PROGRESS ON DTL DESIGN FOR ESS

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Abstract

In 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. In this paper the progresses on design of DTL tanks with the beam dynamics errors studies and the RF design are shown.

INTRODUCTION

Table 1: Summary of ESS DTL 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	23	25	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

The ESS 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.

The accelerator includes an initial warm linac section, composed by Ion Source, LEBT, RFQ, MEBT and DTL. INFN-LNL is in charge of the design of the DTL accelerator. A 4 tank DTL came out of the design phase, accelerating the beam from 3 MeV to 77.7 MeV. Each tank is about 8 m long, for a total length of 31.8 m, including inter-tank sections (Fig. 1). Each tank is composed by 4 mechanical modules. In Table 1 main properties of the present ESS DTL are listed [2].

BEAM DYNAMICS WITH FIELD FULL MAP AND PMQ MULTIPOLES

In order to verify the effects of PMQ fringe field and continuous RF field on the beam dynamics, Tank 1 beam dynamics has been checked including full field map in the simulation. The Permanent Quadrupole Magnets (PMQ) field comes from 3D COMSOL simulation and the RF fields (electric and magnetic) on the bore radius zone come from the MDTFish full tank simulation. The results are shown in Fig. 2 and Fig. 3. Using a 6 σ Gaussian input beam distribution no emittance growth is observed at the end of Tank 1.

The impact of multipole contents in the PMQ has been evaluated as well. Multipoles of order $3 \leq n \leq 6$ are randomly generated in COMSOL model of the PMQ, as described in the next section. It should be notice that dipole (n=1) is not considered in this analysis and quadrupole (n=2) is considered as error in gradient and fixed at ±1%. Looking to the emittance growth (Fig. 4), the prescription for multipole content in the PMQ is $Bn/B2 \leq 2$ % at r = 10 mm to the beam axis, for multipole order $3 \leq n \leq 6$.

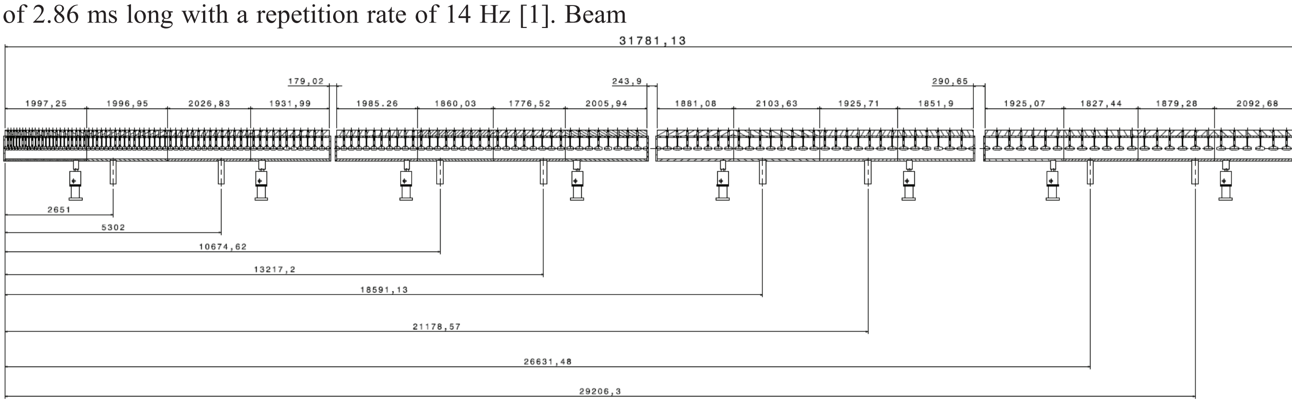

Figure 1: DTL overview.

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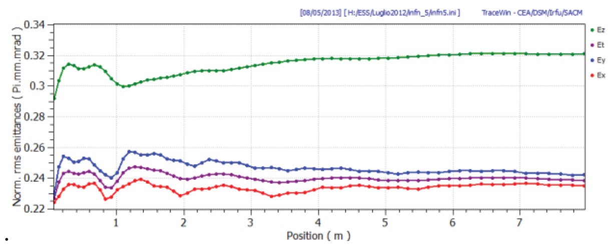

Figure 2: Emittance growth through Tank1.

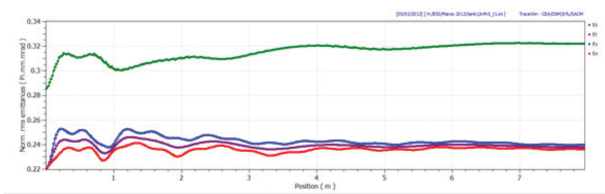

Figure 3: Emittance growth through Tank1 with full field maps.

