ESS DTL BEAM DYNAMICS COMPARISON BETWEEN S-CODE AND T-CODE

M. Comunian, L. Bellan[1], A. Pisent, F. Grespan, INFN-LNL, Legnaro, Italy
[1]also at Dipartimento di Fisica e Astronomia, Università degli Studi di Padova, Padova, Italy

Abstract

The Drift Tube Linac (DTL) for the ESS accelerator will accelerate protons up to 62.5 mA average pulse current from 3.62 to 90 MeV. The 5 tanks composing the DTL are designed to operate at 352.21 MHz in pulses of 2.86 ms long with a repetition rate of 14 Hz. The accelerating field is around 3.1 MV/m, constant in each tank. Permanent magnet quadrupoles (PMQs) are used as focusing element in a F0D0 lattice. The empty drift tubes accommodate Electro Magnetic Dipoles (EMDs) and Beam Position Monitors (BPMs) in order to implement beam corrective schemes. This paper presents the beam dynamics comparison over the 5 tanks between t-code PARMELA and the s-code Tracewin code.

INTRODUCTION

The following analysis was performed in order to check the consistency of the incremental law of particle velocity with the cell geometry of DTL, since we noticed that for the same value of cell lengths; different definitions gave different values of synchronous phase.

In order to bypass the intrinsic problem of the s-code (where equations of motion are integrated in space) with the relative synchronous phase definition, we decided to use a t-code (equations of motion integrated in time) with the absolute phase definition. This allowed us to check the correlation between space and time and the DTL self-consistency generation.

In the ESS DTL, the synchronous phase is ramped on Tank 1 from -35° to -26°, then it is kept constant at 25° up to the end of DTL, except for the inter-tank regions where one gap is missed and the phase is used to match the beam in the longitudinal plane, as shown in Figure 1. About transverse plane, the values of the PMQs of the F0D0 channel are fixed to obtain an equipartitioned beam evolution and a good phase advance matching with the RFQ at low energy side and with the SC linac at high energy side. The RMS input emittances are: Trans./Long. = 0.28/0.36 mm mrad (0.1436 π deg MeV). The emittance growth is $\Delta\varepsilon_{\perp,rms}$ = 2%, and $\Delta\varepsilon_{l,rms}$ = 1% [1].
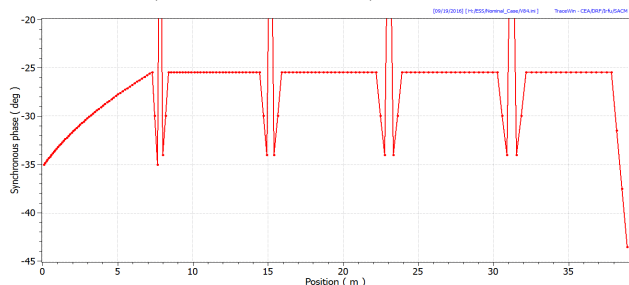

Figure 1: Synchronous Phase along the DTL.

SYNCHRONOUS PHASE DEFINITION

The ESS DTL was generated by GenDTL code. This code uses the full field map obtained from Superfish to synchronise the cell lengths with a given RF phase law. Starting from the nominal cell lengths and the other acceleration parameters given by GenDTL-SuperFish, we recalculated the synchronous phase values with the Wangler-Carne formula [2,3], to check the self-consistency of this model. The agreement of the two methods is better than 1 deg, with the larger error concentrated in the tank-to-tank interface (Figure 2).

To evaluate the effects of such difference on the beam, we track the particles through the entire DTL, using full tank field maps, so that the geometry itself sets-up the synchronous phase.
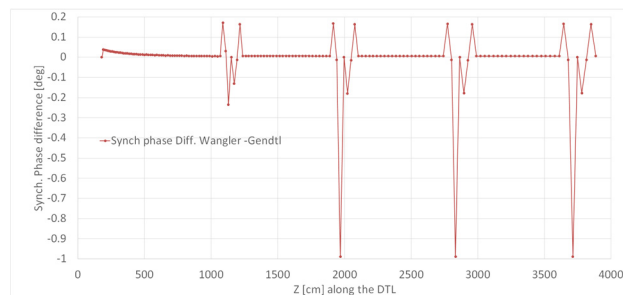

Figure 2: synchronous phase difference between Wangler-Carne formula and nominal phase law.

