ESS DTL ERROR STUDY

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Abstract

The Drift Tube Linac (DTL) of the European Spallation Source (ESS) is designed to operate at 352.2 MHz with a duty cycle of 4% (3 ms pulse length, 14 Hz repetition period) and will accelerate a proton beam of 62.5 mA pulse peak current from 3.62 to 90 MeV. The error study is decisive to define the DTL manufacturing tolerances and to evaluate its robustness. In this paper the DTL performances are shown.

INTRODUCTION

The DTL of the high power linac of the European Spallation Source has been changed, respect to 2013 design, to meet the new linac optimized parameters, with higher current and final energy of the DTL [1]. The high reliability and availability of the accelerator requires short repair times and sets a loss limit for hands-on maintenance of the machine to 1 W/m above 30 MeV, on beam losses. Another limit on the tolerances on the nominal DTL design is coming from the maximum amount of emittance growth admitted in the DTL of 10% for all the planes, on top on the emittance evolution without errors [2].

ERRORS STUDY STRATEGY

The DTL nominal parameters are reported in Table 1.

Table 1: DTL beam parameters

Parameter	Value
Input Tran. Norm. RMS Emit.	0.28 mmmrad
Input Long. Norm. RMS Emit.	0.39 mmmrad (=0.15 MeVdeg)
Input current	62.5 mA

Table 2: DTL main requirements

Parameter	Value
Emit. Growth definition	$\Delta\varepsilon=(\varepsilon_{out}-\varepsilon_{in})/\varepsilon_{in}$
Maximum emittance growth	$\Delta\varepsilon$ <20%
Losses (above 30 MeV)	< 1W/m

For the statistical error studies a Gaussian input beam distribution cut at 3σ has been used, this is used to overestimate the errors beam sensitivity. Each error has been studied individually to check the single sensitivity respect to the parameter. The simulation program used is TraceWin with the space charge routine picniR (20x40 as mesh) and 50 000 macroparticles. The statistical number of DTLs generated is 500 for each single error with a uniform distribution. A final check with all the errors applied has been done. The DTL input is considered at 20 mm before the input flange on the first cell with the first PMQ, to start in a zone without fields. To simulate machine operation, the steeres are optimized for each given error set run, considering a finite resolution on the BPM. A set of sensitivity on PMQ position with and without steeres has been considered to check the steeres advantage and relax the PMQ position tolerances.

ERRORS INVESTIGATED

The errors examined, as single error and for all the planes, are:

- Input beam:
  - Emittance change
  - Current jitter
  - Position and divergence
  - Mismatch
  - Energy jitter
- PMQ:
  - Position with and without Steeres
  - Rotation
  - Gradient
  - Ageing: PMQ gradient degradation
  - Multipoles and dipoles.
- DTL RF:
  - E0 Field flatness cell by cell
  - Sync. Phase, i.e. DT relative position
- DTL tanks:
  - Klystron RF phase and amplitude
  - Relative position
- Global:
  - All the input beam errors
  - All PMQ, RF and tanks errors

These sets of errors permit to define the mechanical tolerances for machining, welding, positioning, powering of the Drift Tube and the input beam characteristics needed from the MEBT. The errors applied are uniformly distributed between plus and minus maximum of the defined range. Each tank is fed by one klystron and therefore all the errors caused at that level are coupled. Synchronous phase and field amplitude errors in each cell are determined by the shape and position of drift tubes and are uncoupled.

The observable used as output of the errors study is the final emittance and the presence of losses. The maximum admitted final transverse/longitudinal RMS emittance is 0.328/0.441 mmmrad with a 17% and 13% emittance growth respect to the input emittance without errors for the Gaussian input beam distribution. The transverse acceptance of the DTL is 13.4 mm.mrad; this is a large

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margin before to get losses, so the limit on the emittance growth is the most demanding parameter for delineate the tolerances. In practical the limit on emittance growth is reached almost always without losses. An exception to that is with the PMQ position errors, without steeres, where with a PMQ position inaccuracy of +/- 0.1 mm the emittance growth is 15% and the losses are 8.4*10^{-5} % with a power loss of 0.17 W.

The nominal emittance growth with the actual MEBT design is 5% and 7% on the transverse and longitudinal plane, with the uniform distribution the nominal emittance growth without errors is 2% and 1%.

Three steeres/tank/plane are used with a maximum strength of 16 mT*m. The diagnostics associates with the steeres are 3 BPM/tank/plane with a precision of +/- 0.1mm.

The principal advantages of the steeres are on the reducing the final transverse emittance growth, than to avoid losses, so during the normal operation may be useful to use the steerers to reduce losses in the high energy part of the linac.

