A SEPARATED FUNCTION DRIFT-TUBE LINAC FOR THE ISAC PROJECT AT TRIUMF

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Abstract

A variable energy drift tube linac (DTL) is required as part of the post-accelerator for the ISAC project at TRIUMF. A novel *separated function* DTL concept has been developed. Five independent interdigital H-type structures, each operating at 105 MHz and 0° synchronous phase, provide the acceleration, while quadrupole triplets and triple-gap split-ring resonators placed between IH tanks provide periodic transverse and longitudinal focussing respectively. Beam simulations show that the DTL can accelerate beams with little or no emittance growth over the complete energy range. `MAFIA` has been used to optimize the rf structures. Design and fabrication of the first IH tank is underway. Results of the beam dynamics and `MAFIA` studies, as well as the final linac specifications are presented. The status of the DTL engineering is summarized.

1 INTRODUCTION

A radioactive ion beam facility with on-line source and linear post-accelerator is being built at TRIUMF. [1] The accelerator chain comprises a 35 MHz RFQ [2] to accelerate beams of $q/A \geq 1/30$ from 2 keV/u to 150 keV/u and a post stripper, 105 MHz variable energy drift tube linac (DTL) to accelerate ions of $1/3 \geq q/A \geq 1/6$ to a final energy between 0.15 MeV/u to 1.5 MeV/u. Both linacs are required to operate *cw* to preserve beam intensity.

A *separated function* DTL concept has been developed.[3, 4] Five independently phased IH tanks operating at $\phi_s = 0°$ provide the main acceleration. Longitudinal focussing is provided by triple gap, split-ring resonator structures[5] positioned before the second, third and fourth IH tanks. Quadrupole triplets placed after each IH tank maintain transverse focussing. To achieve a reduced final energy, the higher energy IH tanks are turned off sequentially and the voltage and phase in the last operating tank is varied. A schematic drawing of the DTL is shown in Fig. 1. Diagnostic boxes are placed between the bunchers and the IH tanks.

2 BEAM DYNAMICS AND SPECIFICATIONS

2.1 Full Energy Mode

The code `LANA` [7] has been used to study the beam dynamics and to set the general specifications for the tanks. `MAFIA` has been used to model the rf characteristics. At full voltage the beam dynamics are typical for a 0° accelerating structure[6] with the benefits that the acceleration efficiency is optimum and rf defocussing is reduced. The calculated beam envelopes for the full energy case are shown

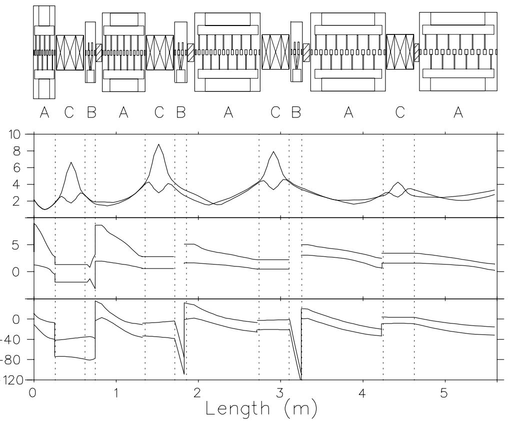

Figure 1: Schematic drawing of the ISAC variable energy 105 MHz DTL (upper figure) consisting of five IH tanks (A), three split-ring resonators (B) and quadrupole triplets (C). Beam envelopes (lower figure) define the x and y maximum half sizes and the energy and phase spread in the beam as a function of linac length. The calculations are for a beam with normalized emittances of 0.25π μm and 1.6π keV/u·ns longitudinally.

in Fig.1 for matched, normalized emittances of 0.25π μm and 1.6π keV/u·ns. The strong periodic focussing yields small beam sizes and increased acceptance. The longitudinal and transverse acceptance are 4.8π keV/u·ns and 0.6π μm respectively. A summary of before and after emittances for the full energy mode using particles simulated through the RFQ and MEBT for two different MEBT conditions are given in Table 2.1.

The gross specifications of the five IH tanks and the three split-ring resonators for the design particle of $q/A = 1/6$ are given in Table 2. The chief design considerations are the variable energy requirement and the *cw* operation. The quantity of cells in each tank is chosen to satisfy both transverse beam size requirements and debunching constraints in variable energy mode. Tank apertures are chosen to give sufficient transverse acceptance while maintaining a gap-to-aperture ratio of at least 1.2 for efficient acceleration.

Case		ϵ_x (π μm)	ϵ_y (π μm)	ϵ_z (π keV/u·ns)
A	in	0.221	0.192	1.95
	out	0.236	0.210	2.06
B	in	0.199	0.194	0.737
	out	0.209	0.194	0.737

Table 1: Beam quality before and after DTL for two MEBT setups. Quoted emittances are normalized and contain 98% of particles.

