SURFACE-LOSS POWER CALCULATIONS FOR THE LANSCE DTL

Sergey S. Kurennoy, LANL, Los Alamos, NM 87545, U.S.A.

Abstract

The surface losses in the drift-tube linac (DTL) tanks 3 and 4 of the LANSCE linear accelerator are calculated using 3-D electromagnetic modeling with the CST MicroWave Studio (MWS). The results are used to provide more realistic power estimates for the 201.25-MHz RF upgrade design within the LANSCE-R project. We compared 3-D MWS results with those from traditional 2-D Superfish computations for DTL cells and their simplified models and found differences on the level of a few percent. The differences are traced to a 3-D effect consisting in a redistribution of the surface currents on the drift tubes (DT) produced by the DT stem. The dependence of MWS results on the mesh size used in computations is also discussed.

INTRODUCTION

There are some disagreements between the existing results on the surface-loss power in the LANSCE DTL tanks 3 and 4 [1]. In particular, the power values cited in the book [2], respectively 2.745 and 2.674 MW, are noticeably higher than the historical maxima in 1994-1998, 2.090 and 2.493 MW, as well as the values found in old design reports, 2.33 and 2.33 MW [1].

More accurate values of the power loss in the DTL tanks 3 and 4 are important for finalizing a design of the 201.25-MHz RF system upgrade within the LANSCE-R project. The surface losses in the DTL tanks 3 and 4 were recalculated using both 3-D electromagnetic modeling with MicroWave Studio (MWS) [3] and the traditional approach with Superfish (DTLfish) [4]. This paper summarizes our results.

CALCULATION METHOD AND RESULTS

We used a piece-wise approach to calculate the surface losses in the DTL tanks, performing MWS computations separately for a few selected cells in the tank, with electric boundary conditions on the cell end walls. The standard DTLfish approach is essentially the same: 2-D Superfish (SF) computations are performed for a few selected half-cells and the results are interpolated [4]. The parameters of the DTL tank cells were taken from the LANSCE online database and post-coupler tuning tables. Figure 1 shows the MWS model of the DTL cell DT98, the first cell in the tank 3. The cell is about 43 cm long and has 44-cm radius. The MWS model includes a drift tube (DT), stem with bellows, and post-coupler. The picture inset shows the post-coupler with two tab rotations, at 22.5 and 45°. These two virtual tab shapes are vacuum-filled and not used in this particular calculation; however, their presence influences the MWS mesh.

Figure 2 shows the surface currents calculated by MWS in the model of the DTL cell DT165, the last cell in the tank 4. Its length is 55.6 cm, and the DT is almost 35 cm long. The highest current density is on the DT stem near its connection to the DT.

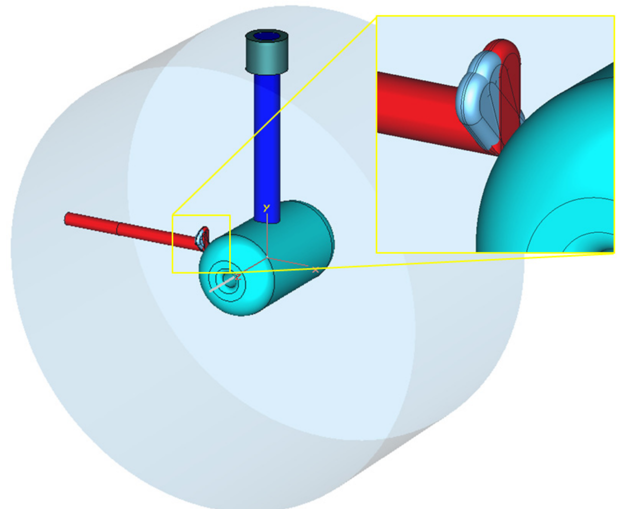

Figure 1: MWS model of DTL cell: drift tube (cyan), stem (dark-blue), bellows (sea-green), and post-coupler (red).

