INVESTIGATION OF A NORMAL CONDUCTING 175 MHZ LINAC DESIGN FOR IFMIF

A. Sauer, R. Tiede, H. Deitinghoff, H. Klein, U. Ratzinger
Institut für Angewandte Physik, Frankfurt/Main, Germany

Abstract

The work for the project study of an **I**nternational **F**usion **M**aterial **I**rradiation **F**acility (IFMIF) has been continued. The linac part of the facility has to provide a 40 MeV, 125 mA D+ beam for the homogenous irradiation of a Li target to produce very high neutron fluxes for fusion chamber wall material tests. The linac consists of a Radio Frequency Quadrupole (RFQ) accelerator followed by a Drift Tube Linac (DTL). To different rf structures have been investigated for the DTL: the well known Alvarez type and the IH-type, both operating successfully at several large laboratories. Moderate rf power losses in the structure has been one main aspect in the design with respect to the required cw operation. Results of multiparticle beam dynamics simulations demonstrate the capability of each structure to handle the very high currents without particle losses and at moderate emittance growth. While the Alvarez DTL design shows less emittance growth with and without errors, the IH-DTL is attractive with respect to its compactness and mechanical robustness [1].

1 INTRODUCTION

Design studies have been successfully performed for a modular built DTL of the Alvarez type, which demonstrated the suitability of the conceptual design. Since that some parameters have been reconsidered: the aperture in the high energy part was increased from 1.5 to 2.0 cm for higher safety margins against particle losses. The tank end walls were included in the design to get more exact total power estimations of the DTL. Further inter tank matching was improved by adjusting the first and last two quadrupoles in the last four tanks. Results showed the capability of an Alvarez-type DTL to handle a high current beams even with combined standard errors without beam losses. Two end energies of the DTL were fixed: 40 MeV to 35 MeV for the irradiation of ceramic materials. The results of the calculations will be presented in the following section. In addition a room temperature IH-DTL design has been investigated for IFMIF application. First beam dynamics calculations showed that the IH-DTL is capable to accelerate such high current beams without losses. Some modifications were necessary to improve the beam quality and the performance of the IH-DTL: The number of gaps per resonator was reduced, which results in a smaller transverse beam size. By that the number of tanks is now 10. Furthermore for the first time error and tolerance studies for the IH-DTL have been performed. All the multi particle simulations for the Alvarez-DTL were done with the program PARMILA with 50,000 macro particles. The space charge forces are calculated with a Poisson solver with cylinder symmetric meshes. The multi particle simulations for the IH-DTL have been made with the program LORASR, 10,000 macro particles and a particle in-cell space charge solver, using the KONUS concept [2].

2 MULTI PARTICLE SIMULATIONS

2.1 Results for the Alvarez-DTL

Fig. 1 shows a schematic layout of the newest version of the Alvarez DTL design study for IFMIF generated with SUPERFISH and PARMILA.

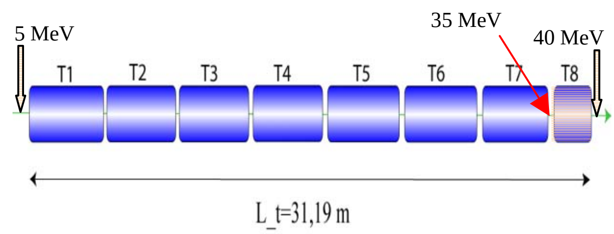

Fig. 1: Schematic layout of an Alvarez DTL for IFMIF. At 35 MeV end energy tank 8 provides no acceleration.

Table 1 summarizes the most important parameters.

Table 1: Structure and beam parameters of an Alvarez DTL for IFMIF.

