The Neutral Particle Beam Space Experiment (NPBSE) Accelerator Designs

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Abstract

Accelerators that are designed to operate in a space environment are more strongly constrained by hardware envelope size, power consumption and cooling requirements than are equivalent ground based systems. The challenges presented by these constraints have resulted in the development of novel features in the Neutral Particle Beam Space Experiment (NPBSE) accelerator designs, which may also find application in ground systems. We will describe both the low power 2.0 MeV RFQ and 5.11 MeV ramped gradient DTL designs. The initial DTL cell is suitably phased as a compactor to provide longitudinal matching and the first four DTL PMQs have different strengths to obtain transverse matching. Minimum beam momentum spread is essential to the minimization of chromatic aberrations in the downstream optics components but drift space for beam expansion prior to compaction is highly limited. We therefore shift to positive synchronous phase in the tail of the DTL to minimize the required pre-compaction drift length. These and other accelerator design details will be described.

I. INTRODUCTION

The NPBSE accelerator is a 425 MHz, 12.5 m straight beamline designed to deliver a 5 MeV neutral hydrogen beam with a divergence of 30 mrad. Table 1 provides a component parameter summary of the beamline. In this table, the power figures in parentheses are the projected RF unit sizes.

Component	W(MeV)	L(m)	P(kW)	$P_{thermal}$(kW)
Injector	0.035	0.820	50	50
RFQ	2.000	1.587	234(300)	183
Drift	-	0.028	-	-
RGDTL	5.110	1.721	291(300)	210
Optics	-	6.520	42(60)	42
Total	5.110	10.676	617(660)	485

Table 1. Component Parameter Summary

The 35 keV injector system was designed at Culham Laboratories[1]. It and the RFQ are complete at a level suitable for near term fabrication. The RFQ feeds a single tank, ramped gradient, $\beta\lambda$ FO-DO DTL to accelerate the beam to the 5 MeV output energy[2]. To minimize length and total power consumption, the two novel features have been incorporated in to the DTL. They are: a direct coupling scheme between the RFQ and DTL with transverse and longitudinal beam matching accomplished within the initial few cells of the DTL; and the incorporation of much of the post DTL drift into the DTL thus achieving the required momentum compaction and eyepiece matching while minimizing overall length. Positive cell phasing is used in the final four DTL cells to stretch the bunch and increase the energy spread within the DTL such that momentum compaction can be achieved in as short a distance as possible. These techniques are described in section III. The output optics is described in reference 3.

II. RFQ

Due to the requirements of the space mission, the RFQ has been designed to minimize RF power consumption and length. This has been effected by using a relatively narrow "BEAR like" aperture (0.255 cm at the choke point) with an inter-vane potential of 68.4 kV (at the choke point) which leads to a current limit of approximately 73 mA. In this design, the length reaches the output energy in 2.25 λ. It has a nominal transmission of 94% with output emittance values of 0.01080 π cm-mrad and 0.06943 MeV-deg. The design and operation of the RFQ is summarized in table 2.

Particle mass	1.0084 amu	Frequency	425 MHz
Rest Energy	939.293MeV	Wave Length	70.54 cm
Max. modulation	2.306	Radius of Curv.	3/4 r_0
Min Vane Aper.	0.163 cm	Inter-vane Pot.	68.4/78.9 kV
Ave. Aper.	0.255/.294 cm	Peak Sur. field	37.06 MV/m
Min. Long. ρ	0.604 cm	Kilpatrick factor	1.83
Nom. Input I	28.0 mA	RF Cav. power	182.5 kW
Transmission	92.1 %	RF Beam power	51.2 kW
Phase Adv.	19.7° / 5.7°	Sync. Phase	-27.1°

Table 2. RFQ Design Parameter Summary

III. RGDTL

Table 3 is the cell table for the RGDTL. This device accelerates the beam to an output energy of 5.1105 MeV. It has 32 cells at a mean synchronous phase of -27.1°. The two unusual features of the DTL are shown in this table. The direct DTL to RFQ coupling is seen in the initial three cells (four magnets). (There is also a small 2.8 cm drift between

