitudinal phase plane. The energy and phase spectra at the end of the RFQ are shown in fig. 4 along with the distribution in *x-y* and phase spaces. Table III

Table 3: RFQ Design Parameters

Beam current (i_b)	25	mA
Inter vane voltage (V)	65	kV
Particle	H^+	
Total length (L)	6.52	m
Modulation Parameter (m)	1 – 1.915	
Minimum aperture radius (a_{min})	2.20	mm
Average radius (r_0)	3.30	mm
Synchronous phase (φ_s)	-90 – -30	°
Transmission efficiency (h)	96.3	%
Input emitt. $\varepsilon_{t,rms}(n)$	0.20	πμm.rad
Output emitt. $\varepsilon_{t,rms}(n)$	0.20	πμm.rad
Output emitt. $\varepsilon_{z,rms}(n)$	0.10	deg.MeV
Quality factor (Q_0)	9000	
Total power loss	539	kW
Max. surface E field (E_{max})	26	MV/m
Kilpatrick	1.4	

lists the design parameters of the RFQ for protons. The same RFQ is again simulated with 25 mA H^- ion beam. The transmission efficiency and beam emittances in x-x′, y-y′ and ΔW-$\Delta\varphi$ phase planes are 96.6 % and 0.197, 0.198 π.mm.mard and 0.0998 deg.MeV respectively. In the simulation studies with PARMTEQM, an input emittance of 0.2 π.mm.mrad (normalized rms) is assumed in both the transverse planes. In order to simulate the effect of increased emittance from the ion source, the output beam parameters were studied by varying the input emittance. Figure 4 shows the transmission efficiency and beam emittances at the output of RFQ as function of input normalized rms emittance.

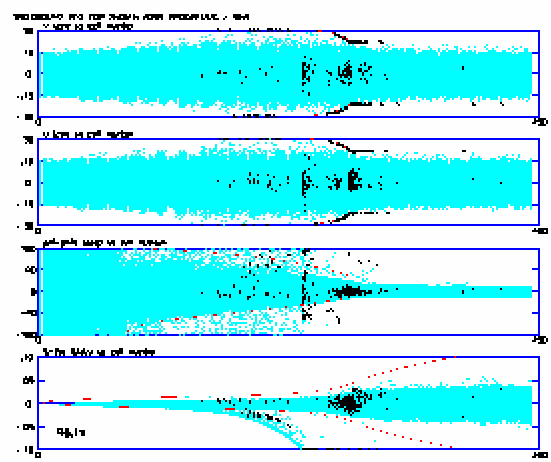

Figure 2: Beam transmission through RFQ. The pictures from top show x vs cell no., y vs cell no., φ – φ_s vs cell no. and W – W_s vs cell no. respectively.

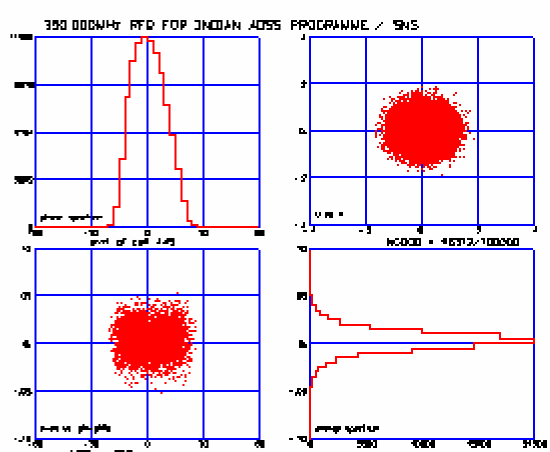

Figure 3: The Phase (top left) and energy (bottom right) spectra at the end of RFQ; Top right and bottom left: distributions in x-y and ΔW-Δφ.

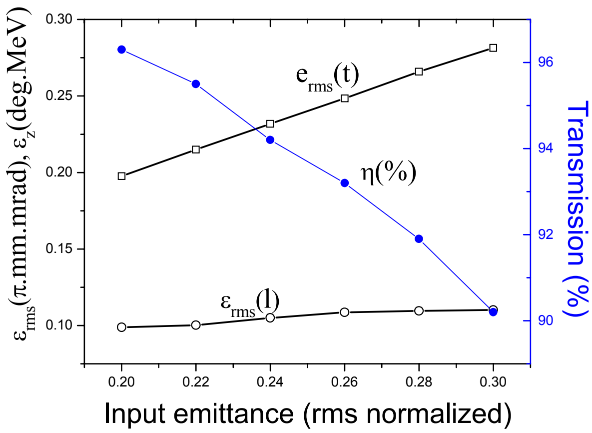

Figure 4: Normalized rms output emittance and transmission efficiency as a function of normalized rms input emittance

3 RFQ CAVITY DESIGN

The RFQ cavity is designed with SUPERFISH. Being CW accelerator, the main consideration while designing the cavity was the minimum power dissipation. Apart from selecting the lower inter-vane voltage, the geometry of the RFQ, is optimized to keep the power dissipation minimum. The structure is optimized such that the power dissipation in cavity with 65 kV inter-vane voltages is 600 W/cm. However for the thermal analysis, we have considered the heat dissipation of about 800 W/cm having safety factor of 1.33 and is described in ref. [4]. The power densities are in the range of 8 – 6 Watts/cm^2. The adjacent dipole mode frequency as predicted by SUPERFISH is 340 MHz. Figure 5 shows the field distribution for the quadrupole mode.

4 CONCLUSION

The RFQ beam dynamics design is optimized for maximum transmission, minimum emittance growth and lower power dissipation to suit the CW operation.

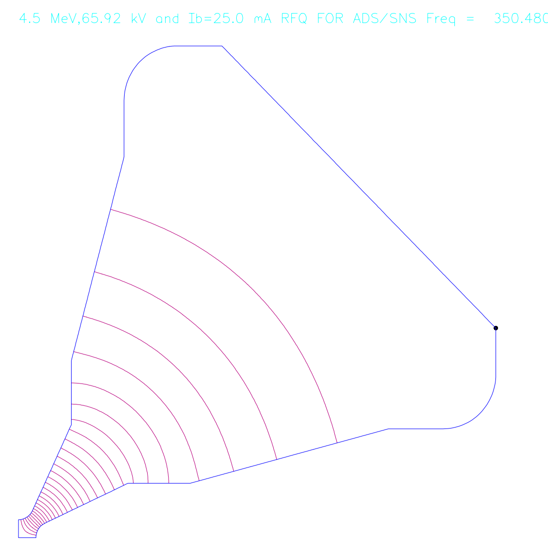

Figure 5: One quadrant of the RFQ showing the Quadrupole mode.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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