	Alvarez	Units
A/q	2 (D^+)	
I design	125.0	mA
f_{rf}	175.0	MHz
N_T / N_{cell}	8 / 124	
$<L_T>$	3.66	m
$P_{Cu+Beam/T}$	0.750	MW
$P_{Cu/T}$	0.180	MW
$P_{Cu/L}$	0.048	MW/m
W_{in} / W_{out}	5.0 / 40.	MeV
$W_{tot/L}$	1.12	MeV/m
L_{tot}	31.19	m
E_oT	1.34 – 1.43	MV/m
r_o	1.5 - 2.0	cm
G_{quad}	7.00 - 2.20	kG/cm
B_{quad}	1.00 - 0.44	T
ZT^2	12.90 - 45.18	MV/m
b_{Kilp}	0.90	
In/Out rms ε^n_{trans}	0.040 / 0.041	cm×mrad
In/Out rms ε^n_{long}	0.080 / 0.082	cm×mrad

Having found a proper design of the DTL with good beam quality a tolerance study must proof the stability and robustness of the layout. In Fig. 2 the full beam sizes of the reference design without errors are compared to the beam behaviour with typical tank errors like randomly distributed phase and amplitude errors of ± 1% and an amplitude slope + 1%. The aperture factor is still two times beam size and no particles are lost.

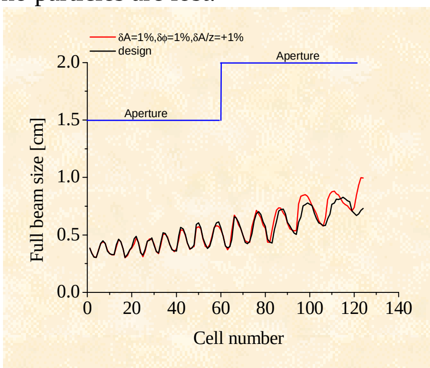

Fig. 2: Full transverse beam size with (red) and without (black) statistic tank errors vs. cell number of the DTL.

Fig. 3 illustrates the beam behaviour of the DTL with applied combined randomly distributed quadrupole errors of ± 0.1 mm misalignment in X and Y, rotation angle of ± 1° in X,Y and Z and gradient errors ± 1%. Even with this critical tolerances for an Alvarez the beam is smooth, without particle losses, the aperture factor is still quite large which guarantees hands-on maintenance.

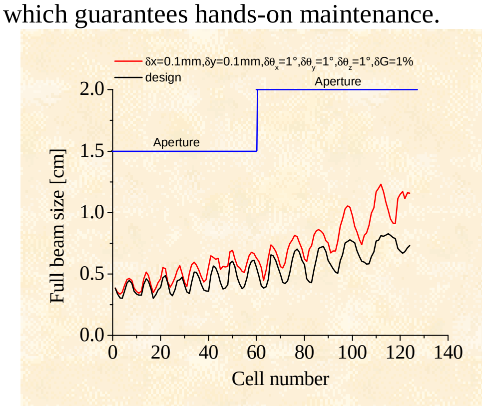

Fig. 3: Full transverse beam size with (red) and without (black) statistic quad errors vs. cell number of the DTL.

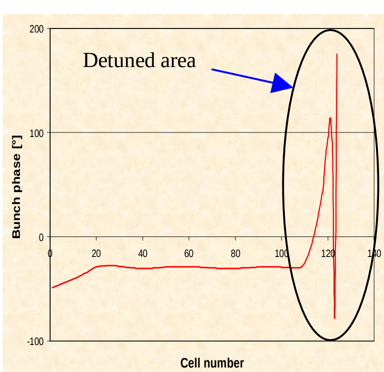

Fig. 4: Bunch phase of the DTL vs. cell number with the last two tanks adjusted for 35 MeV end energy.

The IFMIF DTL must provide a 125 mA D^+ beam with two end energies of 35 and 40 MeV. Figs. 4 – 5 show the bunch energy and phase for the detuned DTL at 35 MeV. In tank 7 the rf field amplitude has to reduced 70 % in tank 8 the rf field level is 0. The quadrupole gradients have to be slightly decreased. With this changes good results in transverse and longitudinal phase space were achieved. The longitudinal bunch size is at 35 MeV still confined but in phase about ± 15° larger.

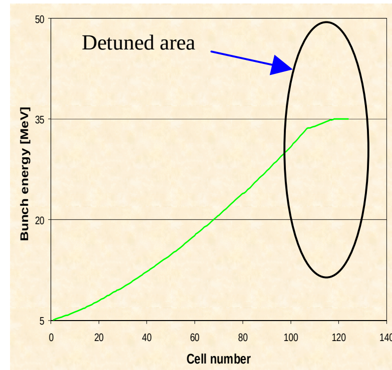

Fig. 5:Bunch energy of the DTL vs. cell number with the last two tanks adjusted for 35 MeV end energy.