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Cell No.	Energy out (MeV)	Beta out (cm)	Cell Len (cm)	Gap Len (cm)	Drift Tube Length 1st Half (cm)	2nd (cm)	Total (cm)	Quad Len	Eff. Quad Grad (kG/cm)	Eo (MV/m)	ϕ_s (deg)	Match. Param. [EoT/β]	Total Len (cm)
in	2.0003	0.0652				0.9428	1.8855	2.50	-23.6721				
1	2.0003	0.0652	4.5962	1.1012	0.9428	2.5462	4.2851	2.50	25.8609	2.2753	-90.0	26.954	4.5962
2	2.0736	0.0669	4.6380	1.1150	1.7389	1.7749	3.5407	2.50	-25.0869	2.2993	-27.1	27.037	9.2342
3	2.1492	0.0681	4.7217	1.1430	1.7658	1.8021	3.5950	2.50	25.4118	2.3200	-27.1	26.863	13.9559
4	2.2270	0.0694	4.8064	1.1714	1.7928	1.8295	3.6494	2.50	-24.5000	2.3411	-27.1	26.696	18.7624
5	2.3071	0.0706	4.8921	1.2004	1.8199	1.8570	3.7038	2.50	24.5000	2.3625	-27.1	26.536	23.6544
10	2.7456	0.0770	5.3361	1.3538	1.9668	2.0061	4.0046	2.50	-24.5000	2.4757	-27.1	25.808	49.4361
15	3.2527	0.0837	5.8071	1.5217	2.1132	2.1546	4.2993	2.50	24.5000	2.5990	-27.1	25.079	77.5188
20	3.8363	0.0908	6.3049	1.7041	2.2745	2.3183	4.6244	2.50	-24.5000	2.7330	-27.1	24.451	108.0363
25	4.5055	0.0984	6.8306	1.9014	2.4341	2.4801	5.9890	2.50	24.5000	2.8783	-27.1	23.812	141.1267
26	4.6507	0.0999	6.9391	1.9427	3.5090	1.4687	4.3500	2.50	-24.5000	2.9134	+27.1	23.758	148.0659
27	4.7998	0.1015	7.0490	1.9846	2.8813	2.9353	5.4797	2.50	24.5000	2.9445	+27.1	23.587	155.1148
28	4.9531	0.1031	7.1600	2.0271	2.5444	2.5919	5.1716	2.50	-24.5000	2.9760	+27.1	23.450	162.2748
29	5.1105	0.1039	7.2722	2.0702	2.5797	2.6277	5.2553	2.50	24.5000	3.0080	+27.1	23.350	169.5471
out	5.1105	0.1039			2.6277								

Table 3. Ramped Gradient DTL Cell Table

the RFQ output and the first DTL magnet.) Longitudinal matching is effected by phasing the first DTL cell at -90°. Transverse matching is obtained varying the first four DTL drift tube permanent magnet quadrupoles (PMQs). In this manner a relatively current independent match has been achieved. A direct comparison of beam envelops in Trace-3d shows the beam well matched to the DTL in all three of the phase space planes.

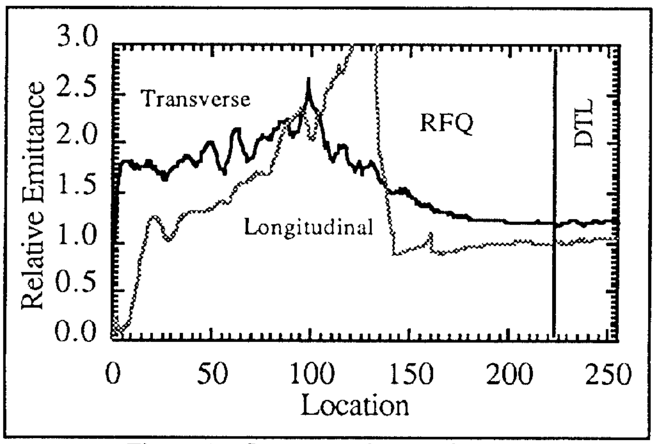

Figure 1. System Emittance Growth

The relative emittance growth through the accelerator components is shown in figure 1 and Figure 2 shows the same growth through the DTL. Due to the small vertical scale used in figure 2, the effect of the positive cells on the longitudinal emitance can easily be seen. The additional small continuous growth throughout the DTL in the longitudinal emittance is attributed to the small negative slope seen in Table 3 in the matching parameter $\{E_0T/L\}$. This arose due to a system redesign that was driven by a need to increase the value of the RFQ longitudinal radius of curvature from approximately 0.4 cm to the final value of 0.604 cm.

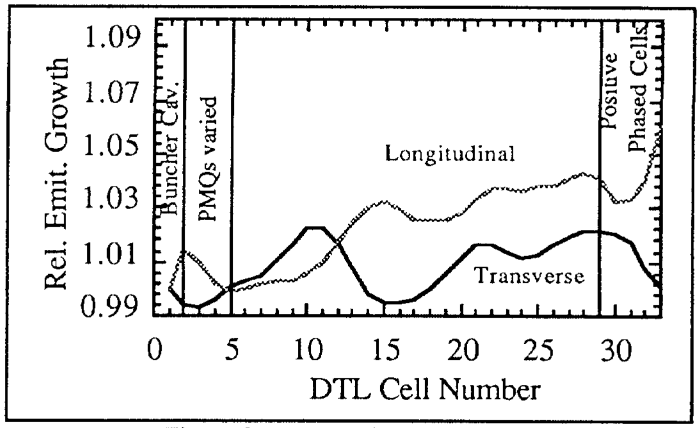

Figure 2. DTL Emittance Growth

The pre-stretching of the beam is necessitated by the fact that there is virtually no length available for pre-compaction drifting following the DTL. Therefore the beam is stretched in both phase and energy prior to the 425 MHz compaction by utilizing a +27° phasing in the last four DTL cells. The output momentum spread achieved in this manner is:

$$\delta p/p \sim 6.6 \times 10\text{-}4.$$

Figure 3 show the beam brightness through the DTL with varying RFQ input parameters. The parameter space spanned by the input beams runs from the nominal case to the extreme case of 64 mA at 0.013 π cm-mrad. (The beam input values for the 7 cases may be found in Table 4.) All curves in Figure 3 are basically flat with the differences entirely attributable to the current limit of the RFQ. This indicates that the DTL design is relatively insensitive to the input beam parameters.

