DTL DESIGN FOR ESS

M. Comunian, F. Grespan, A. Pisent, INFN/LNL, Legnaro, Italy
M. Eshraqi, ESS, Lund, Sweden
R. De Prisco,ESS Lund University, Lund, Sweden and INFN-LNL, Italy
P. Mereu, INFN Torino, Torino, Italy

Abstract

In the present design of the European Spallation Source (ESS) accelerator, the Drift Tube Linac (DTL) will accelerate a proton beam of 50 mA pulse peak current from 3 to ~80 MeV. It is designed to operate at 352.21 MHz, with a duty cycle of 4% (2.86 ms pulse length, 14 Hz repetition period). Permanent magnet quadrupoles (PMQs) are used as focusing elements in a FODO lattice scheme, which leaves space for steerers and diagnostics. In this paper beam dynamics studies and preliminary RF design are shown, including constraints in terms of quadrupole dimensions, total length, field stability, RF power, and peak electric field.

INTRODUCTION

The ESS, going to be built at Lund, will require a high current linac to accelerate protons for the spallation process on which high flux of pulsed neutrons will be generated. The accelerator is 5 MW superconducting proton linac delivering beams of 2.5 GeV to the target in pulses of 2.86 ms long with a repetition rate of 14 Hz [1]. Beam current is 50 mA, which at 352.21 MHz is equivalent to ~ 9×10^8 protons per bunch.

Both handling on maintenance and machine protection set a strict limit on beam losses and have been a concern in every high power linac: Therefore it is crucial, especially for high power accelerators, to design a linac which does not excite particles to beam halo and also minimizes emittance growth. The ESS linac is carefully designed to minimize such effects all along the linac and transfer lines.

INFN is in charge of the design of this DTL accelerator. This design is based on the mechanical design and prototyping of CERN Linac4 [2], to which INFN has participated in the last years. In this paper the Physical design of ESS DTL is shown.

DTL DESIGN

Table 1: Main DTL Parameters

Parameter	Value
Duty cycle (%)	4
Frequency (MHz)	352.21
Injection Energy (MeV)	3.0 (β=0.008)
Output Energy (MeV)	77.5 (β=0.383)
Accelerated beam current (mA)	50

The design is done by respecting practical technology limits and by avoiding losses along the DTL structure. The maximum RF power per tank is fixed at 2.15 MW. The surface electric field limit is 1.4 Kilpatrick, to avoid sparking, specially at the first DTL cells, due to the contemporaneity presence of electric and static magnetic fields.

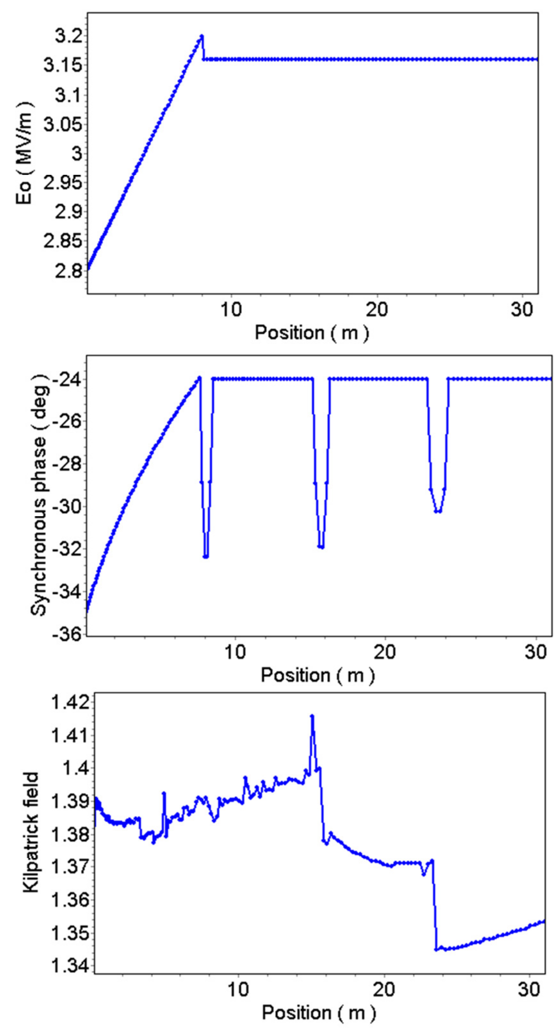

Figure 1: Design E0, synchronous phase and Surface field, along the DTL.

