Double Alpha MEBT For H$^-$ Beam

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Abstract

This note describes simulation studies of the H$^-$ beam matching condition between a 750keV rod radio-frequency quadrupole (RFQ) and the existing Fermilab drift tube linac (DTL). The RFQ design used in this study is that of an existing RFQ designed and built by A. Schempp from IAP- Goethe University. It is assumed that the medium-energy beam transport (MEBT) line uses hardware built for a positron emission tomography (PET) project. The MEBT is made out of two Alpha magnets and seven quadrupoles and was designed by D. Larson. The beam from the exit of the RFQ is matched to the entrance in the DTL in all three dimensions. The study shows that up to 65mA of H-beam can be transported and cleanly injected into the present linac.

Introduction

For the PET project[1] a special type of the MEBT[2] was designed and built, Figure 1. This system was used to match 1MeV single charged $^3He^+$ beam coming from a 200MHz

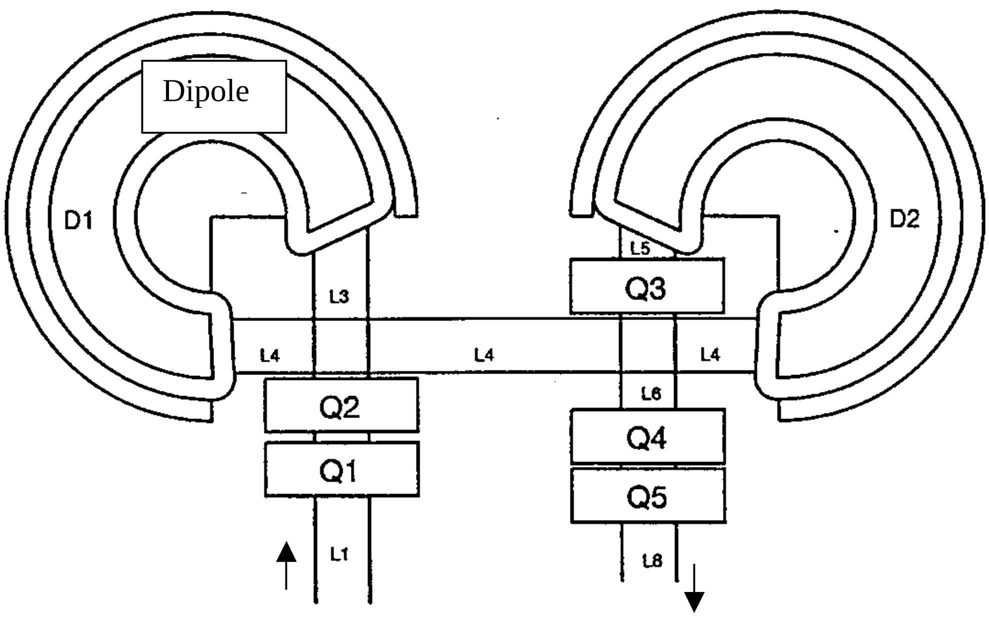

Figure 1. MEBT elements, D1, D2 are Alpha Dipoles. Arrows show the beam direction

RFQ to a 400MHz RFQ. The beam in the beginning of the MEBT was stripped and the 400MHz RFQ then accelerated a double-charged $^3He^{++}$ beam. The peak current of the $^3He^+$ single charged beam was 17mA and the stripping efficiency was better than 70%. The MEBT was made out of seven quadrupoles and two 270 degree gradient magnets, so called Alpha magnets. Quads and dipole magnets were designed for the $^3He^{++}$ beam. The beam's kinetic energy is 1MeV with a peak current of 28 mA. In the operation of this system, up to 21mA of the double charged beam was transported to the matching point of the first 400MHz RFQ. The MEBT as a whole performed as designed. The design tool used was Trace3D[3]. The Trace3D calculations include effects of the linear space charge, but during the design phase of the MEBT and before its completion, there were discussions about the accuracy of both the design and functionality of the whole approach. The major worry was based on the fact that the beam coming from the exit of the first RFQ is small in all three dimensions and the lack of strong focusing even along the short distance, will blow-up emittance of the beam. This would make the beam too large for injection into the next RFQ. One explanation for the success of the approach was based on the fact that the Gas Charge Stripper was positioned very close to the exit from the RFQ and the beam's charge was fully neutralized along the distance where the beam size was small. If charge neutralization is well controlled process, this method of matching is very elegant and probably the most efficient way of transferring low energy beams from one RF structure to the next. We have proposed testing this approach using PET MEBT hardware with an H^- beam. To accelerate this beam, we propose using the existing 750keV RFQ of A. Schempp (IAP-Goethe Univ.) which is presently stored at Fermilab.

