REDUCING THE FIELD PERTURBATION PRODUCED BY SHIFTED GAPS IN A DRIFT-TUBE LINAC

K. R. Crandall, AccSys Technology, Inc
and
D. Raparia, Superconducting Super Collider Laboratory*

Abstract

A space of three cell lengths is left between tanks in the SSC DTL. This space contains two quadrupoles and beam diagnostic equipment. To compensate for the absence of longitudinal focusing in this space, the gaps in two end cells of both neighboring tanks are shifted upstream to produce a phase shift of as much as 45 degrees. These displacements of the gaps from the approximate geometrical centers of the cells cause frequency errors and significant perturbations in the fields in the vicinity of these cells. Adjusting the gap widths to get the correct frequency is not sufficient to reduce the field perturbations. In this paper we describe the technique used for reducing the field perturbations in the SSC DTL.

I. Introduction

In the SSC DTL [1], three cell lengths are left between tanks. The two inter-tank quadrupoles are variable-strength permanent-magnet quadrupoles that can be used for transverse matching. These quadrupoles can also be deliberately displaced to steer the beam, if necessary. Beam-diagnostic equipment will be placed between the quadrupoles. The absence of three acceleration gaps, which also focus the beam longitudinally, requires additional longitudinal focusing to be used in order to prevent a severe longitudinal mismatch. A buncher cavity could be placed in the middle of the inter-tank space, but this would take up space and require a separate power source that would need adjusting to find its correct amplitude and phase. An alternative is to provide extra longitudinal focusing in the end cells of the two tanks by shifting the gaps in these cells. To compensate for the three missing gaps between tanks in the SSC DTL, the gaps in the two end cells of each tank were moved to cause a phase shift of as much as 45 degrees from their nominal values.

It had been assumed that the gaps could be shifted without significantly affecting either the local resonant frequency or the voltage across the gap. Wrong! Both are affected, but it takes multi-cell SUPERFISH run to detect and learn how to compensate for these perturbations. The magnitude of the field perturbation increases with increasing cell length, and the perturbations are not reduced by the fact that the rest of the cells in the tank are "normal" cells. The remainder of this paper discusses the various techniques that we tried for bringing the fields near to their design values, the changes that were made, and the results of these changes.

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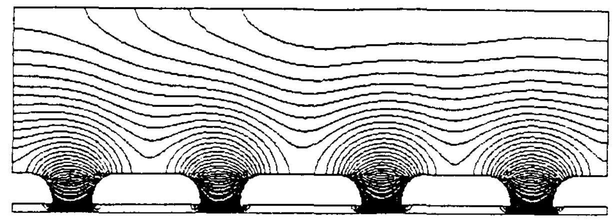

Figure 1: Field lines obtained by running SUPERFISH for the first four cells in Tank 3 before modifications were made.

II. Field perturbation caused by shifted gaps in the SSC DTL

The gaps in the two end cells of the high-energy end of Tanks 1-3 and in the low-energy end of Tanks 2-4 are all shifted by as much as 45 degrees in phase. That is, the length of the drift tubes have been modified so that the " design particle" arrives at these four gaps when the phase of the rf is approximately -75 degrees (from peak) rather than -30 degrees. This makes the half drift tube in the high-energy end walls longer than normal, and the next-to-last full drift tube shorter than normal; the half drift tube in the low-energy end wall is shorter than normal, and the second full drift tube is longer than normal. The average (normalized to 1 MV/m) field, E_0, in each cell is listed in Table 1 for the multi-cell SUPERFISH runs in all four tanks. It was possible to run 8 cells at end of Tank 1 and at the beginning of Tank 2, 7 cells at the Tank 2-3 interface, and 6 cells at the Tank 3-4 interface. The perturbations are more severe at the high-energy end of the tank than at the low-energy end of the following tank. The field lines produced by a SUPERFISH run for the four end cells in the low-energy end of Tank 3 are shown in Figure 1.

III. Strategies to correct the field perturbations

In searching for a successful strategy for correcting the field perturbations we concentrated on the low-energy end

Table 1: Relative values of E_0 (normalized to 1 MV/m) obtained in multi-cell SUPERFISH runs before modifications were made.

Cell #	Tank 1	Tank 2	Tank 3	Tank 4
1		0.889	0.848	0.784
2		1.029	1.066	1.098
3		1.066	1.121	1.193
4		1.031	1.046	1.045
5		1.010	0.998	0.959
6		0.995	0.971	0.922
7		0.992	0.952	
8		0.987		
n-7	0.916			
n-6	0.920	0.733		
n-5	0.937	0.756	0.498	
n-4	0.951	0.805	0.554	
n-3	0.968	0.881	0.670	
n-2	0.980	0.966	0.848	
n-1	1.055	1.186	1.285	
n	1.253	1.645	2.116	

of Tank 2. Of course we wanted to make as few changes as possible and to impact the design as little as possible.

Strategy # 1. SUPERFISH runs were made for cell 1 and for cell 2 separately , using the full assymetric cell as defined by PARMILA (with the gaps displaced). The frequency of these individual cells were found to be low by 5.7 MHz. The gaps in each cell were adjusted to bring the frequency up to its design values. A SUPERFISH run was then made for the four end cells. The frequency of the 4-cell segment was correct, but the field perturbations were just as bad as in the "unmodified" case.

