CONSIDERATION ON FIELD RAMP FOR THE LINAC4 DTL DESIGN

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Abstract

Nowadays some DTLs are designed with ramped average electric field E_0 for the purpose of being less sensitive to RF errors as compared to a design with a constant electric field, as it is the baseline of LINAC4. The Linac4 Machine Advisory Committee in January 2008 recommended considering a DTL design with ramped electric field. A study has been done to evaluate benefits of the DTL design with ramped field, its sensitivity to RF errors and practicality for Linac4.

Introduction

The baseline DTL design for Linac4 [1] consists of three tanks and accelerates H^- ions from 3 to 50 MeV over 19 m with $2\beta\lambda$ inter-tank space. The design is done with a constant average axial electric field E_0=3.2 MV/m in all three tanks. The synchronous phase is ramped from -30 to -20 deg in the first tank and then it is kept constant at -20 deg in the next two tanks.

During the Linac4 Machine Advisory Committee review in January 2008 it was proposed to consider a ramped field DTL design in view of improving its performance and sensitivity to RF errors.

Different DTL designs with and without field ramp and different synchronous phase profile were generated with GenDTL code [2]. The beam dynamics design and RF error studies are done using TraceWin code [2]. The designs are compared in terms of longitudinal emittance growth, "longitudinal losses" (un-accelerated particles), energy and phase jitter, energy and phase spread. The phenomenon affecting the beam quality and RF error sensitivity of the DTL has been identified.

DTL designs

Four different DTL designs are generated with different electric field and synchronous phase profile. One of the designs is done with a ramped electric filed and the other three, including the baseline design, are designed with a constant electric field. The design parameters are summarized in Table1.

Table 1. Design parameters of the studied DTLs

	DTL baseline	**DTL-1**	**DTL-2**	**DTL-3**
Energy (MeV)	3-50	3-50	3-50	3-50
E_0 (MV/m)	3.2, const.	1-3.5, ramped	3.2, 3.5, const.	3, 3.45, const.
φ_s (deg)	-30 to -20	-42 to -25	-32 to -24	-40 to -24
N cells	108	144	107	112
N tanks	3	3	3	3
ε_z growth (%)	13.5	11.9	11.8	9.4
Length (m)	19.02	21.75	18.68	19.16

As the choice of the electric field and synchronous phase affects the length of the structure, the field in the second and the third tanks is pushed up to some reasonable value (in terms of Kilpatrick criterion and effective use of available RF power) in the DTL designs 1, 2 and 3 to have a length as close as possible to that of the baseline DTL.

As described in the paper by T. Wangler et al. [3], when E_0T and φ_s are constant, k_{0l} and the external focusing force decreases with increasing β. The longitudinal emittance growth can be reduced by ramping the accelerating field as β increases, to keep k_{0l} constant. However, to keep k_{0l} constant with increasing β and synchronous phase in Linac4 DTL, the starting value of the field has to be rather low, making the linac structure longer. This also implies a weaker focusing force k_{0l} at low energies (see Fig. 1), when the space charge force is stronger.

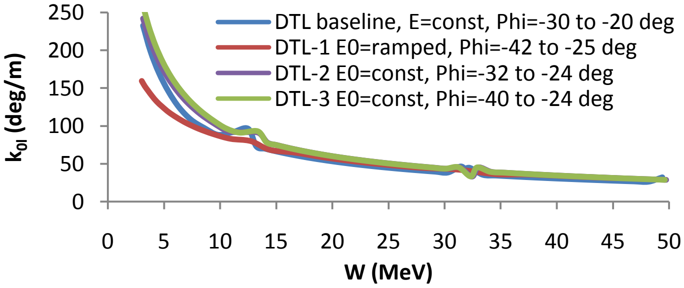

Fig. 1. Phase advance per meter

Beam centroid phase oscillations

The beam energy gain in the gap is expressed as $\Delta W=E_0Tl\cos\varphi$. The energy gain for two equidistant particles with respect to the synchronous phase ($\varphi=\varphi_s\pm\Delta\varphi$) is not the same as $\cos(\varphi_s-\Delta\varphi)\neq\cos(\varphi_s+\Delta\varphi)$ (see Fig. 2). This results in a non-symmetric oscillation of those particles around the synchronous one and consequently the beam centroid oscillates around the synchronous phase. This difference in the energy gain and the resulting beam centroid phase oscillation amplitude is higher for a higher synchronous phase (see Fig. 3). However, this effect is dumping rapidly with acceleration as the ration of the energy spread to the beam center energy is decreasing (see Fig. 3).

