Beam Dynamics of Multi-tank DTL and CCL Designs*

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ABSTRACT

In many cases, LINAC tank sequencing schemes are dictated more by external requirements such as cost, power, and/or length considerations rather than beam dynamics considerations. In these situations, the problem of obtaining designs capable of providing the desired high current, low emittance output beam is challenging. This paper presents the results of a study of the effect on longitudinal and transverse emittance growth of tanking and non-accelerating cells. The major portion of the study involved numerical simulations using the multi-particle design codes; PARMILA[1] and PARMCCL[2]. Scaling relations obtained from the simulations are presented. Examples are provided showing the performance characteristics and limitations that may be expected from various designs.

I. INTRODUCTION

As accelerator design and applications progress, the requirements for the control of longitudinal and transverse emittance become more stringent. Transverse emittance is directly related to the transverse phase space area of the beam. A high transverse emittance increases beam physical size, limits the current carrying capacity of the transport and accelerating elements, and increases the effect of small nonlinearities in the optical elements. The combined effect of these limitations is to directly reduce the brightness, and therefore the effectiveness, of the beam, or to produce beam spillage. Longitudinal emittance growth increases the effect of chromatic aberrations on the beam. Additionally, coupling will act to mix the effects.

Most accelerator designs consist of a series of individual accelerating sections called tanks. In DTLs this discretization is the result of a number of individual constraints, many of which tends to push toward more tanks. Drift tube alignment errors within tanks increase dramatically with cell number. Room is needed for diagnostic and beam steering elements. Power supply and coolant system design is modular. Increasing peak fields, peak power densities, and average power often require periodic changing of the cell design. Longitudinal emittance growth is optimally controlled by maintaining longitudinal focussing. This requires ramping the electric field with energy which in turn leads to multiple ramped tanks.

In the following paragraphs, the numerical simulation codes PARMILA and PARMCCL have been used to study the effect on transverse and longitudinal emittance of a variety of tanking schemes. In this study, the interface between tanks is defined by: the number of "non-accelerating cells" located between the tanks, and the use or non-use of matching between the tanks. Where matching is used, it consists of variation of the magnetic fields of the inter-tank quadrupoles and of running the end cells of each tank at -90° while sculpturing the end cell geometry to obtain a transit time factor which will give the desired $\{E_o T L\}$ in those cells. In all cases, the magnetic focussing (quadrupole) periodicity is maintained through the inter-tank space. For most portions of this study, the base case used is the result obtained by bolting the tanks together, or equivalently, the no-transition case. Sections II and III of this paper contain the results obtained for FO-DO DTLs and CCLs. Section IV contains the results of an investigation into the insertion a non-accelerating cells between tanks in a FO-FO-DO-DO DTL.

II. EFFECT OF NON-ACCELERATING DTL CELLS

The initial investigation concerned the effect of inserting a series of non-accelerating cells in an 80 cell, 425 MHz, FO-DO DTL sequence. Figure 1 shows the relative emittance growth for 12 cases. Case 1 (extreme left) is the base case and all other results are normalized to the average results of this case. In order to eliminate dependence on the initial distribution, a series of eleven runs were made for the base case and for the last case using different seed for the random number generator. The error bars shown correspond to the mean ± one standard deviation. Table 1 describes each of the cases.

Case 12 has been provided as an indicator of how good the results can get. It is,however, arguable as to whether or not it can actually be achieved. In the first two cases the matching has been

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accomplished by modifying the fields of 3 magnets and the $\{E_oT\,L\}$ of the end cells on either side of the gap. The third case is matched using 2 magnets and the end cells. The variation in the fields of the quadrupoles is quite small and is readily achieved. The same cannot, however be said of the transit time factor variation in the end cells. In the sense used here, these cells are essentially being used as buncher cavities. However, since they are part of the tank, we cannot vary the field amplitude to obtain the desired matching. In this case the field amplitude is determined by the tank field and cannot be changed without simultaneously altering the tank field, and the length in set by the local value of $\beta\lambda$. Therefore, the only variable left is the transit time factor. It was found in the case attempted that, matching was achieved using the following transit time factors:

Case	Description	Inter-tank Cell Loc. 1/4	1/2	3/4
1	Base Case	0	0	0
2	No matching	1	0	0
3	No matching	0	1	0
4	No matching	0	0	1
5	No matching	2	0	0
6	No matching	0	2	0
7	No matching	0	0	2
8	No matching	2	0	1
9	No matching	0	2	1
10	No matching	2	2	0
11	No matching	2	2	1
12	Matched	2	2	1