MEBT and H^- Beam

The Trace3D studies of the MEBT were carried out based on the following assumptions:

- H^- beam with Kinetic energy of 750keV
- Beam entering MEBT comes from a 201MHz RFQ
- MEBT starts at the end of this RFQ
- Only the PET project's quads and dipoles are used in the MEBT
- MEBT ends at the entrance of the Fermilab DTL linac

The beam parameters at the end of the RFQ were provided by Ding Sun. He has modeled rod RFQ designed and built by Schempp. Table 1 is based on an input beam with a normalized rms emittance of 0.13π mm-mrad. It contains a set of runs for different input currents.

I (mA)	α (x)	β (x)	ε (x)	α (y)	β (y)	ε (y)	α (z)	β (z)	ε (z)	Tr
20	-1.3866	0.0893	27.3138	2.1269	0.1417	20.3032	0.265	0.9744	401.814	0.96
30	-1.8438	0.1213	22.6817	2.7158	0.1752	22.2345	-0.0586	1.1034	390.9361	0.958
40	-1.7799	0.1106	23.1159	2.1182	0.1585	23.7877	-0.1848	1.5308	391.0592	0.944
50	-1.9185	0.1238	23.8437	2.5883	0.1731	26.5479	0.1241	1.7219	392.1339	0.926
60	-1.8172	0.119	26.6124	2.798	0.1825	27.2324	0.2463	1.5362	418.7197	0.882
70	-1.4416	0.1018	36.4626	2.5646	0.1682	27.1442	0.074	1.6432	474.793	0.826
80	-1.4121	0.1018	29.9223	2.4202	0.1643	32.9212	-0.0182	1.3962	618.8199	0.792
90	-1.8801	0.1176	30.4518	2.2012	0.1463	37.802	0.0003	1.4813	606.2384	0.748
100	-1.6246	0.117	28.9042	2.4725	0.1578	41.8179	-0.1036	1.532	613.1793	0.696

Table 1, Input emittance 0.13π mm-mrad

The first column in the table is beam peak current entering RFQ, the α, β, ε are the usual beam parameters in each dimension at the exit of RFQ. The last column is the transmission efficiency at the end of RFQ. Table 2 contains similar information and is based on an input emittance of 0.25π mm-mrad. The beam parameters listed in both tables are for the beam with kinetic energy of 750keV, beam emittance is unnormalized five times the rms emittance for each plane, and the beam envelopes are $\sqrt{5}$ times their respective rms values. These are the units used in Trace3D. A note about the space charge calculation used in the Trace3D and the assumptions of the calculations follows. For the space-charge forces to be linear, one must postulate that beam has a uniform charge distribution in the real space. It has been shown that for distributions having elliptical symmetry, the evolution of the rms-beam envelope depends almost exclusively on the linearized part of the space-charge force, so a “real beam” can be replaced by a equivalent uniform beam having identical rms properties. In reality, beams do not have sharply defined boundaries, but it is typically found that less than 5% of the particles of the real beam are outside of the boundary displayed by Trace3D.

I (mA)	α (x)	β (x)	ε (x)	α (y)	β (y)	ε (y)	α (z)	β (z)	ε (z)	Tr
20	-1.4721	0.0882	35.6475	2.2015	0.1433	34.256	0.0049	0.6753	486.9354	0.964
30	-1.3666	0.084	35.2933	1.8127	0.1258	35.7074	0.0912	1.0423	450.7356	0.952
40	-1.5347	0.101	35.9797	2.3952	0.1524	34.6116	0.0405	0.9769	448.9031	0.932
50	-1.6138	0.1009	36.5902	2.1685	0.1464	36.5015	-0.086	1.2225	461.642	0.912
60	-1.6901	0.107	38.6662	2.2829	0.1527	38.2934	0.0388	1.3736	566.9273	0.888
70	-1.5398	0.0982	41.5054	2.4187	0.1522	38.8282	-0.0741	1.5582	507.9884	0.862
80	-1.7957	0.1095	38.5421	2.0715	0.1376	41.1759	0.055	1.4739	573.2169	0.806
90	-1.716	0.1054	39.5502	2.1883	0.1383	41.7991	-0.0621	1.3552	645.437	0.75
100	-1.7779	0.1117	43.5568	2.2911	0.1503	38.7072	-0.1032	1.3115	709.0758	0.718

Table 2, Input emittance 0.25π mm-mrad

In the figures that follow, the upper left two boxes display the horizontal, vertical and