Each triplet unit has an effective length of 32 cm, with a bore aperture of 28 mm and a maximum gradient of 67 T/m. They will occupy a 40 cm space between tanks.

Maximum accelerating gradients are determined by restricting the total power per unit length to less than 20 kW/m based on shunt impedance calculations with MAFIA. The drift tube aperture is significantly larger (see table) in Tank 2-5 than in Tank 1. The increased capacity of the larger tubes requires a lower tank radius than that of Tank 1 to obtain the desired resonant frequency. Ridge parameters, in particular the ridge base width and ridge length, were varied in MAFIA to alter the inductance for frequency correction. In all cases the drift tube wall thickness of the IH tanks is 5 mm. This results in a reasonably conservative peak surface field in the last tanks of 14 MV/m. The peak surface field in the bunchers is reduced by careful shaping of the drift tubes[5].

2.2 Variable Energy Operation

A plot of the tank voltage and phase required for a given final energy is shown in Fig. 2. Each point represents a tune that has been simulated. In all the cases for input beams of 1.6πkeV/u·ns the final emittance was $\epsilon_z \leq 1.7\pi$keV/u·ns. For a reduced voltage the particle bunch is phased negatively with respect to the synchronous phase so that as the particles lose step with the synchronous particle and drift to more positive phases they gain the required energy. Below some minimum voltage (set by multi-pactoring criterion) the phase alone is used to fine tune the output energy. For the lower energies the upstream buncher is used to match the beam to the de-tuned tank. The buncher following this tank is then used to capture the diverging beam. The three gap split-ring structure [8] is chosen for its large velocity acceptance and large multipactor-free voltage range. The three bunchers must operate over β regimes given by 1.8%→2.2%, 1.8%→3.1%, 1.8%→4.1% respectively and over voltage ranges from 15% to the tabulated value. Three resonators with gap structures synchronized to beam velocities of $\beta = 2.3\%$, 2.7% and 3.3% have been specified.[5]

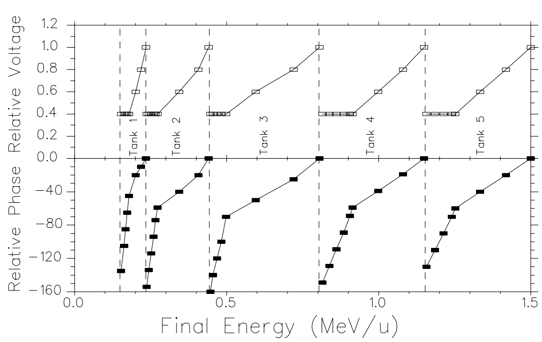

Figure 2: Tank voltage and phase required for a certain final energy. Upstream tanks are turned off. The full energy case corresponds to tank voltages of 1.0 and phases of 0°.

In Fig. 3 we show the initial and final position of a grid of particles in longitudinal phase space after acceleration in Tank 1 for two different tank voltages, $V = 0.4$ and 0.8. Distortion of phase space occurs for phases greater than that of the maximum energy gain. Below this the energy gain falls off nearly linearly. The diagram is useful in choosing the proper matching conditions entering the detuned cavity to reduce emittance growth during acceleration and to minimize phase spread in the next debunching cavity.

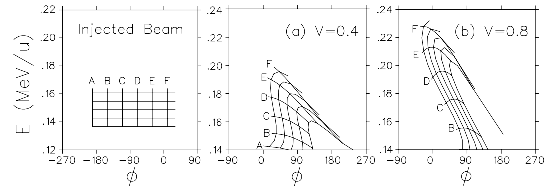

Figure 3: Final positions in $E-\phi$ space of initial grid of particles after acceleration through Tank 1 for voltages of 40% and 80% of the full energy setting.

3 TANK 1

The first IH tank (Tank 1) will be fabricated on an accelerated schedule as a working prototype for the other IH tanks. The engineering design is presently under review in preparation for detailed design. Detailed dynamics studies were completed prior to the engineering design and are reported below.

3.1 MAFIA Optimization

In an IH structure the capacitance is concentrated in the drift tubes. Hence as the cell length increases with β along the tank, with corresponding decrease in capacitance, the field profile will be asymmetric, higher at the first half of the cavity and falling off towards the end-plates. This leads to an uneven power distribution in the stems and a non-uniformity in the peak surface field on the tubes. In the case of Tank 1 the small length results in extra capacitance between the end plates and the ridge support. Shifting the ridge support to an asymmetric position improves the asymmetry at the expense of the shunt impedance. By varying the gap to cell length ratio, g/ℓ (Fig. 4(a)) the field profile on axis can be flattened (Fig. 4(b)). Note that although the g/ℓ variation changes the distribution of the field in a cell there is no substantial change in the distribution of the average field along the tank. However the peak surface field in each cell is made more uniform as is the power loss per stem. In flattening the maximum accelerating field the peak surface field variation in Tank 1 is reduced from 18% to 5%.