Table 1. Case Description Indicating DTL Breaks

Last cell of tanks 1 & 2: $\bar{T} = 0.83{*}T$

Last cell of tank 3: $\bar{T} = 0.56{*}T$

First cell of tanks 2 & 3: $\bar{T} = 1.04{*}T$

First cell of tank 4: $\bar{T} = 0.80{*}T$

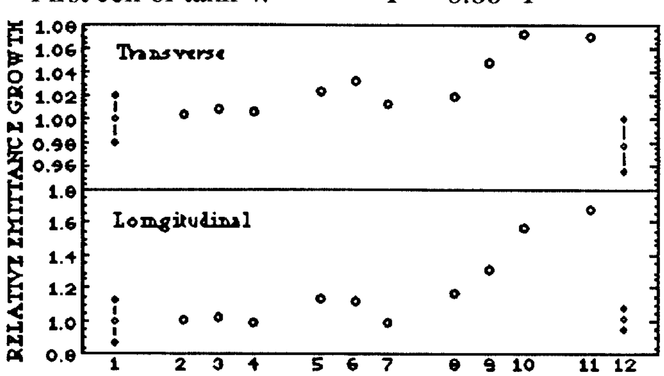

Figure 1

Figure 1 indicates that at least for low numbers of non accelerating cells, reasonable results are obtainable. Figure 2 shows the fractional emittance growth obtained by inserting 0 through 4 non-accelerating cells at the 1/4 point of an 80 cell DTL. These results are normalized to the input values.

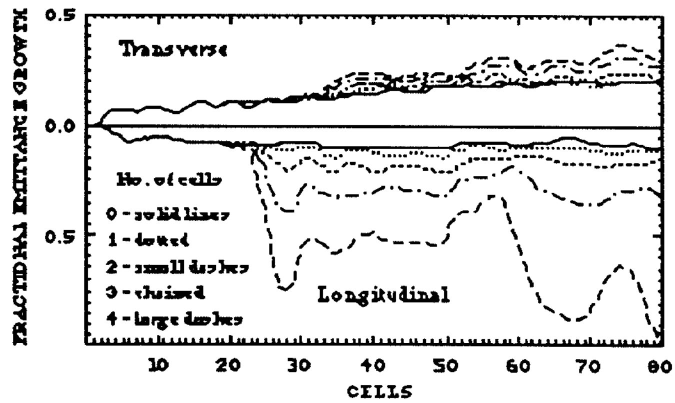

Figure 2

Although it is obvious that reasonably large oscillations occur in figure 2, it can also be seen that after approximately 10-15 cells beyond the disturbance, the relative change between cases is approximately independent of energy. Figure 3 explicitly shows this for the transverse emittance.

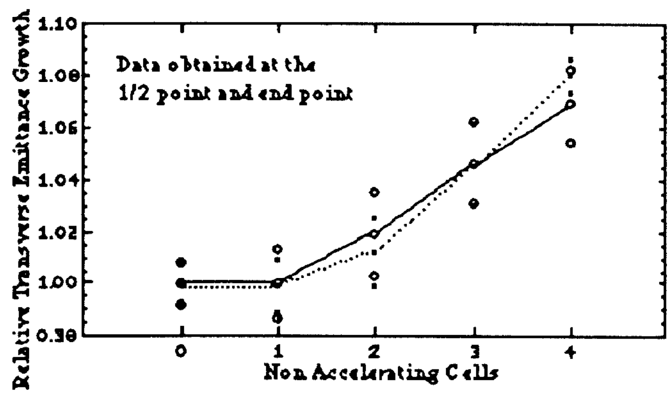

Figure 3

Multiple runs were made to eliminate the effect of the initial distribution. As before, the error bars indicate plus and minus one standard deviation. The solid lines are the higher energy plot in each case. To provide an easy way of determining the effect of these non-accelerating cells, the data was fitted to a second order polynomial with the following results:

$$\frac{\varepsilon_t}{\varepsilon_t(M{=}0)} \approx 1.00 + 0.0047\cdot M^2, \qquad \text{and}$$

$$\frac{\varepsilon_L}{\varepsilon_L(M{=}0)} \approx 1.00 + 0.008\cdot M + 0.025\cdot M^2.$$

In these equations, M the number of non-accelerating cells.

III. Effect of Non-Accelerating CCL Cells

A similar investigation was carried out for a 12 tank CCL. For consistency, the CCL design used was a 3 cell 850 MHz, FO-DO system. All disturbances occurred in the second tank and consisted of a single blank cell, two blank cells, or three blank cell (missing tank). The resulting effect on the transverse and longitudinal emittances is shown in Figure 5.

Here the relative (to the non-disturbed case) fractional transverse emittance growth is plotted in the upper half of the graph and the relative fractional longitudinal emittance growth is plotted in the lower half of the graph. The solid lines correspond to a single non-accelerating cell, the dotted lines to two non-accelerating cells, and the dashed lines to three non accelerating cells. The ordinate refers to the element number past the second tank.