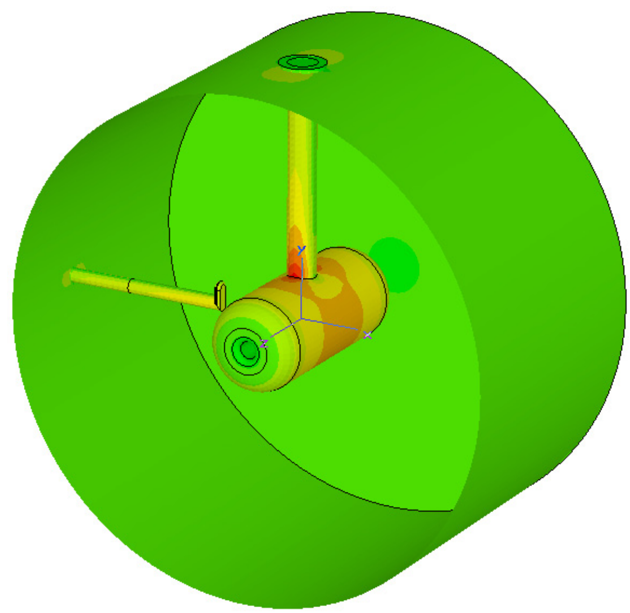

Figure 2: Surface-current magnitude in DT165 cell (red corresponds to the highest value, dark-green to zero).

In the Superfish approach, 2-D computations are performed for an axisymmetric model of the (half-)cell that includes only the cavity and DT. After that a theoretical perturbation correction is added to include the DT stem effect [4], but post-couplers are usually not taken into account. In the MWS 3-D models with post-couplers, we impose the electric boundary conditions on the side walls and find the modes with the MWS eigensolver. Such an approach is justified when the post-couplers are in the neutral position, at 0°. The effects due to post-coupler tab rotations will be discussed below.

The MWS computation results for the surface losses in a few representative cells of the DTL tank 3 with 38 cells are summarized in Table 1. The MWS computations were performed for cells 1, 10, 19, 28, and 38, both with rough meshes of 0.7-0.8 million mesh-points over the full cell, and with fine meshes of 4-4.2M points (Table 1). The cell power values are scaled to the tank nominal electric field gradient E_0 = 2.4 MV/m, given at 100% duty, and assume the surface conductivity of copper $\sigma = 5.8 \cdot 10^7$ $(\Omega \cdot m)^{-1}$. SF results for the same cells with the stem corrections (and without post-coupler ones) are shown for comparison at the bottom.

Table 1: Loss power in tank 3 cells from MWS & SF

Cell # (DT #)	1 (98)	19 (116)	38 (135)
Q-factor	71046	70348	69712
Power P_c, kW	42.91	49.94	56.95
P_c distr.,: wall, %%	46.2	46.0	45.2
: DT, %%	40.7	42.2	43.9
: stem, %%	7.82	7.23	6.85
: bellows, %%	1.53	1.32	1.17
: post-c. at 0°, %%	3.72	3.23	2.86
Superfish *Q*-factor	70231	69570	68817
Superfish P_c, kW	42.97	50.08	57.26

Figure 3 shows the interpolation of the loss-power results to the other cells in tank 3. The MWS results with fine meshes (marked MWS2) and the Superfish ones are within 1% of each other for all cells, even though the post-coupler losses (3-4% of the cell surface-loss power) are not included in the SF results. The MWS power values with rougher meshes (MWS1) are lower by about 4%, while the *Q*-factors are 4-5% higher. In all cases the power distribution along the tank is close to linear.

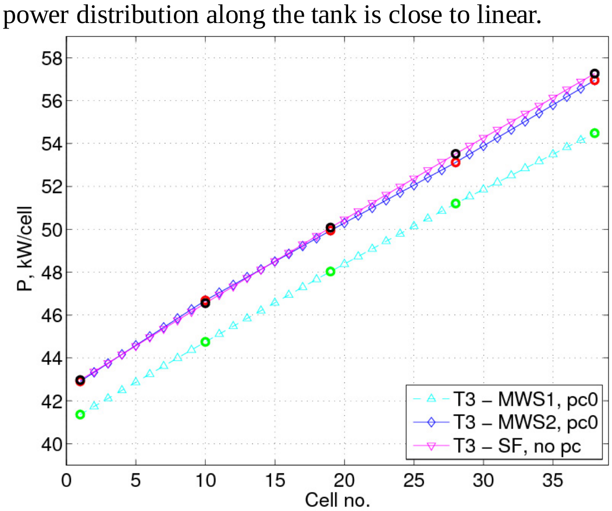

Figure 3: MWS and Superfish result interpolation for surface losses in the DTL tank 3.

