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de Prisco, Renato; Karlsson, Anders; Eshraqi, Mohammad; Levinsen, Yngve; Miyamoto, Ryoichi

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INTEGRATION OF INTERFACES AND STABILIZATION SYSTEM IN THE DESIGN OF A DRIFT TUBE LINAC

R. De Prisco*, A. Karlsson, Lund University, Lund, Sweden
M. Eshraqi, Y. I. Levinsen, R. Miyamoto, ESS, Lund, Sweden

Abstract

Making an accurate Radio Frequency, RF, design of any accelerating structure is fundamental to ensure that electromagnetic and beam dynamics requirements will be achieved. This is essential for the most complicated accelerating structures like the Drift Tube Linac, DTL; in this case a meticulous design facilitates the RF commissioning too. In this paper the influence of the interfaces and of the field stabilization system on the RF design is analyzed and an advanced design methodology to mitigate field degradation is presented.

INTRODUCTION

A *preliminary design* of a DTL is usually done by considering the cavity as a stand alone object without the presence of the stems, of the stabilization system and of the interfaces (power couplers and vacuum grids) with the external systems. The preliminary design is very useful to reach the desired RF properties of the cavities and to optimize the *nominal* accelerating field [1]. Once the preliminary design is done it is necessary to *integrate* in the design the stems, the stabilization system and all the cavity interfaces, compensating their detuning, to keep the same properties and the same optimized accelerating field of the preliminary design.

In this paper the detuning induced by the stems, by the stabilization system and by the interfaces is evaluated; then its influence on the accelerating field is calculated; finally the integration of all the mentioned components in the design of the European Spallation Source, ESS, DTL design [2], on which the first author has directly worked, is proposed. The ESS DTL is an in-kind contribution from INFN/LNL [3,4]. It is composed of five RF cavities (or tanks) that are used to accelerate a proton beam of 62.5 mA from 3.62 MeV to 89.68 MeV at 352.21 MHz; the transverse focusing system is composed of permanent magnet quadrupoles arranged in a F0D0 lattice.

GLOBAL AND LOCAL FREQUENCIES

We can imagine the DTL tank as composed of N consecutive cells, each with its own resonant frequency, *local frequency*, such that the frequency of the tank is f_0, *global frequency* (for the ESS DTL f_0 is 352.21 MHz). As thoroughly discussed in [5], the desired flatness of the accelerating field in each DTL tank can be reached by properly tuning the frequencies of all the cells: at the end of the preliminary design a vector of N frequencies, *nominal local frequencies*, f_{0n}, with $n \in [1; N]$, is defined for each tank in order to get the *nominal accelerating field*, $E_{0,nom}$ [1].

The insertion of the stems, post couplers and all the interfaces modifies the nominal local frequencies and induces undesired accelerating field tilts. To prevent these undesired tilts it is necessary to retune each cell such that the nominal local frequencies are preserved.

3D VS 2D SIMULATIONS

It is possible to use 2D simulations if the DTL can be considered cylindrically symmetric about the beam axis. This means that the detuning of the post couplers, the stems and the interfaces can be evaluated only with 3D simulations.

The Drift Tube, DT, geometry is accurately described in [6] in which the sensitivity of each geometrical DT parameter is calculated for the ESS DTL. Due to the fact that the DTs are located in a region in which the electromagnetic field changes rapidly and due to the fact that the ratio between the length of each DT parameter and the tank diameter is much smaller than 1, resolution requirements can lead to a very big number of mesh elements. For a fixed resolution, a 2D simulation requires less computational resource or, vice versa, fixed the computational resources, a 3D simulation, for a very complex structure, as each tank of the ESS DTL, could be performed only by decreasing the resolution requirements.

We define Δf as the difference between the frequency calculated with a 2D simulation, using $9 \cdot 10^3$ surface elements, and the frequency calculated with 3D simulation, using a tetrahedral mesh for the first *half* cell just 3.76 cm long, in Low Energy, LE, side, of the ESS DTL.

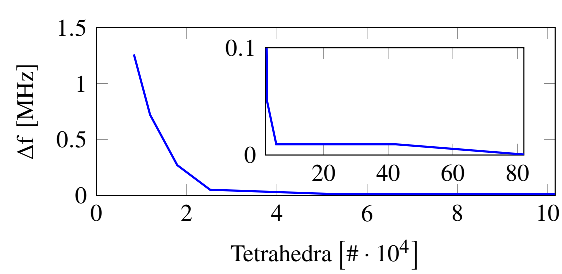

Figure 1: Dependence of the difference between the resonant frequencies, calculated by 3D and 2D simulations, from the 3D mesh elements for the first half cell, in LE side, of the first tank.