2.2 Results for the IH-DTL

Fig. 6 gives a schematic layout of the last version of the IH-DTL design for IFMIF generated with LORASR. Main parameters are summarized in Table 2.

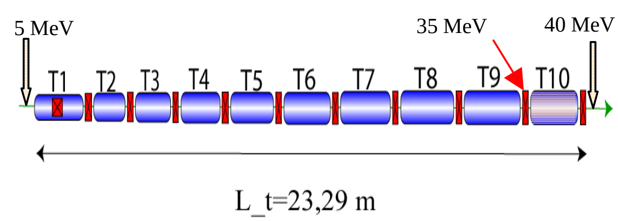

Fig. 6: Schematic layout of an IH DTL for IFMIF. At 35 MeV end energy tank 10 provides no acceleration.

Table 2: Structure and beam parameters of an IH-DTL.

	IH	Units
A/q	2 (D^+)	
I design	125.0	mA
$\mathbf{f_{rf}}$	175.0	MHz
$\mathbf{N_T / N_{cell}}$	10 / 157	
$\mathbf{\langle L_T \rangle}$	1.97	m
$\mathbf{P_{Cu+Beam/T}}$	0.536	MW
$\mathbf{P_{Cu/T}}$	0.095	MW
$\mathbf{P_{Cu/L}}$	0.0487	MW/m
$\mathbf{W_{in} / W_{out}}$	5.0 / 40	MeV
$\mathbf{W_{tot/L}}$	1.51	MeV/m
$\mathbf{L_{tot}}$	23.29	m
$\mathbf{E_oT}$	1.82 - 0.78	MV/m
$\mathbf{r_o}$	1.5/2.0	cm
$\mathbf{B_{quad}}$	1.3 - 0.94	T
$\mathbf{ZT^2}$	150.00 - 58.27	MV/m
$\mathbf{b_{Kilp}}$	0.43	
In/Out rms ε^n_{trans}	0.035 / 0.068	cm×mrad
In/Out rms ε^n_{long}	0.070 / 0.098	cm×mrad

As before the design has to be checked on error sensitivity. In the IH-DTL case we present only two important examples. In Fig. 7 the full transverse beam size with and without statistic distributed gradient errors of ± 0.5 % of the quad triplets is plotted. The beam is smooth, no particles are lost and the aperture factor is ≈ 1.5.

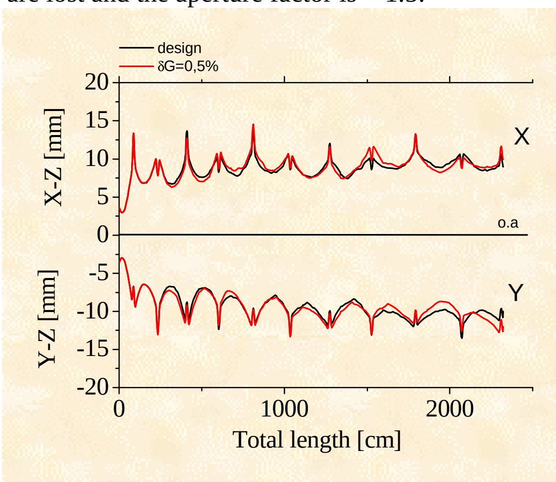

Fig. 7: Full transverse beam size with (red) and without (black) statistic quad grad errors vs. cell number of the IH-DTL.

The example in Fig. 8 deals again with quad errors. The whole quad triplets have a randomly distributed misalignment error of ± 0.1 mm and a rotation angle of ± 1°. Also in this case the beam has nice transverse properties, no particle losses and the aperture factor is ≈ 1.5 again. Finally we varied the end energy of the IH-DTL to 35 MeV and analysed the beam quality. Figs. 9 to 10 show the full longitudinal beam sizes in phase space. To hold the beam size small we reduced the triplet gradients a little bit and the longitudinal bunch increases in energy and phase about ± 10 % but is still well confined. The rf field of tank 9 is 79 % reduced and of tank 10 is switched off.