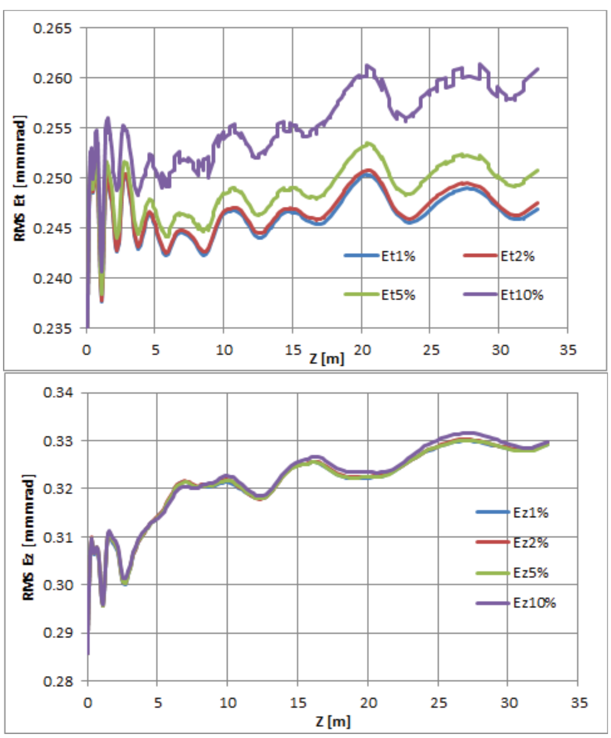

Figure 4: emittance growth due to multipole contents in PMQ (dipole excluded). The impact is negligible for longitudinal emittance. It is acceptable up to Bn/B2≤2% for transverse emittance.

THERMO-MECHANICAL SIMULATION

The cooling channel layout is based on the mechanical design of CERN Linac4 DTL [3]. The validity of this solution for the ESS case has been checked with an integrated COMSOL simulation, solving the problem series RF→Thermo-mechanical→Geometry Deformation →RF.

Figure 5 shows the results for two representative cells (Tank1 first cell, Tank4 last cell). The simulation inputs and outputs are listed in Table 2. Water regime inside cooling channels is assumed to be turbulent at 3 m/s. The dynamic frequency fluctuations will be compensated in operation by 3 movable tuners per tank and the field stabilization will be provided by *post couplers* [4].

Table 2: Summary of ESS DTL Properties

Parameter/Cell	C01-T1	C25-T4	unit
Length	68.534	325.770	mm
E0	2.80	3.16	MV/m
Max power dens.	2.4	5.4	W/cm2
Max Temp.(T0=20°)	22.3	26.3	°C
Max Nose Deform.	$+5\times10^{-3}$	$+15\times10^{-3}$	mm
Max Tank Deform.	$+8\times10^{-3}$	$+8\times10^{-3}$	mm
Freq. Perturbation	-10	-23	kHz

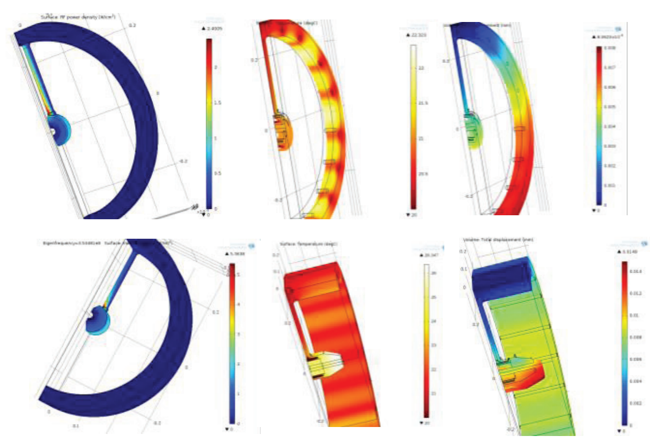

Figure 5: thermo-mechanical simulation of Tank1-Cell01 and Tank4-Cell25.

PMQ DESIGN

ESS DTL is equipped with 80 PMQs for transverse beam focusing, designed following Halbach's principle. Tank 1 has PMQs 45 mm long, Tank2-3 4 have PMQs 80 mm long, in order to relax the gradient. The PMQ is composed by 16 blocks of rare-earth material (SmCo), mounted in a stainless steel body. PMQ dimensions are: outer diameter = 60 mm, bore diameter = bore radius + 1 mm, inner steel jacket thickness = 0.5 mm, rectangular block sizes = 4mm x 14 mm (Fig. 6).

Main error sources in PMQ production are the machining, coating and magnetizing of the rare-earth pieces and their positioning in the stainless steel jacket. In order to quantify the PMQ specifications needed to comply the requirements of beam dynamics (multipole Bn/B2<2%), PMQ have been simulated with values of

Magnetization Br and Magnetization Angle θ randomly distributed over the 16 pieces in a defined range. The results show that error on Br of 5% and error on θ of 5 deg are acceptable (Fig. 7).