It is clear from the Fig. 1 that to have a *good resolution of each DTL cell* the amount of tetrahedra becomes enormous since each cell of the ESS DTL has a very detailed structure and since each tank is longer than 7 m [2]. In case of less

* renato.deprisco@esss.se

computational resource than required, *reducing the 3D mesh accuracy is not a solution*: this introduces a frequency error, cell by cell, with respect to the nominal local frequency, that affects all the RF parameters and, in particular, that induces strong tilts on the accelerating field. In this case a 3D simulation of a full ESS DTL tank is not adequate for evaluating the RF parameters (e.g. the field flatness). The eventual presence of post couplers flattens the tilt of the accelerating field *due to the mesh inaccuracy* that could induce, cell by cell, a higher detuning with respect to the maximum detuning due to the manufacturing errors [6].

STEMS

The stems induce a perturbed accelerating field, E_{stem}, and a consequent error on the accelerating field, $\Delta E_0 = E_{nom} - E_{stem}$ shown in Fig. 2.

The local frequency perturbation due to the DT stems, $\Delta f_{stem,\,n}$ with $n \in [1; N]$, can be calculated cell by cell using a 3D simulation or using a 2D simulation and, then, applying the Slater theorem. Each cell can then be retuned to be resonant at the frequency $f = f_{0n} - \Delta f_{stem,\,n}$. This guarantees that each cell, *with the stem*, is resonant at its own nominal frequency.

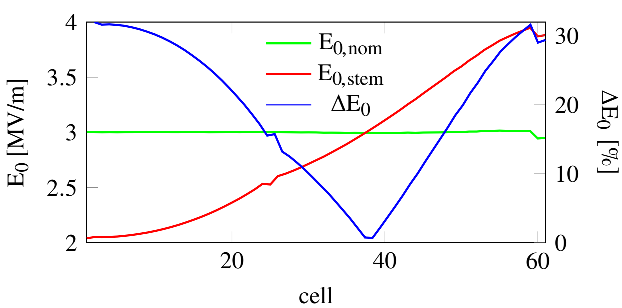

Figure 2: Nominal accelerating field (green), field perturbed by the stems (red) and its relative error to the nominal (blue) for the first tank of the ESS DTL.

The presence of the stems induces a global detuning; it is 2.5 MHz in case of the first ESS DTL tank. The compensation of this detuning could be achieved by increasing the tank diameter. *This only assures that the global frequency, f_0, is reached; however the nominal accelerating field is not achieved.*

POST COUPLERS

Post Couplers, PCs, are used to stabilize the on axis accelerating electric field against tilts produced by mechanical errors (that, locally and randomly, change the nominal resonant frequency of each cell). We define the *optimum lengths* of the PCs as the lengths for which there is the *confluence* [5]. The local frequency shift, due to the inserted PCs with their optimum lengths, must be compensated to avoid the *self perturbation* phenomena: uncompesated PCs produce additional tilts of the accelerating electric field against which they are inserted.

Having fixed the optimum position of PCs [6], we define $d_{PC\text{-}PC}$ as the average distance of each PC to the neighborhood ones. The optimum length, L_{opt}, of the PCs in the first tank of the ESS DTL is shown in Fig. 3.

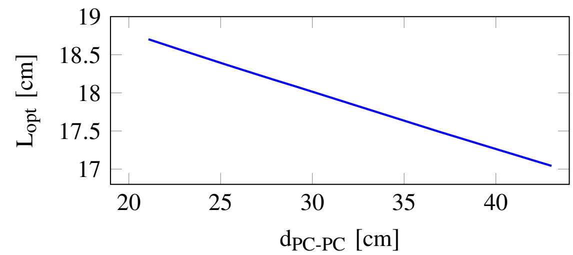

Figure 3: Optimum length, L_{opt}, of the PCs in the first tank of the ESS DTL to reach the confluence.

The local frequency perturbation due to the PCs can be calculated exactly in the same way done for the stems. It is very important to underline, again, that *the compensation of the PC detuning, done increasing the tank diameter, assures only that the global frequency, f_0, is reached, but not the nominal accelerating field.*

VACUUM GRIDS

The vacuum grids, Fig. 4, also cause a frequency detuning that induces a tilt of the nominal accelerating field. The grid positions, i.e. tank and cell number, for the cases in which the vacuum grids are in correspondence of just one cell, and the local detunings due to them are reported in the Table 1 .

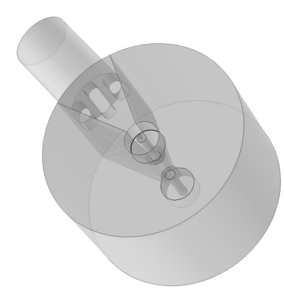

Figure 4: Vacuum grid [7].