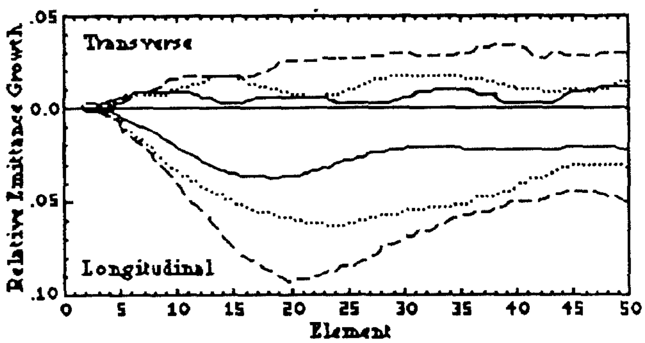

Figure 5

As with the DTL, these results were fitted to analytic expressions. The results are:

$$\frac{\varepsilon_T}{\varepsilon_T(M=0)} \approx 0.0042 + 0.012 \cdot \mathrm{Ln}(M) + \left[0.00003 + 0.00014 \cdot M\right] \cdot N, \text{ and}$$

$$\frac{\varepsilon_L}{\varepsilon_L(M=0)} \approx 0.0192 + 0.038 \cdot \mathrm{Ln}(M) - \left[0.00003 - 0.00008 \cdot M\right] \cdot N .$$

In these expressions, the variable M stands for the number of non-accelerating cells and N for the number of cells past the disturbance.

IV. Effect of Tank Breaks in FO-FO-DO-DO DTL Schemes

An additional question arises when a FO-FO-DO-DO focussing scheme is used in a DTL. At the point midway between any two focus or defocus magnets the beam is transversely elongated but almost parallel. It therefore has minimum divergence at this point. Alternatively, at the point midway between a focus and defocus magnet the beam is transitioning between its maximum and minimum radii and although virtually circular, has maximum divergence.

A series of runs was made to determine if this additional pattern would have any effect on the choice of break (drift) location. Figure 6 shows the relative transverse emittance growth versus cell number. As with previous results the emittance shown is normalized to the no-transition result at each cell. There are two breaks in the range covered by this figure They occur at cells 62 and 72. The dotted line corresponds to the case where each of these breaks occur midway between magnets of like sign. To generate the dashed curve, the system was rearranged to make the transitions occur at the same points as the magnetic transitions. In each case, an

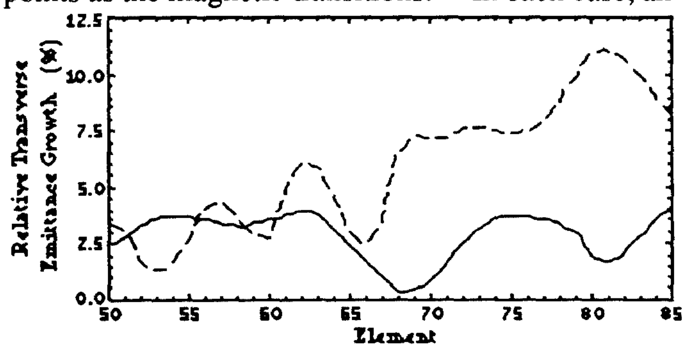

Figure 6

emittance growth can be seen to occur a few cells downstream from the transition. The first transition resulted in a growth of approximately 3.5% growth, while the second transition resulted in a growth of approximately 3%. There was no discernable effect on the longitudinal emittance.

V. Conclusion

Sections II and III have presented preliminary results of an investigation into the effect of inserting a series of "non-accelerating" cells (tanking with inter-tank drifts) in DTLs and CCLs. As is probably to be expected, the results indicate that by keeping the number of such cells down the resulting emittance growth is minimal.

Section IV presented the results of an investigation into the effects of inserting a "non-accelerating" cell into a FO-FO-DO-DO DTL system both at the point of magnet transition and at the point midway between like-sign magnets. The results show a transverse emittance rise of approximately 3% when the insertion point corresponds to a magnet transition point.

VI. References

[1] G. P. Boiscourt; "PARMILA -- An Overview", *Proc. Workshop on Linear Accelerator and Beam Optics Codes*, San Diego Ca, January 19-21 1988; AIP Conf. Proc. No. 177 (1989) 1.

[2] C. C. Paulson and R. A. Hartley; "Effect of Tank Sequencing on CCL Accelerators", *Proc. 1990 Linear Accelerator Conference*, Albuquerque, NM; September 10-14 1990; Los Alamos Report No. LA-12004-C (1991) 321.