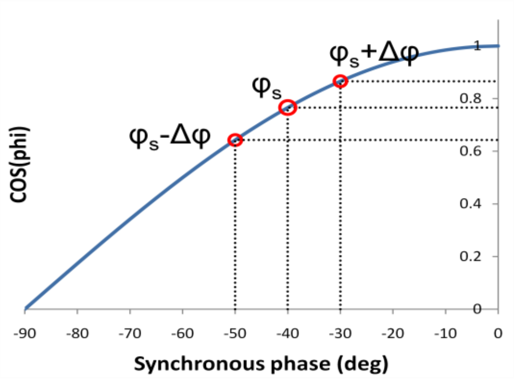

Fig. 2. Energy gain in the RF field

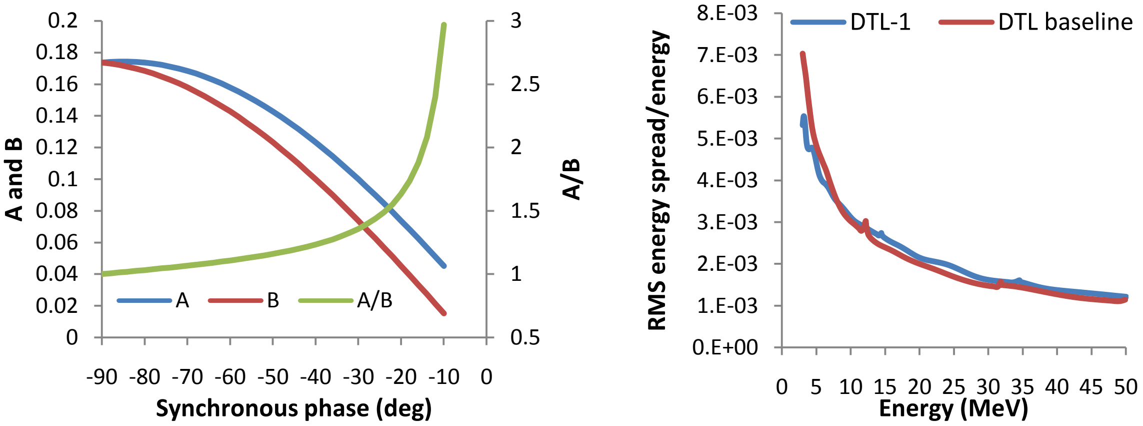

Fig. 3. Energy gain difference for two equidistant particles ($\varphi=\varphi_s\pm\Delta\varphi$),

$A=\cos\varphi_s-\cos(\varphi_s-\Delta\varphi)$, $B=\cos(\varphi_s+\Delta\varphi)-\cos\varphi_s$ (left);

ratio of the energy spread to the beam center energy (right).

Plotted in Fig. 4 is the beam centroid phase oscillations for the studied DTL designs. It shows that the oscillation amplitude is higher for the designs where the synchronous phase is higher. This entails longitudinal emittance growth, reduction of the effective longitudinal acceptance and consequently, un-accelerated particles (“longitudinal losses”). The effect is further amplified in presence of RF errors.