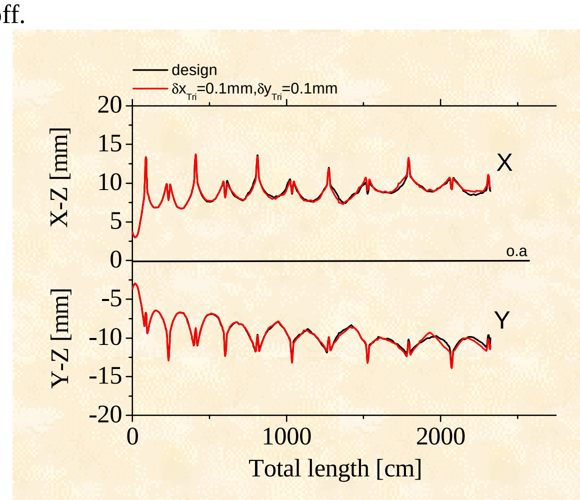

Fig. 8:Full transverse beam size with (red) and without (black) statistic quad misalignment errors vs. cell number of the IH-DTL.

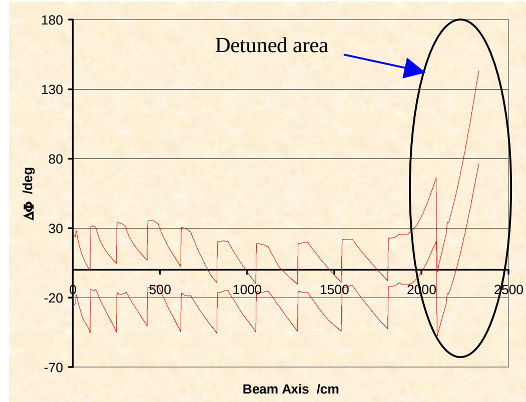

Fig. 9: Full phase width along the detuned IH-DTL.

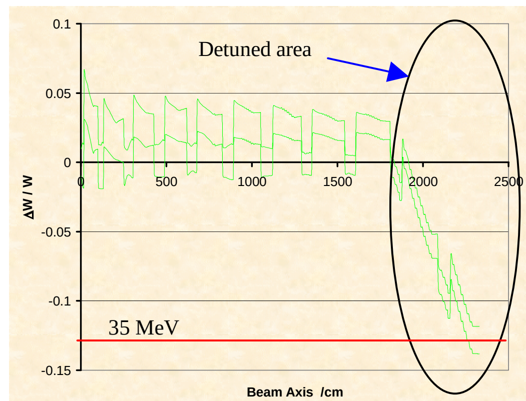

Fig. 10: Full energy spread along the detuned IH-DTL.

3 CONCLUSION

The beam dynamics design of an Alvarez type DTL for IFMIF is far advanced. The results of the multi particle simulations demonstrates a good capability of this design approach for IFMIF. Extended calculations have been performed for an IH-DTL with higher rf efficiency. The beam dynamics behaviour turned out to be fully sufficient for the IFMIF requirements. The modular construction of the DTL with inter tank focusing eases handling and adjustment. Integrated beam dynamics simulations for the whole linac (RFQ+DTL) are going on to ensure the safety of the injector facility against losses and activation [3].

REFERENCES

[1] A. Sauer, R. Tiede, H. Deitinghoff, H. Klein, U. Ratzinger, "PARTICLE DYNAMICS INVESTIGATIONS FOR A HIGH CURRENT D^+ DTL", PAC 2001, Chicago, USA, June 2001.

[2] U. Ratzinger, Habilitationsschrift, Fachbereich Physik der Johann Wolfgang Goethe-Universität Frankfurt, "Effiziente HF-Linearbeschleuniger für leichte und schwere Ionen", Frankfurt, Germany, Juli 1998.

[3] A. Sauer, Ph.D Thesis in preparation, Institut für Angewandte Physik, Universität Frankfurt/Main.

*Work performed in the EFDA/IFMIF collaboration