COMPARISON S-CODE T-CODE

Software's used for the comparison are Parmela [4] and TraceWin [5]. Both are PIC codes, with a 2D (r-z) grid mesh. The mesh size was adjusted as indicated in the reference [6], in order to minimize the 6D RMS emittance growth.

The input distribution was a not stationary waterbag, of 62.5 mA proton beam at 352.21 MHz @ 3.62 MeV. The input emittance was $\varepsilon_{n,\perp,rms}$ = 0.2797 mm mrad while the Twiss parameters were α_x = 0.0525 β_x = 0.1823 mm/mrad, α_y = 0.0354 β_y = 0.9527 mm/mrad. The longitudinal emittance was $\varepsilon_{l,rms}$ = 0.1545 deg MeV, α_l = -0.0175 β_l = 269.3992 deg/MeV.

Due to the bunch distance over the bunch length (20°/360°= 0.15 ns/2.8 ns) the head and tail effect of the previous and subsequent bunches could be neglected.

The five DTL tanks were modelled in two different methods:

- The first method uses the field maps: magnetostatic for the PMQ (obtained by Comsol Simulation) and RF for

the full tank (supplied by Poisson-Superfish-MDT-Fish, shown in Figure 3). This model is introduced in Parmela and TraceWin in order to compare the results.

- The second method uses the thin gap approximations and the hard edge model for the PMQ's. This model is introduced only in TraceWin and the results compared with full field maps output.

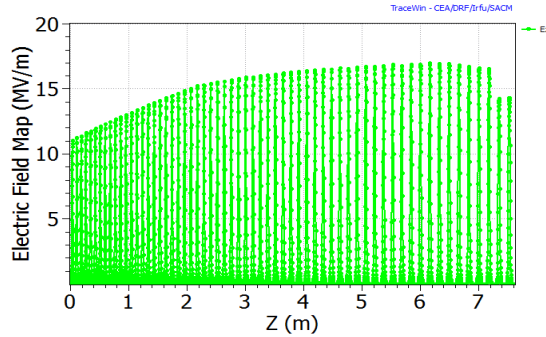- In both cases, the RF phase tank by tank was adjusted to meet the nominal value of energy

Figure 3: Electric field map of the full Tank1.

The understanding of possible differences between these two models is very important to speed up the calculations using the thin gap model.

Figure 4 shows the output phase space of PARMELA and TraceWin code obtained using the full tank field maps. The good agreement between the two codes is quantified in Table 1, were the differences between the output rms emittances and Twiss parameters presented.
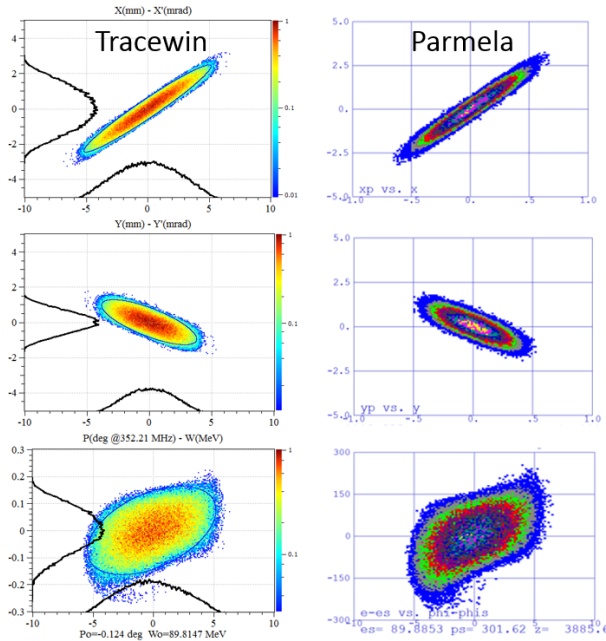

Figure 4: phase spaces at the end of the DTL (x-x',y-y', ΔW-φ going from up to down) for the Tracewin software (sx) and for PARMELA (dx).