Summing the interpolated power values P_i for the fine meshes (blue diamonds in Fig. 3 marked MWS2) and adding two end-wall contributions (28.04 kW and 34.12 kW at the upstream and downstream end of the tank), we obtain an estimate of the total dissipated power in the DTL tank 3: P_{T3} = 1964.1 kW. Interpolating *Q*-values from the MWS calculations gives the tank *Q*-factor as $Q_{calc} = \Sigma Q_i P_i / P_{T3}$ = 68088. The sum of the DTLfish results gives an estimate 1907.8 kW, without the end-wall contributions. One important observation here is that the product $P_{T3}Q_{calc}$ remains practically the same for both MWS calculations, with the fine and rough meshes: the difference is less than 0.5%.

Similar computations were performed for the DTL tank 4 with 30 cells; Fig. 4 shows the power-loss interpolation. The Superfish results are higher than the MWS ones with fine meshes of 5M points (marked MWS2) by 1%, while the *Q*-values are about 2% lower. The MWS results with meshes of about 3M points (MWS1) are 2% above the SF results; the corresponding *Q*s are about 3% lower than for MWS2. Again, the power distribution along the tank is close to linear, which simplifies the result interpolation. Summing the interpolated MWS power values (MWS2 in Fig. 4) and adding two end-wall contributions (34.33 kW and 39.35 kW), we obtain an estimate of the total dissipated power in the DTL tank 4: P_{T4} = 1942.7 kW. Interpolating *Q*-values allows us to find the *Q*-factor of the tank 4: $Q_{calc} = \Sigma Q_i P_i / P_{T4}$ = 66576. The sum of the DTLfish results provides an estimate 1888.2 kW, without the end-wall contributions.

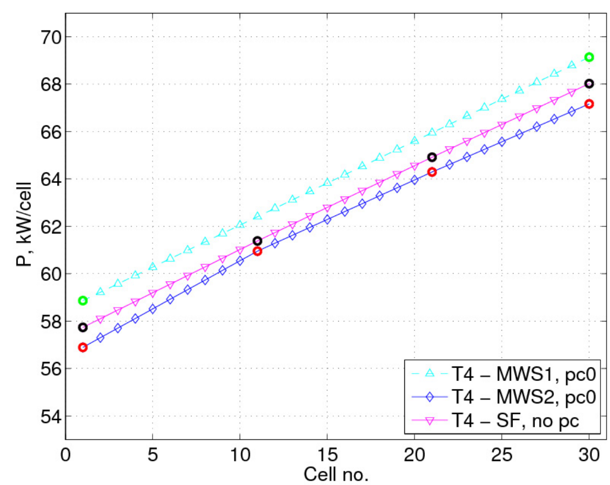

Figure 4: MWS and Superfish result interpolation for surface losses in the DTL tank 4.

DISCUSSION

MWS versus SF. The fact that Superfish (SF) results for the surface-loss power are higher than those from MWS is unexpected: the opposite would be natural since the MWS models include post-coupler losses, in addition to the elements taken into account by SF. To understand this difference, we compared three different MWS models of the same cell, the last cell in the tank 4 (DT165), with the SF model in detail [5]. The first model calculates exactly the same problem as SF does: only the cavity with a DT, no stem, and no post-coupler. In the second model, we added a simple stem. The third one is the model used for MWS computations above, with the post-coupler at 0°, see Fig. 2. When the problem solved by MWS and SF is exactly the same – an axisymmetric layout with a DT – the calculated power values are close (0.5-1.5%

difference). In the SF approach, when the stem perturbation correction is added, the losses on the cavity wall and DT are assumed unchanged. 3-D MWS computations show redistributed currents on the DT surface. Overall, the SF result for this layout is 2-3% higher than the MWS-calculated results. The difference becomes smaller, ~1%, for the complete cell (MWS model with post-coupler, Fig. 2; SF – without); the post-coupler adds ~2.5% of the total cell power loss. If the post-coupler correction were added to the SF result, it would be even higher, 3-4% above the MWS value. Note that MWS computations for such a comparison must be performed with very fine meshes; otherwise, the MWS result inaccuracy can be larger than the effect, see below.