Table 1: Vacuum Grid Position and Detuning

Tank	**Cell**	**Detuning**
2	C17	−190 kHz
2	C33	−160 kHz
3	C2	−160 kHz
3	C14	−150 kHz
3	C28	−140 kHz
4	C2	−130 kHz
4	C12	−120 kHz
4	C25	−110 kHz

The compensation of the vacuum grids can be done by using the same strategy discussed in the case of stems.

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POWER COUPLER

The power coupler, PWC, shown in Fig. 5, is a crucial element in the design of an RF cavity. Power from an RF source is transported to the cavity by a waveguide, in the ESS case is the rectangular half-height waveguide WR2300, and transferred into the cavity through the power coupler. The total power is delivered to each tank by two iris power couplers with 1.1 MW peak power each.

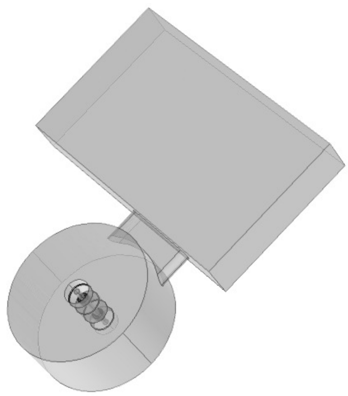

Figure 5: Power coupler [7].

The local detuning of the power coupler, evaluated over a length of 20.1 cm, is -3.57 MHz. Two solutions are compared for the compensation of the power coupler: the first is done with a dedicated tuner, the second is done using the algorithm discussed in [5].

Compensation of the Power Coupler Detuning with Dedicated Tuner

Static tuners [2] compensate the frequency shift due to manufacturing errors. It is important to underline that the position of the tuners, located at 45° with respect to the stem axis, is chosen *to mitigate the detuning that the penetration of the tuners induces on the local frequency of the PC 0-mode*.

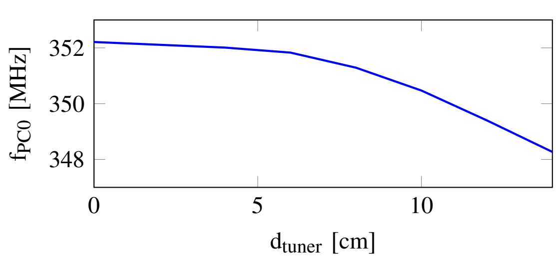

Figure 6: Detuning of the tuner penetration on the post coupler 0-mode.

Below 6 cm of penetration the effect of the tuners on the PC 0-mode is less than 0.38 MHz.

The influence of the dedicated tuner on the PC 0-mode is shown in the Fig. 6: a penetration higher than 6 cm affects strongly the PC 0-mode.

To compensate the PWC detuning of -3.57 MHz, using a dedicated tuner with diameter of 9 cm, shown in Fig. 7, a penetration of 12.1 cm is necessary that induces a local detuning of the PC 0-mode of 3 MHz.

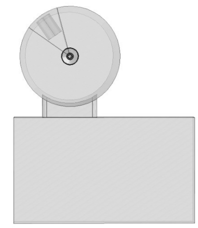

Figure 7: Dedicated Tuner [7].

It is important to underline that the solution with dedicated tuner assures *only* that the global frequency f_0 is reached. The tuner perturbs the nominal accelerating field as much as its diameter increases and as much as it is not longitudinally aligned with the PWC (mechanical constraint). The RF commissioning becomes more complicated because of the dependency of the PC 0-mode by the dedicated tuner too.

Power Coupler Compensation with Cell Redesign

Knowing the PWC detuning, it is possible to compensate it by applying the alghoritm [5]. This avoids the use of a dedicated tuner with unnecessary mechanical constraints. It also keeps the stabilization system 0-mode independent from the tuner penetration.

CONCLUSION

The using of 3D simulations is very useful to analyze 3D details or representative *short sub-structure of the DTL*, but, for a full DTL tank, it can introduce relevant errors on the calculation of the RF parameters and, consequently, induce strong tilts on the accelerating field.

Once the preliminary design is done, it is crucial that stems, post couplers, vacuum grids and power couplers are *integrated by a re-design of specific cells*. Uncompensated interfaces perturb strongly the nominal local frequencies *inducing a detuning comparable with the detuning of the manufacturing errors*.

A stabilization system, designed for specific manufacturing tolerances, could be unsuitable to compensate *design inaccuracies* that could lead an unexpected higher and untunable accelerating field tilts.

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