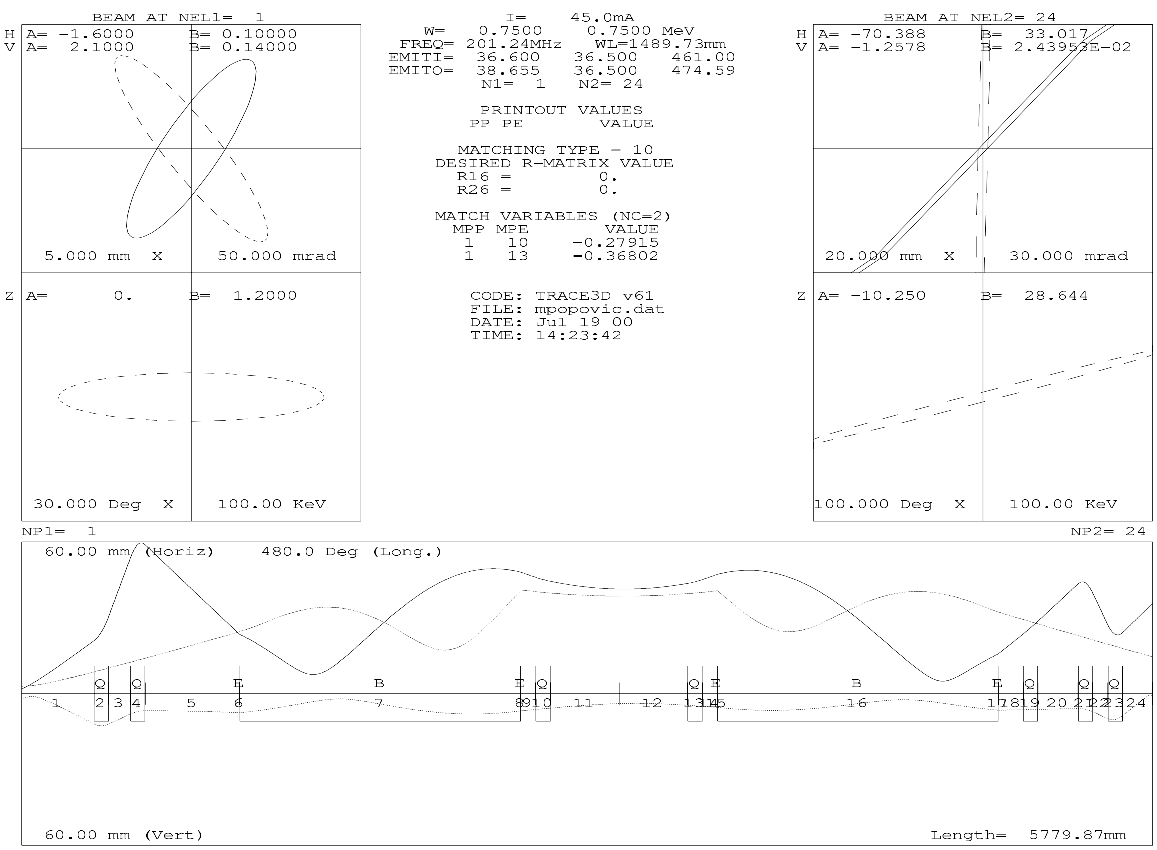

Figure 2, 0.25π mm-mrad beam

longitudinal beam ellipses at the start of the MEBT. The two boxes on the upper right side display beam ellipses at the end of the transport line. The bottom box contains the beam line elements and beam envelopes in the three planes. The upper two traces are the horizontal beam envelope and bunch length along the transfer line. The lower trace is the beam envelope in the vertical plane.