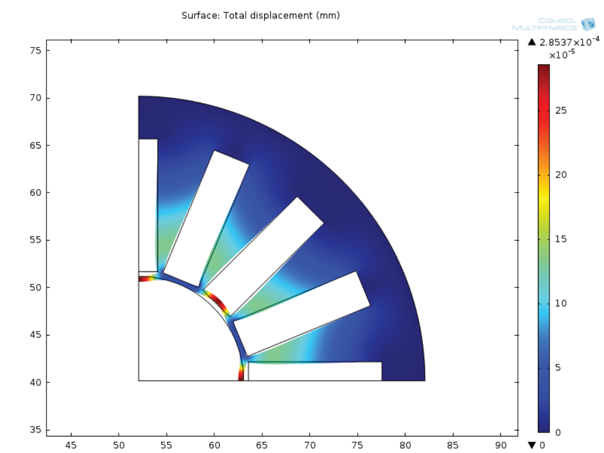

Figure 6: PMQ body deformation with Br=1.1 T, Gradient=65 T/m.

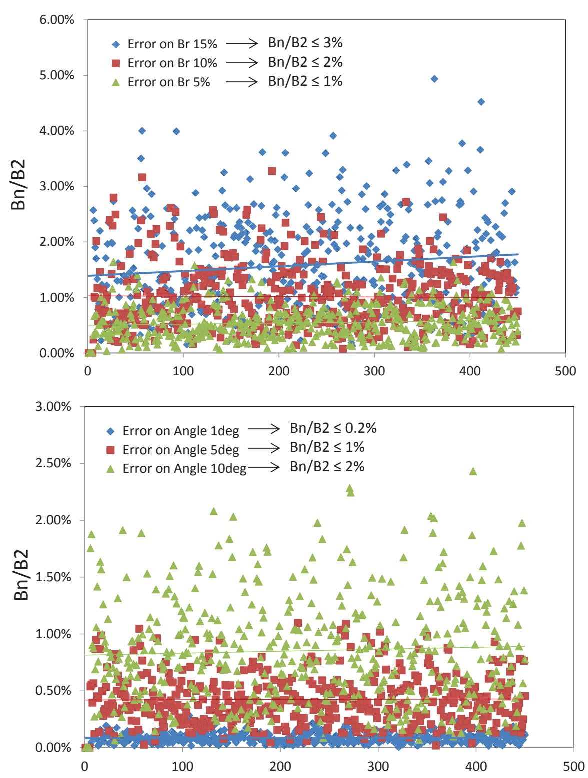

Figure 7: PMQ multipole contents with random error on remanence Br and magnetization angle θ.

DRIFT TUBE PROTOTYPING PROGRAM

The DTL design is mainly derived from CERN Linac4, therefore the drift tubes (DT) are aligned in the Tank using the precise positioning given by the Girder, with the Master /Slave criteria [3].

While the design of the drift tube with PMQ is the same of LINAC4, a new design has been done for the Drift Tube with BPM and Steerer. For these two types there are construction and installation issues, due to the presence of power and diagnostics cables, which need to be integrated inside the stem body.

The present design is based on a DT main body, as well, as the inner flow separator components, which are divided in two halves and are EB-welded after the insertion of BPM and Steerer. The passage for the cables is done by placing an inner thin-walled SS oval pipe inside the inmost flow pipe of the stem.

The prototyping program of the Drift Tubes is presently aimed to validate the design, with the involved integration issues of the various components, as well as the overall technological an assembly process. In particular a complete set of Drift Tubes is under construction that is BPM, EMD and PMQ type (Fig. 6).

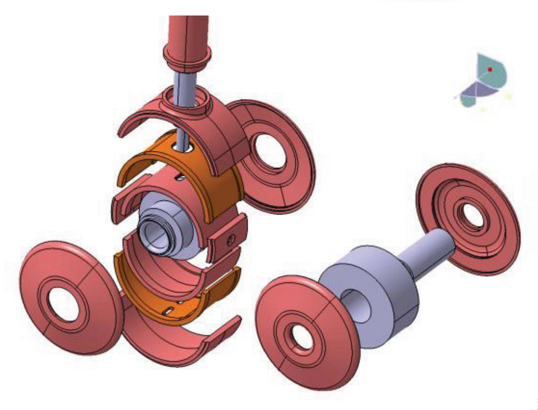

Figure 8: drift tube solution for steerer or BPM.

CONCLUSIONS

Several progresses have been done in last year toward the engineering design phase of the ESS DTL. The validity of this part is confirmed even if some of the fundamental parameters of the ESS Linac are going to be changed.

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