Tab rotation effect. An important question is what happens when post-coupler tabs are rotated. A few MWS runs were performed to compare the tab at 0° and 45° imposing both electric and periodic boundary conditions (BC) on the cell side walls. For electric BC, in tank 3 cells with post-couplers at 0° the power dissipated on the post-coupler is 3-4% of the cell power dissipation, cf. Tab. 1; in tank 4, it is below 3%. When the tabs are rotated to 45°, the power dissipated on the post-coupler jumps to 10-20% of the total cell power loss for the cells near the tank ends.

Unfortunately, the surface-loss results even in these cells are misleading and cannot be trusted because of the strong mixing between the accelerating mode and post-coupler mode. The mixing is much stronger in a short resonator (a cell with electric BC on its end walls) than it would be in a long tank. This becomes especially obvious when MWS calculations with the tabs at 45° are performed for the tank central cells where the accelerating and post-coupler modes are very close in frequency: the mixing is so strong that most of the cell power dissipation occurs at the post-coupler, e.g. 54% in the cell 28 (DT 125) of tank 3. The relative field difference between two gaps in that case is very large: $\Delta E/E_{av}$ = 0.36, many times higher than in a long tank with one post-coupler rotated.

On the other hand, when periodic BCs are imposed on the cell end walls, the calculated losses are almost the same for the tabs at 0° and 45°. Of course, when the tab is not rotated (0°), the results with periodic or electric BC should be identical due to the cell symmetry. In a long tank with a flat electric field, the situation in a particular cell is close to periodic BC due to almost equal fields on the cell "end walls". Because of that and the fact that for periodic BC the losses are the same with rotated and non-rotated tabs, we believe that the calculations above with the post-coupler tabs at 0° give the correct results.

Dependence of MWS results on mesh size. The values of P_c and Q vary by a few percent (as much as ±8% for rough meshes in the results above) depending on the MWS mesh size, but in opposite directions, so that their product PQ remains practically unchanged (the maximal deviation was below 1%) [5]. One possible explanation is that the secondary resonator parameters like Q are derived based on the definition $Q = \omega W/P$, where W is the field energy and ω is the mode frequency, using the fields computed by the eigensolver. The MWS eigensolver solves for the electric field (eigenvector) and frequency (eigenvalue), thus naturally W and ω are calculated more accurately. The surface-loss power – a surface integral of the squared magnetic field – is likely less accurate. From the above definition, slightly lower values of P give higher Qs and vice versa, while their product $PQ = \omega W$ remains more accurate.

SUMMARY

The surface losses in the DTL tanks 3 and 4 are calculated both in 3D with the MicroWave Studio and using the traditional 2-D Superfish approach. For practical estimates, it is usual to increase the calculated power values by 15% or even 20% to account for the difference in the theoretical and real surface conductivities. In the case of the LANSCE DTL tanks, we can use the measured values of the tank Q-factors. The calculated power value should be multiplied by factor $f_P = Q_{calc}/Q_{meas}$, the ratio of the calculated Q-factor of the tank to the measured one. The measured value for the DTL tank 3 is Q_{meas} = 59460; for tank 4, different measurements give results from 53400 to 57780 [1]. The summary of our calculation results (the averaged power for the nominal electric field gradient E_0 = 2.4 MV/m, 100% duty, post-couplers at 0°, end-walls included) is presented in Tab. 2.

Table 2: Surface-loss power in the DTL tanks 3 and 4

	P_{calc}, MW (MWS)	Scaling factor $f_P = Q_{calc}/Q_{meas}$	P, MW ($f_P \cdot P_{calc}$)
Tank 3	1.964	1.145	2.249
Tank 4	1.943	1.152–1.247	2.238–2.423

If the MWS results with rougher meshes for tank 3 (P_{calc} = 1.890 MW and Q_{calc} = 71069) were used, the scaling factor would be different, f_P = 1.195, but the power estimate would remain almost the same, P = 2.259 MW

From comparison of the surface losses calculated by MWS and Superfish (SF), we see that SF overestimates the losses in DTL cells by a few percent. This is due to the surface-current redistribution – a purely 3-D effect that cannot be taken into account in 2-D calculations. This result is important since SF results are widely used in surface-loss calculations.

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