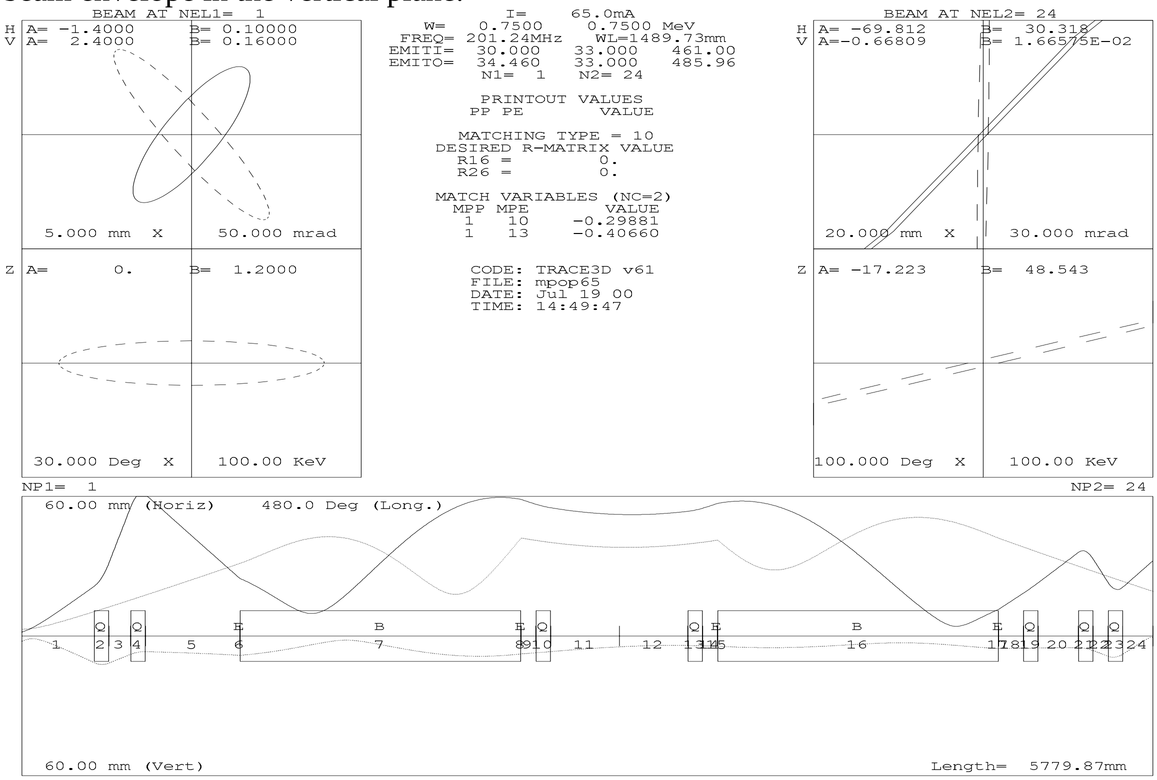

Figure 3. Input Beam emittance 0.13π mm-mrad

Figure 2 shows the solution for the case of the larger beam, 0.25π mm-mrad, coming from the source when the input current to the RFQ was 50mA. The drift spaces and currents in the quads were used as free parameters to match the beam in both of two presented cases. Figure 3 is the case of a source with lower emittance and a peak current of 80mA. In the process of adjusting quad currents, one simple but arbitrary condition was used. Currents in the quads where allowed to be not more than 20% above operating currents in the PET project. Table 3 lists the beam size in each transfer line element. In both cases the beam is large in the horizontal plane in the dipoles and that limits high current beam to be transported. This is not unexpected, the magnetic elements that we are using were designed for different beam species, different kinetic energy and peak beam current of only 28mA.

No	Name	X(mm)	Y(mm)
1	Drft	20.95	11.97
2	Quad	30.67	12.11
3	Drft	53.61	8.15
4	Quad	59.63	6.9
5	Drft	58.53	6.82
7	Bend	49.43	7.9
9	Drft	47.97	6.83
10	Quad	45.92	6.3
11	Drft	44.38	5.75
12	Drft	43.62	4.67
13	Quad	45.13	5.07
14	Drft	47.22	5.5
16	Bend	48.82	6.47
18	Drft	23.65	6.45
19	Quad	28.75	6.32
20	Drft	43.4	5.99
21	Quad	44.23	6.1
22	Drft	39.02	7.41
23	Quad	26.6	10.06
24	Drft	35.73	0.94
Curr	45mA		
MAX	VALUES	59.63	12.11
EMITi=	36.6	36.5	461.00,

45mA, 0.25pi mm-mrad beam

No.		X(mm)	Y(mm)
1	Drft	21.4	11.47
2	Quad	31.54	11.66
3	Drft	55.32	7.95
4	Quad	61.59	6.83
5	Drft	60.49	6.79
7	Bend	59.63	8.52
9	Drft	58.62	7.73
10	Quad	56.57	7.24
11	Drft	55.1	6.72
12	Drft	53.63	4.14
13	Quad	54.98	4.26
14	Drft	57.02	4.43
16	Bend	58.05	4.87
18	Drft	18.49	5.27
19	Quad	22.99	5.19
20	Drft	35.9	5.1
21	Quad	36.68	5.22
22	Drft	32.58	6.44
23	Quad	22.56	8.86
24	Drft	32.32	0.74
Curr	65mA		
MAX	VALUES	61.59	11.66
EMITi=	30	33	461.00,

65mA, 0.13pi mm-mrad beam

Table 3.

Conclusion

Under the restrictions that were described in the text, the solution in Figure 3 is the one with maximal peak current, 65mA, which can fit in the available aperture. The H^- beam with a peak current of 65mA will be enough to fully test space charge effects in this type of MEBT. Success of presented setup will be excellent starting point for design that will be dedicated for an H^- beam with kinetic energy optimized for injection into the DTL linac. If the planned R&D program demonstrates that this system works as well as these calculations imply, it might be interesting to use it to inject into the existing drift-tube linac. However to achieve significant performance gains and good enough reliability for routine operation, a new system specifically designed and optimized for that purpose should be acquired.

References

[1] R.J.Pasquinelli, et.al. A $^3He^{++}$ RFQ Accelerator for the Production of PET Isotopes,

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[3] K.R.Crandall and D.P.Rusthoi, Trace 3-d Documentation, LA-UR-97-886