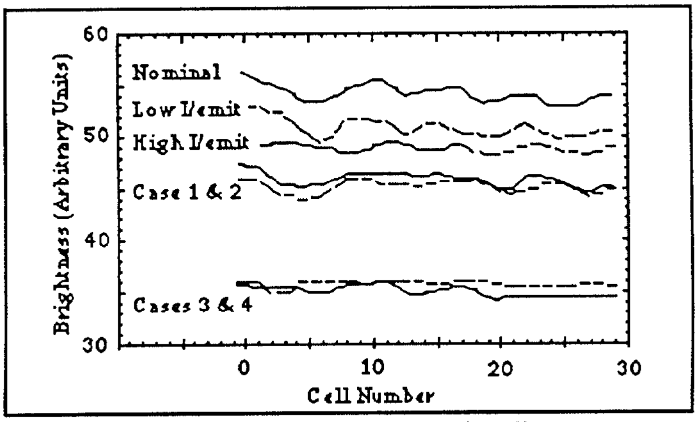

Figure 3. Brightness Through DTL

	Current (mA)	Emit. (π cm-mrad)
Nominal Input	28	0.009
Low Current/Emit. Input	15	0.006
High Current/Emit. Input	40	0.012
Case 1 (90% value)	47	0.009
Case 2 (90% value)	51	0.010
Case 3 (90% value)	54	0.012
Case 4 (90% value)	64	0.013

Table 4. RFQ Input Parameters

The irregular phasing of the first cell and the final four cells in the design has led to some difficulty. The phasing changes are effected by changing the distance between gaps from one cell to the next. However, the center-to-center spacing of the PMQ lattice does not change. It is maintained in order to minimize the effect of the phase change on the beam transverse properties. This results in the PMQs being offset to the end of the drift tubes and therefore being shorter with higher field gradients. At both ends, the PMQs still require some minor but readily achievable redesign. Presently the largest problem seems to be the low energy end-plate PMQ which will probably have to use an inner radius of 0.4 cm to fit in the drift tube.

The stretching of the beam in the high energy end is effected by phasing the final four cells at +27° rather than -27°. The use of the same angle minimizes the impact on the final energy. A study was made to determine the how many cells could be phased in this manner before there is a significant emittance growth in the beam output. The system was run with zero through 6 cells phased in this manner. The results are shown in Figure 4. Although more positive cells were desired, it was concluded that the maximum stretching that could reasonably be accomplished without significantly affecting beam performance was 4 cells.

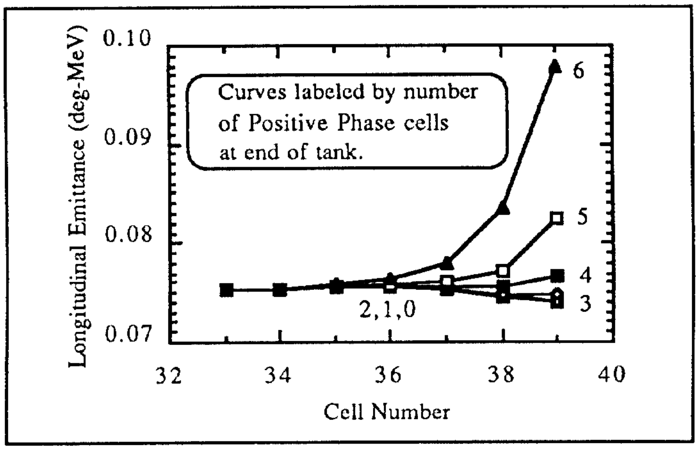

Figure 4. Effect of Positive Phasing on Beam Performance

IV. CONCLUSIONS

The physics design of the NPBSE 5 MeV accelerator has been presented. The standard concepts of device matching were revisited in the design which uses novel concepts for the entrance & exit matching in the DTL. These techniques has proven to be very successful. Off nominal analyses have begun and have shown the accelerator to be exceptionally robust in coping with inputs far from the nominal values. The use of the DTL cells for matching have proven to be workable over a parameter range far in excess of anything that would have been anticipated.

V. ACKNOWLEDGMENT

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VI. REFERENCES

[1] M. Nightengale; priv. comm.

[2] A.M.M. Todd; "Applications of Proton and Deuteron Accelerators"; to appear in Nuclear Instruments and Methods B, April 93.

[3] M. F. Reusch and D. L. Bruhwiler; "Optics Simulations of the 5 MeV NPBSE FOX Telescope"; these proceedings