The tank length is limited at 8 meters (9.3 λ), to avoid stability problem on the voltage RF design. The total number of tanks is 4, to reduce the global RF power needed. The DTL beam bore radius is increased along the DTL to avoid losses. The optimized solution has been found by using GenDTL, from the CEA suit of codes.

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BEAM DYNAMICS

The PMQ law has been selected as a FODO channel, i.e. with half of the drift tubes with empty space, in this way it is possible to allocate diagnostics and steeres inside the DTL. The values of the PMQs permit an equipartitioned beam evolution (Figure 2) and a good phase advance matching with the RFQ at low energy and with the SC linac at high energy: The PMQ range is from 70 to 30 T/m, using permanent magnets (Figure 3).

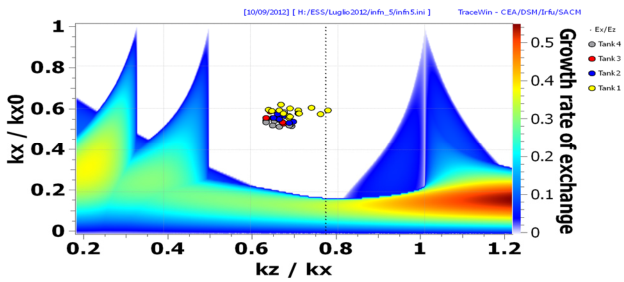

Figure 2: Stability plot for the DTL.

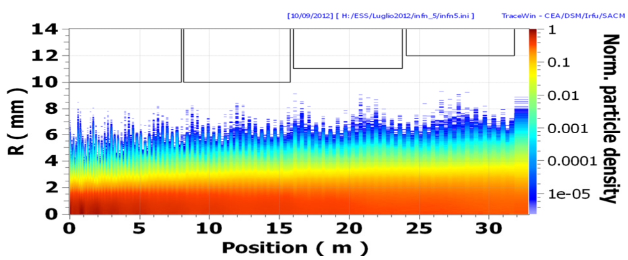

Figure 3: Particles density along the DTL.

RF DESIGN

The presence of DC magnetic field lowers the limit given by Kilpatrick's criterion for electric breakdown [2], [3]. In the first cell of ESS DTL, the maximum surface electric field is on the DT nose at R=12 mm. At that point the PMQ fringe field (B'=70T/m) is 0.092 T. This value of B reduces the maximum E_{surf} to 1.4Kilp (Figure 4).

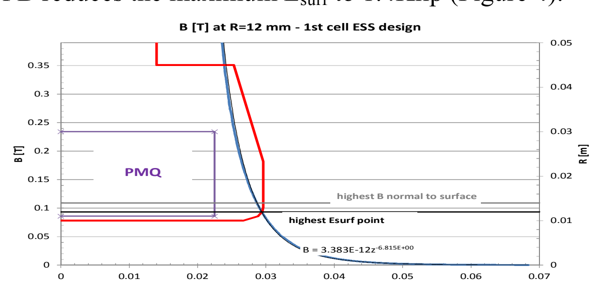

Figure 4: fringe magnetic field in the first cell of tank1.

Beam dynamic and Superfish (GenDTL) runs provide relevant quantities (E0, T, ZTT, Energy gain, Synchronous Phase law, Number of Cells, Cell and Gap lengths). These values, together with other geometric parameters, are inputs for RF design. First of all it is important to evaluate the frequency perturbation induced by stem over each cell. This perturbation can induce a ramped field shape. The stem effect is compensated by an equivalent variation of the face angle. Once all the cells are resonant at the same frequency, they compose the tank. The accelerating field E0 is not yet the nominal one: the final adjusting of E0 law is obtained changing face angles once again. Finally, the mechanical feasibility of the drift tube geometries is checked. A dedicated Matlab routine has been done to run Superfish and obtain a consistent tank design.