3.2 Beam Dynamics through Realistic Fields

The specifications and initial beam simulations of the DTL were calculated using a square field approximation in LANA. For Tank 1, these calculations were repeated with three-dimensional fields output from MAFIA to check the analytic gap-focussing calculation in the square wave model and to calculate accurately the effect of the E_y field

Tank	No.	L	a	R	β_{out}(%)	$\overline{E_o \cdot T}$	E_s	V_{eff}	Z	P_ℓ	P	E_{out}
-	Cells	(cm)	(mm)	(cm)	$\beta_{in} = 1.5$	(MV/m)	(MV/m)	(MV)	(MΩ/m)	(kW/m)	(kW)	(MeV/u)
1	9	26	10	46	2.2	2.1	10	0.5	480	12	3.3	0.23
2	13	50	14	38	3.1	2.4	12	1.2	495	16	7.8	0.44
3	15	77	16	38	4.1	2.5	14	2.0	464	18	14	0.78
4	14	90	16	38	5.0	2.4	14	2.2	400	19	17	1.14
5	13	98	16	38	5.6	2.3	14	2.2	365	19	19	1.50
B1	3	10	14	28	2.2	1.9	9.8	0.19	77		6.4	0.23
B2	3	12	14	28	3.1	2.3	11	0.26	75		11	0.44
B3	3	14	14	28	4.1	2.3	11	0.32	72		14	0.78

Table 2: Parameter specifications for each IH tank and buncher (B1-B3) for the design particle of $q/A = 1/6$ in full energy mode. All cavities operate at 105 MHz. Here L is the length, a is the tube aperture, R is the tank radius, $\overline{E_o \cdot T}$ is the effective field gradient, E_s is the peak surface field, Z is the effective shunt impedance and P_ℓ is the power per unit length. The quoted shunt impedance values are from MAFIA. The power/unit length and power calculations assume a shunt impedance 75% of the value quoted.

on axis (dipole component) caused by the IH stem structure. A comparison of the transverse and longitudinal calculations using both the square wave model and the realistic field simulations compared very closely.

The dipole component plus the effective integrated voltage from the field is plotted in Fig. 4(c). This field produces a maximum deflection of 0.6 mrad with a maximum shift in beam centroid of $12\ \mu$m. The cumulative deflection is negligible due to the alternating nature of the kick. Nevertheless some steering will be incorporated into the quadrupoles to allow for fine tuning of the beam position.

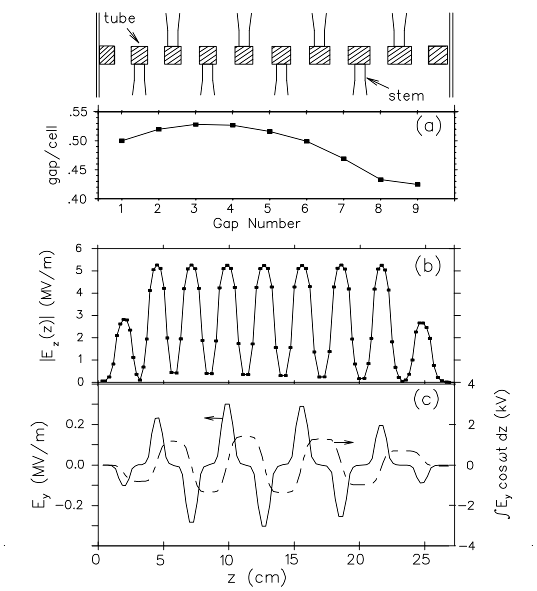

Figure 4: Tank 1 longitudinal (b) and vertical (c) field profiles from MAFIA for the gap to cell length ratio shown in (a).

3.3 Engineering

The tank and ridge are fabricated from mild steel. Cooling channels will be drilled in the ridge and hollow copper cooling inserts will be fit on the end plate in the vicinity of the beam entrance and ridge end. Stems are fabricated from copper and cooled through two holes drilled from stem base to near the drift tube. In order to minimize the ridge length for a given stem base, the stems are all longitudinally asymmetric, with tube positions not centered on the base. Water is supplied through a separate cooling circuit drilled into the ridge. The interior of the tank is to be copper plated with a bright acid finish to a thickness of 0.25 mm. Tuning is done through a capacitive plate with a servo-drive controlled via an rf pick-up loop.

4 CONCLUSIONS

The *separated function* DTL concept provides a low power solution to achieve variable energy heavy ion acceleration in the low β regime without significant increase in the longitudinal emittance. Signal level tests on Tank 1 are expected in early 1998. A working prototype of a split-ring resonator is scheduled to be completed by the spring of 1998. Other IH tanks are scheduled for testing in early 1999 with the DTL to be fully commissioned by the end of 1999.

5 REFERENCES

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