Strategy # 2. The boundaries of the first three cells were taken to be at the middle of the drift tubes. The gap in each of these three cells was adjusted to make each cell independently resonate at the right frequency. A SUPERFISH run for the 4-cell unit also gave the right frequency, and the field pattern looked much better than before. The values for E_0, obtained by averaging over these artificial cells, were close to unity. However, the dynamics calculations used by PARMILA assumed that E_0 is constant when averaged over PARMILA cell lengths. In other words, the voltage across the gap is supposed to be proportional to the (PARMILA) cell length. The first artificial cell was about 12.5% shorter than the PARMILA cell,and the length of the second and third artificial cells were about 6.25% longer than the PARMILA cells. So the gap voltages were off by about this much. Actually, the gap voltage in the first cell was low by about 16% and was high in the second and third cell by about 8%.

Strategy #3. The boundaries of the first two artificial cells were chosen to make these cells symmetric about the gap center. This makes the first cell short by 25% and the second cell long by 25%. The gap in each of these cells was adjusted to make the cell resonate at the design frequency. The SUPERFISH run for the 4-cell unit gave the correct frequency and reasonable looking field lines, but the gap voltages were quite far off: more than 20% low in the first cell and about 20% high in the second cell.

Strategy # 4. Instead of adjusting the gap to get the correct frequency, the first two cells were taken as a unit and the tank radius was adjusted to get the right frequency. In this case, the radius was decreased to bring the frequency up. The frequency of the 4-cell unit was also correct, but the field perturbations were as bad or worse than in the unmodified case.

Strategy #5. The tank wall was moved upstream to make the first two cells have approximate mirror symmetry about the center of the drift tube between these two cells. In this case, the end wall was moved 3 cm. The frequency of these two cells taken as unit was then 20 MHz low. The gaps were then adjusted in these cells to make each cell individually have the right frequency. The two cells operating together also had the right frequency, and the fields in the two gaps were essentially the same, as would be expected from the symmetry of the situation. When the next two cells were added and the four cells run as a unit in SUPERFISH, the frequency was right and the gap voltages were only about 3% high in the two cells and about 3% low in the next two cells.Because the gap lengths had to be increased in the first two cells, the transit-time factors in these two cells were lowered by about 5%. When the transit-time factors are taken into account, the "effective gap voltages" were closer to their correct values.

IV. Result of adjustments in SSC DTL

Because strategy #5 was the most successful of those we tried, we adapted it for the SSC DTL. We moved each end wall (near the shifted gaps) and adjusted the gap widths in the three end cells to get the frequency correct and to minimize the field perturbations. It was a trial-and-error procedure in which we made many 4-cell SUPERFISH runs. The final modification are listed in Table 2. The symbols in this table have following meanings: dw is the distance that a wall moved, a negative value denoting an upstream move (toward low energy) and LE denoting the wall at the low-energy end, HE denoting the high energy end; dg is the change in the gap length, a negative value meaning that the gap is shortened; n refers to the last cell in each tank. The values of E_0 (normalized to 1 MV/m) obtained in the multicell SUPERFISH runs after the modifications, are presented in Table 3. The values given in Tables 1 and 3 are all relative numbers. Take for example the high-energy end of Tank 2 before modifications. The value given in Table 1 for E_0 at the seventh cell from the end (n-6) is 0.773 and E_0 at the final cell is 1.645 . This does not mean that the seventh cell is low by 23% and the final cell is high by 65%, but rather that the field in the final cell is higher than the field in cell n-6 by 1.645/0.773, or a ratio of 2.24. While the "after " values are not perfect, they are a big improvement over the "before" values. Also, the

Table 2: Modification in SSC DTL to compensate for shifted gaps.

Tank #	1	2	3	4
dw_{LE}(cm)		-2.000	-2.375	-2.900
dg_1(cm)		+0.350	+0.441	+0.600
dg_2(cm)		+0.287	+0.436	+0.650
dg_3(cm)		+0.180	+0.436	+0.700
dg_{n-2}(cm)	-0.120	-0.375	-0.480	
dg_{n-1}(cm)	-0.220	-0.375	-0.600	
dg_n (cm)	-0.320	-0.375	-0.480	
dw_{HE} (cm)	-2.000	-2.250	-2.250	

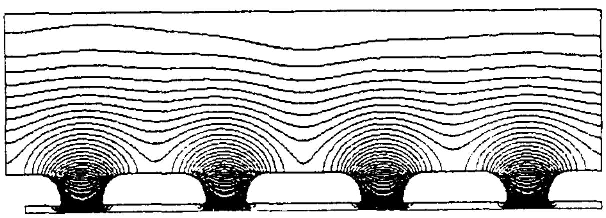

Figure 2: Field lines obtained by running SUPERFISH for the first four cells in Tank 3 after modifications were made.

Table 3: Relative values of E_0 (normalized to 1 MV/m) obtained in multi-cell SUPERFISH runs after modifications were made.

Cell #	Tank 1	Tank 2	Tank 3	Tank 4
1		1.000	1.000	1.017
2		1.026	1.028	1.036
3		1.031	1.041	1.058
4		0.985	0.977	0.959
5		0.987	0.981	0.963
6		0.987	0.984	0.969
7		0.993	0.990	
8		0.994		
n-7	1.017			
n-6	1.016	0.999		
n-5	1.022	1.003	1.016	
n-4	1.018	1.010	1.019	
n-3	1.014	1.024	1.024	
n-2	0.970	0.963	0.958	
n-1	0.971	0.984	0.980	
n	0.977	1.017	1.005	

effective values, which take into account the transit-time factor, are even better because the high fields occur in the cells in which the gaps have been lengthened, which reduces the transit-time factor, and the low fields occur in the cells in which the gap have been shorted, increasing the transit-time factor.

The field lines produced by a SUPERFISH run for the four end cells in the low energy end of Tank 3 after the modification listed in Table 2 were made are shown in Figure 2.

V. References

[1] D. Raparia, *et al*, "SSC Drift Tube Linac Design," these proceedings.