This design procedure has been validated with COMSOL 3D simulation, in a representative tank (5.5m, 26 cells) with aggressive ramped field (Figure 5). The mesh of this simulation consists of 1.100,000 tetrahedrons, generated with a revolution sweep, to better reproduction of the Superfish mesh. The error obtained with respect to the nominal design is 4%, located in the 2 end cells, used for ramping.

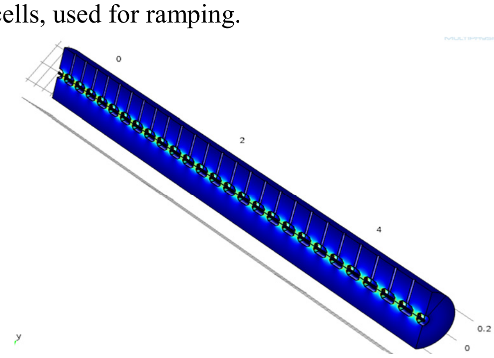

Figure 5: 3D simulation of a tank with ramped field.

The stabilization of the tanks is provided by Post Couplers (PCs). To fix the number of PCs needed in each tank a circuit model of the DTL is used [4]. A reasonable perturbation applied on the end-cells of the circuit induces a tilt on E0. Since the PCs must keep E0 within specifications (±1%) in case of perturbation, the number of PCs per unit length is given by

$$N_{PostCoupler} / m = \frac{\left| E_{first} - E_{last} \right|}{E0} \cdot \frac{1}{L_{Tank}} .$$

Slug tuners in a DTL should compensate the frequency effects due to construction errors. The evaluation of the frequency error is done applying realistic tolerances on the important dimension of the cavity (tank diameter, drift-tube lengths, drift tube diameter, face angles). The tuners have diameter of 90 mm, they are located at 45° with respect to the stem axis and are distributed uniformly every 30 cm along the tank. The tuner sensitivity is 3.5 (kHz/mm) × m, linear around 50 mm of penetration.

One klystron of 2.8 MW running at a duty cycle of 4% feeds the required RF power to each tank.

Power available at RF tank input is 2.15MW (30% margin for waveguide losses and LLRF regulation).

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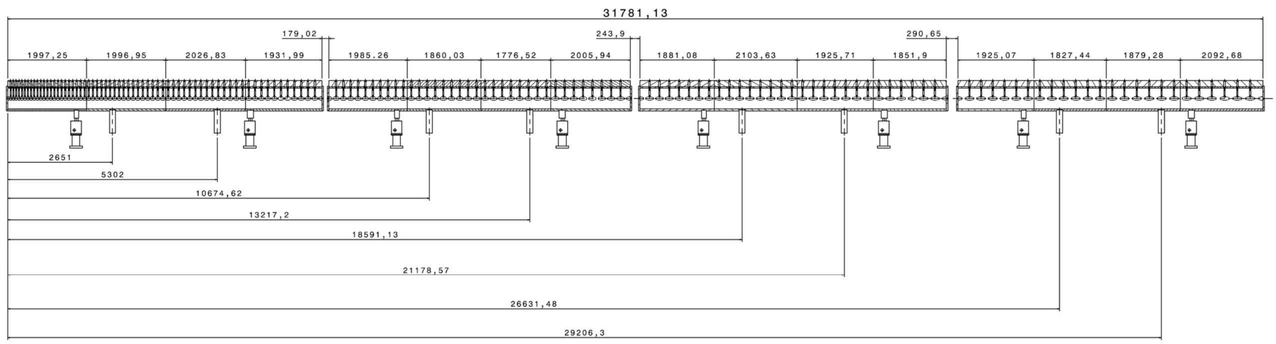

Figure 6: DTL overview.