The longitudinal normalised RMS emittance evolutions (expressed in terms of $\varepsilon_{n,z,rms}$) are shown in Figure 5. Despite the different amplitude of the oscillations, the overall trend is maintained with a maximum difference of 1% all

along the 40 m DTL. Moreover, the difference at the end is lower than 0.5%. Figure 6 shows the transverse emittance evolutions in the two codes. Also in the transverse plane the main trend is maintained with a maximum deviation of 2% and a final difference of 1.7%.

Table 1: Output Emittances and Twiss Parameter Differences Between TraceWin and PARMELA

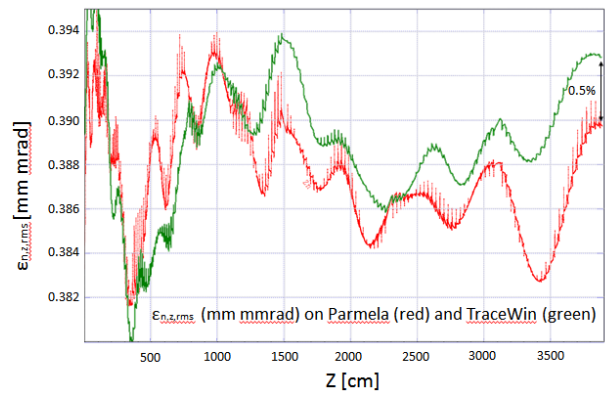| Output parameters	Differences [%]
$\varepsilon_{n,y,rms}$ [mm mrad]	1.5
$\varepsilon_{l,rms}$ [deg MeV]	0.5
α_y	6.7
α_l	0.7
β_y [mm/mrad]	3.2
β_l [deg/MeV]	1.1

Figure 5: Longitudinal emittance evolutions along the five DTL tanks with TraceWin (green) and Parmela (red).
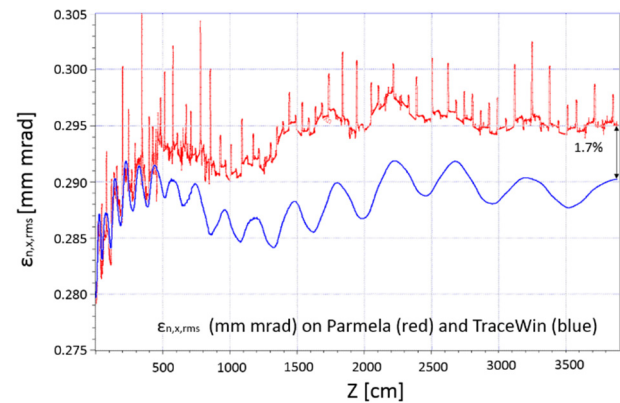

Figure 6: evolutions of $\varepsilon_{n,x,rms}$ between PARMELA (red) and TraceWin (blue) are shown.

COMPARISON FIELD MAP AND THIN GAP MODEL

The second part of the analysis consisted of comparing the field map model and the thin gap model via TraceWin. Taking into account the same beam input conditions for the PARMELA-TraceWin comparison, two simulations were done via the software TraceWin.

4 Beam Dynamics, Extreme Beams, Sources and Beam Related Technology

4A Beam Dynamics, Beam Simulations, Beam Transport

The results in terms of transverse emittance evolutions can be seen in Figure 7. The two emittances have the same amplitude oscillation. The longitudinal emittance evolution is shown in Figure 8. The agreement between the two models is good, with a difference at the end of 1.3%. From all these results, we conclude that the nominal Beam Dynamics of the DTL is well represented by the thin gap model.
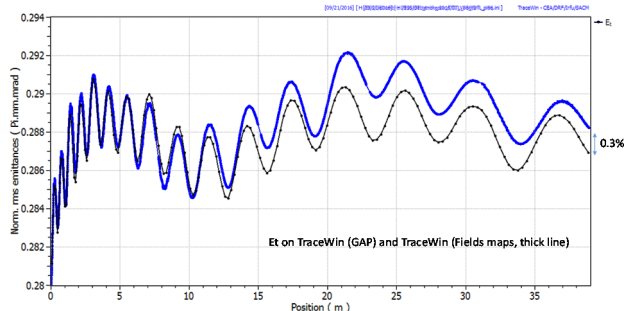