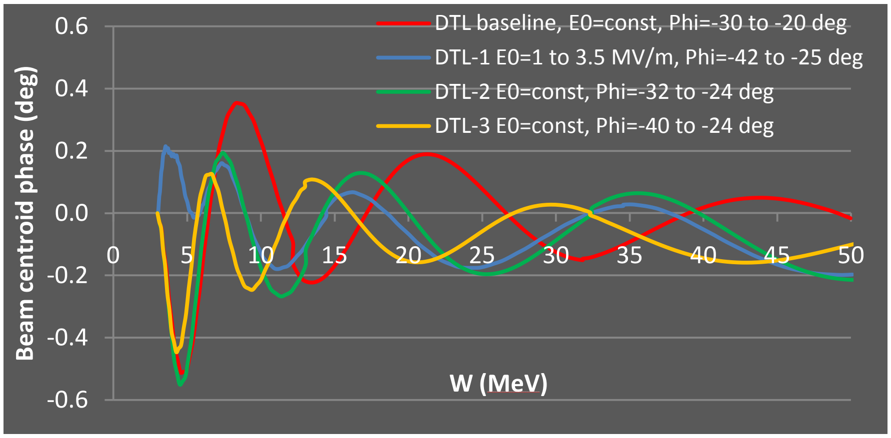

Fig. 4. Beam centroid phase oscillations

RF error study

In order to evaluate the effect of the synchronous phase profile on the RF errors sensitivity, klystron errors studies have been conducted on all four DTL designs. Errors applied are: input beam energy ±6 keV (uniform), klystron field amplitude ±1% (uniform), klystron field phase ±1 deg (uniform). Each of three DTL tanks is assumed to be powered by one klystron. Energy filter $|W\text{-}W_0|>1.2$ MeV (max energy acceptance) has been applied at the end of each structure to remove un-accelerated particles to account for “longitudinal losses”. The same (matched) rms input emittances $\varepsilon_{x,y}$ =0.31 pi.mm.mrad and ε_z =0.15 pi.deg.MeV were used for all DTLs. The results of error studies are summarized in Table 2.

Table 2. Results of klystron RF errors studies

	DTL baseline	**DTL-1**	**DTL-2**	**DTL-3**
Losses (%)	1000/1000 runs	0/1000	0/1000	0/1000
reference	7.04E-3	0	0	0
mean ± STDEV	7.5E-3 ± 3.8E-3	0 ± 0	0 ± 0	0 ± 0
99th percentile	2.1E-2	0	0	0
zz' rms emittance growth (%)				
reference	13.5	11.9	11.8	9.4
mean ± STDEV	15.4 ± 2.7	12.3 ± 1.65	12.5 ± 2.03	10.26 ± 1.71
99th percentile	22.6	15.9	18.2	15.0
Energy jitter (keV)				
mean ± STDEV	0.33 ± 31.73	-1.29 ± 24.43	-1.68 ± 38.4	-5.24 ± 28.66
99th percentile	66.5	50.1	83.4	52.35
Phase jitter (deg)				
mean ± STDEV	0.14 ± 1.9	-0.11 ± 1.87	-0.09 ± 1.63	0.04 ± 1.61
99th percentile	4.5	3.95	3.63	3.58
RMS energy spread (keV)				
reference	57.2	61	58.8	59.1
mean ± STDEV	58 ± 3.87	61.4 ± 3.23	59 ± 3.27	59.3 ± 3.27
99th percentile	67.7	70.2	67.65	67.05
RMS phase spread (deg)				
reference	3.06	2.56	2.64	2.68
mean ± STDEV	3.11 ± 0.27	2.75 ± 0.16	2.88 ± 0.19	2.8 ± 0.19
99th percentile	3.77	3.09	3.34	3.26

The "longitudinal losses" in the baseline DTL design are due to inadequate phase acceptance in the 5-10 MeV energy range. This bottleneck is eliminated by redesigning the DTL with slower synchronous phase ramp in the first tank (DTL-2). Longitudinal emittance growth with klystron RF errors is bigger for the baseline DTL and DTL-2 as compared to the DTL-1, which is due to bigger amplitude of the beam centroid oscillations (high φ_s). The klystron errors study results for DTL-3 design with a constant field, where the synchronous phase profile is similar to that of the DTL-1 design with field ramp, are similar or better than the corresponding parameters of DTL-1. This demonstrates that the choice of the synchronous phase is strongly influencing the sensitivity to RF errors and it has more important contribution to that matter than the electric field profile.

Conclusions

One of the arguments in favor of the field ramp in the DTL design is the provision of constant focusing force k_{0l} with increasing energy to reduce the longitudinal emittance growth. However, in Linac4 DTL it can be achieved only by having a low starting value of electric field. This results in weaker focusing force k_{0l} at low energies, lower acceleration efficiency and longer structure.

The difference in the energy gain for two equidistant particles w.r.t. synchronous phase ($\varphi=\varphi_s\pm\Delta\varphi$) entails oscillation of the beam centroid phase, which is more pronounced at low energies and for higher φ_s. This effect is amplified by RF errors and entails longitudinal emittance growth, reduction of the effective phase acceptance and therefore "longitudinal losses".

The choice of the synchronous phase profile is important in DTL design. It predetermines the sensitivity to RF errors and its contribution to that matter is more important than that of electric field.

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