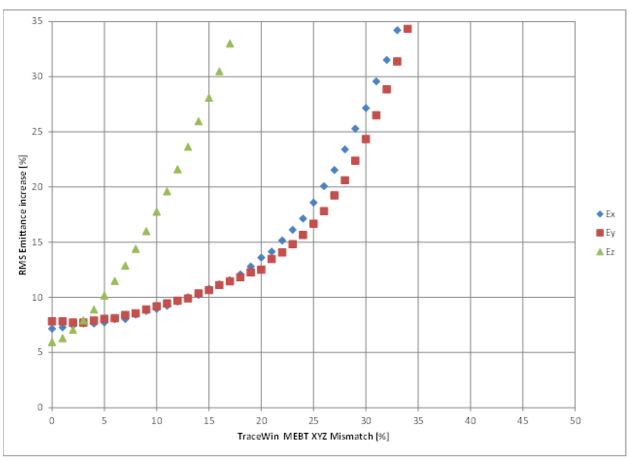

Figure 1: RMS emittance growth, due to the MEBT mismatch on all the planes.

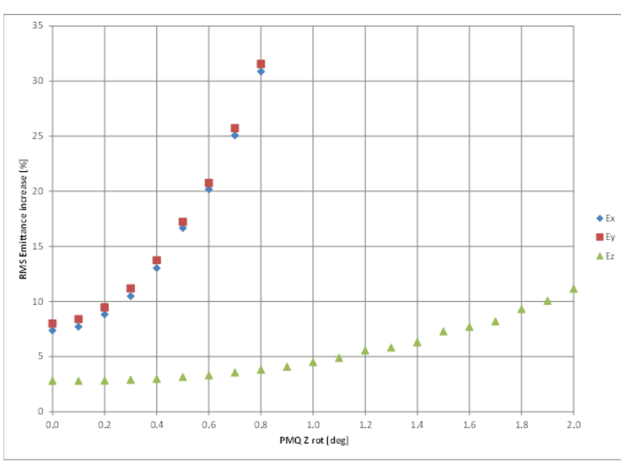

Figure 2: RMS emittance growth, due to the PMQ rotation along the beam axe roll angle.

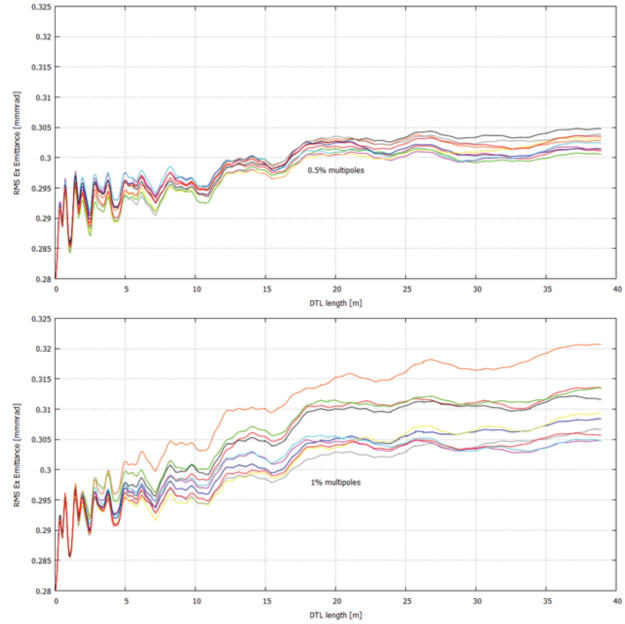

Figure 3: RMS output emittance Ex, due to the multipoles components including the dipoles.

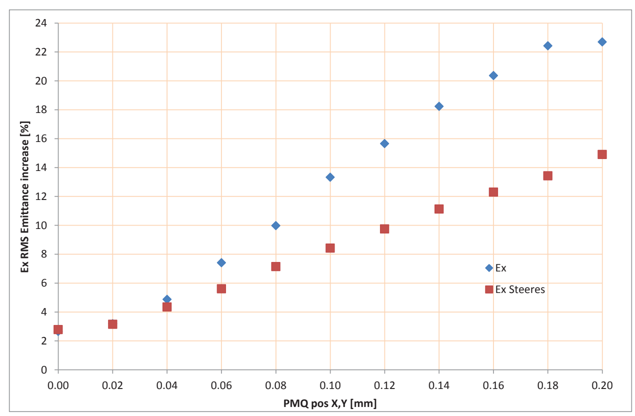

Figure 4: Ex RMS emittance growth without and with Steeres using uniform distribution as input.