Figure 7: evolutions of $\varepsilon_{n,t,rms}$ of the thin gap model and of the field map model.
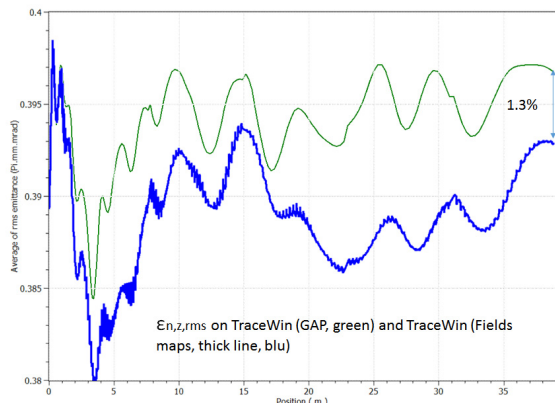

Figure 8: evolutions of $\varepsilon_{n,z,rms}$ along the DTL for the thin gap and the field map model in Tracewin.
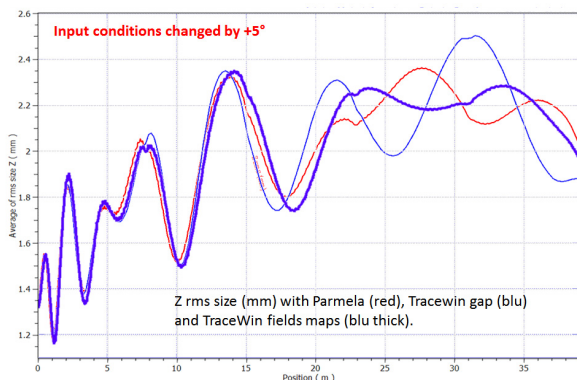

Figure 9: current plot without not accelerated particles in the scan plot zone with smaller mismatch.

BEHAVIOUR OF THE THREE MODELS UNDER ERRORS

One of the most time consuming simulations deals with the error study runs. In order to reduce the computation time, it is important to simplify as much as possible the physics model of the problem.

Some runs with error studies were tested. Figure 9 shows the evolution of the z_{rms} along the five tanks of the DTL, for a change of +5° phase of the beam at the first tank entrance. Some differences arise after the second tank, especially between the thin gap and the two field maps models. However, the difference is within a range of 10% of relative error.

CONCLUSION

T-code and the S-code simulations of the DTL well agree, in particular the emittance growth difference is in the same order of magnitude of the emittance growth itself (2%). Therefore, for easy usage, it is preferable to use the s-model of the DTL and it can be done in such case without losing important part of the physics.

The DTL synchronous phase error of 1 deg is not affecting substantially the beam dynamics of the whole DTL. Therefore, the comparison between the thin gap model and the field maps resulted in a good level agreement. The thin gap model (s-space) can be used for error studies with good approximation of the undergoing physics, being much less time consuming than a full field map model.

Finally, this study results as a check of the correct ESS DTL design with two independent beam dynamics code and methods, together with others similar analysis recently performed [7].

REFERENCES

[1] F. Grespan et al, "ESS DTL Design and Drift Tube Prototypes", *Proceedings of LINAC2014*, Geneva, Switzerland, paper THPP086, p. 1050.

[2] T. P. Wangler, "RF Linear Accelerators" 2nd editions, Wiley-Vch.

[3] A.Carne, "Numerical methods. Acceleration by a gap", edited by P. M. Lapostolle and A. L. Septier, North Holland Pub. Co., 1970.

[4] http://laacg.lanl.gov/laacg/services/serv_codes.phtml

[5] http://irfu.cea.fr/Sacm/logiciels/index3.php

[6] I. Hofmann and O. Boine-Frankenheim, *Phys. Rev. ST Accel. Beams* 17, 124201

[7] G. Mauro et al, INFN-LNL-243(2016) internal note http://www.lnl.infn.it/~annrep/Note_Interne