These 2.15MW should include power dissipated on copper (with 25% margin on Superfish values) and beam power. We foresee 2 iris power couplers per tank [5], designed to have overall coupling factors of $\beta_0=1+P_{beam}/P_{cu}$, see figure 6.

Table 2: Summary of Tank Properties

Parameter/Tank	1	2	3	4
Cells	66	36	29	25
E0 [MV/m]	2.8, 3.2	3.16	3.16	3.16
E_{Max}/Ek	1.4	1.43	1.39	1.37
ϕs [deg]	-35, -24	-24	-24	-24
L_{Tank} [m]	7.95	7.62	7.76	7.72
Bore Radius (mm)	10	10	11	12
Post Couplers	22	23	28	24
Tuning [MHz]	±0.5	±0.5	±0.5	±0.5
Tuners	24	24	24	24
Q0 (SF)	53000	56000	55000	55000
Modules	4	4	4	4
Peak P_{cu} [MW]	0.91	0.91	0.92	0.95
E_{OUT} [MeV]	21.4	41.0	60.0	77.7
P_{TOT} [MW]	2.06	2.12	2.10	2.07

ERROR STUDY

An error study on the parameters sensitivity has been performed, using 100 DTLs and 1.6*10^5 particles (1 W per particle). A uniform input distribution was used with overlapped Gaussian halo distribution. The added halo extends to 3 × σ and the numbers of particles in halo are adjusted to have the equivalent of 1 kW power in the halo. A couple of steeres per axis has been used in each tank, to correct the beam centroid in case of PMQ shaking or input beam error with maximum steerer strength 1.6 mT*m. Figure 7 shows the errors study on PMQ shake, in 10 steps with a maximum of X,Y ±0.2 mm in the centroid position; ±1° on the 3 rotation angles; ±1% on the quadrupole field gradient. The main advantages of the steeres are reduction of the losses by a factor 10 and a reduction of the additional emittance growth by half. The main tolerance results are reported on Table 3.

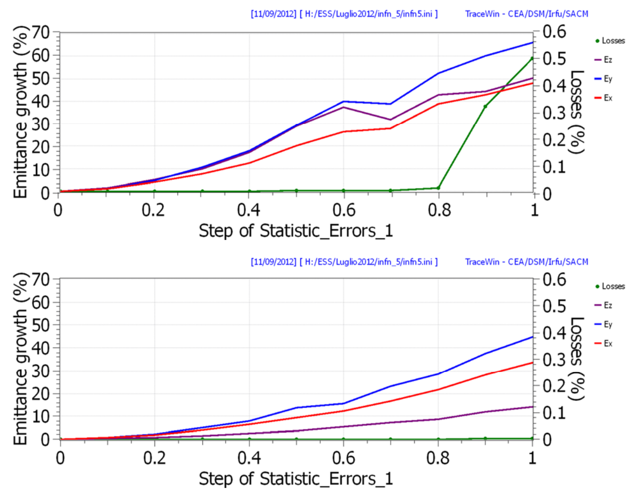

Figure 7: Losses (green) and emittances as a function of applied error on quads, with (bottom) and without (top) steeres.

Table 3: DTL Tolerance Results.

Parameter	Value
Max error on E0 amplitude and phase	+/- 2%; +/- 2°
Max quad error on X,Y position	+/- 0.2 mm
Max quad error on tilting	+/- 1°
Max quad error on amplitude	+/- 1%

REFERENCES

[1] H. Danared, “Design of ESS accelerator”, IPAC12, New Orleans.
[2] S. Ramberger et al., “Drift Tube Linac Design and Prototyping for the CERN Linac4”, linac2008 Proceedings.
[3] A. Moretti et al, Phys. Rev. ST Accel. Beams 8, (2005)
[4] F. Grespan et al., “An Equivalent Circuit for Post Coupler Stabilization in a Drift Tube Linac”, Linac2010 Proceedings.
[5] G. De Michele et al. “Power Coupler Simulations for the Linac4 Drift Tube Linac”, CERN-ATS-Note-2012-002 TECH.