ERROR STUDY RESULTS

The errors studies about the input beam conditions show that the DTL is sensible to the longitudinal mismatch, in particular as show in Fig. 1 is necessary to keep the TraceWin mismatch below 10% to avoid to overcome the limit on 13% on the longitudinal emittance growth, the runs with more than 30% of mismatch are with losses. On Fig. 2 the RMS emittance growth is show as function of the PMQ Z rotation, in this case this is the most sensitive parameter for the PMQ possible rotations, the runs with a Z rotation of more than 1 deg are with losses. Figure 3 shows the effects on RMS emittance growth due to the PMQ multipoles contents, the multipoles are simulated with a thin high order quad and with a thin steerer for the dipole effects, in this case manageable effects are obtained with 1% of multipoles

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global contents.

Figure 4, show the impact of steeres on the emittance growth, using a uniform distribution as input, in this case the emittance increase is reduced of 75% with an errors on the PMQ of +/-0.1 mm, the losses without steeres appear for errors bigger than +/-0.08 mm on PMQ, instead with the steeres the losses are zero up to +/-0.18 mm on PMQ position.

For studying the effects of PMQ degradation an uniform decrease of PMQ gradient has been performed, the limit on emittance growth is reached with a PMQ gradient reduction of about -5%, all the runs shown no losses.

A summary on the possible input beam characteristics that singularly preserve the requirements on emittance growth and without losses is show in Table 3.

Table 3: Input beam tolerances

Beam input Errors	Values
X,Y,Z RMS Emittance variation	+15 %
Current jitter	±10%
Position and divergence	±0.2 mm; ±1mrad
X,Y,Z Mismatch	10 %,
Energy Jitter	±1%

As summary of possible tolerances on each component coming from the errors study results is listed in table 4:

Table 4: DTL tolerances

Errors	Name	Values
PMQ position	δx, δy	±0.1mm,
PMQ rotation	φx, φy, φz	±1 deg, ±0.2 deg,
PMQ gradient	ΔG/G	±1 %,
PMQ ageing	ΔG/G	-5 %,
PMQ multipole contents	$\frac{1}{B_2}\sum_{n=1}^{5} B_n = 1 + \Delta B[\%]$	±1 %,
E0 field flatness	$\Delta E_0/E_0$	±2 %,
Synchronous phase	$\delta\varphi_{synch}$	±2 deg,
Klystron RF phase and amplitude	$\Delta E_{kly}/E_{kly}$; φ_{kly}	±1 %, ±2 deg,
Tank to tank position	X_{tank}, Y_{tank}	±0.1mm,
BPM precision	X_{bpm}, Y_{bpm}	±0.1mm,
Max Steeres strength	Sx,Sy	±16mT*m

By using the defined set of errors a global errors study has been done, all the 500 runs are without losses and the emittance growth is below 20% on about 90% of cases, see Fig 5.

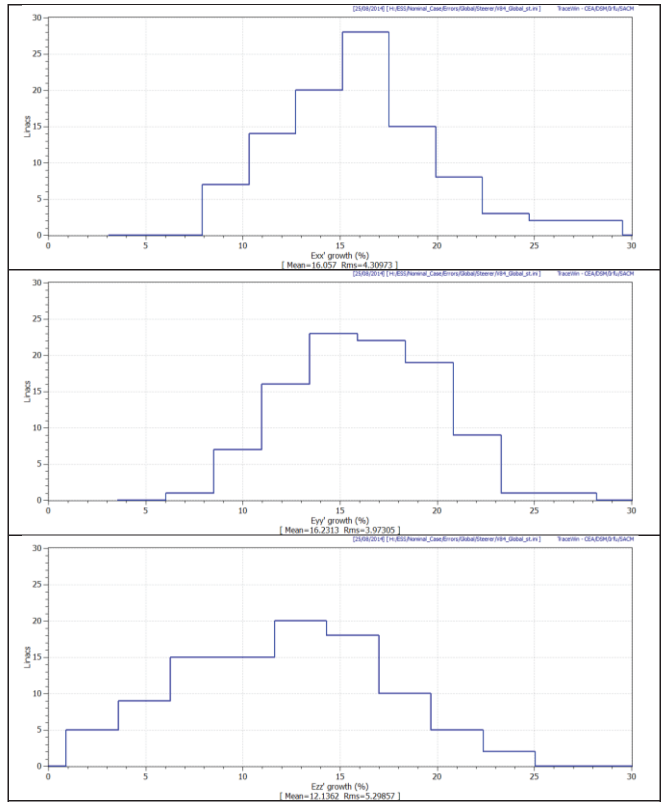

Figure 5: Statistical RMS emittance growth, for the global errors study, with steeres, all runs are without losses.

REFERENCES

[1] A. Ponton et al., "ESS Normal Conducting Linac status and plans", this conference, THPP044.

[2] M. Eshraqi, et.al. "The ESS Linac", Proc. IPAC'14, Dresden, Germany, THPME043.

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